Sugar Research and Development Corporation
Final Report - Project CTA013

Spatial Analysis of the Impact of Land Use on Nutrient Loads in the Herbert River Catchment

CSIRO

COOPERATIVE RESEARCH CENTRE *for*
SUSTAINABLE SUGAR
PRODUCTION

Sugar Research and Development Corporation
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Spatial Analysis of the Impact of Land Use on Nutrient Loads in the Herbert River Catchment

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1.   EXECUTIVE SUMMARY

This Project arose out of concerns for the apparent increase in nutrient and sediment contaminant loads in Queensland coastal waters since European settlement (e.g. DEAP Report, 1992). At the time of Project inception, the origins of this increase had yet to be defined and quantified, however, the sugarcane industry was considered to be a likely contributor because of the large (and increasing) areas of sugarcane involved and the relatively high fertiliser inputs per unit area.

There was, therefore, a need to develop practical tools to integrate existing information and spatially model, at the catchment scale, nutrient and sediment losses from agricultural land. It was the Project teams' intention to provide tools to analyse important issues/questions relating to the sustainable management of existing and potential sugarcane lands of the Herbert River catchment. In response, four core areas of R&D were undertaken. These were:

1. Data collection and integration;
2. Spatial analysis of the impacts of land use and management practices on water quality;
3. Tools for decision support; and
4. Building stakeholder capacity.

Data collection and integration

Data collection activities focused on the acquisition and integration of a range of data sources including soils, land cover, rainfall, terrain, land use, farm management practices, water quality and quantity, cadastral data and social data. A range of innovative methods were used to acquire the data including remote sensing, spatial modelling and interpolation, terrain modelling and soft photogrammetry. All of the data are described in the Herbert River Catchment Spatial Database Directory. This unique database has been made widely available to stakeholders in the Herbert catchment and copies are housed at the Herbert Resource Information Centre in Ingham.

Spatial analysis of the impacts of land use and management on water quality and quantity

A key objective for this Project was to spatially model the distribution of sediment, nutrient and water from non-point (i.e. diffuse) sources in the Herbert River catchment. Numerous models are available for assessing non-point source pollution. Determining an appropriate model is non-trivial, as many variations exist in model structure and design. This Project required a number of key features for a suitable non-point source pollution model. Apart from containing sediment and nutrient components, the model needed to have spatially distributed outputs to facilitate tracing pollution to source areas and mapping pollution fluxes across the catchment. Importantly, the model needed to have the ability to be linked or integrated into a GIS. Other considerations included the scale of the model, both in aerial coverage and time frame. The ability of the model to handle the large spatial coverage of the Herbert River Catchment was also a critical criterion. Both software and hardware limitations of our stakeholders were also constraints.

Given these considerations, the AGNPS model developed by USDA was chosen for use in this Project. AGNPS is an event based, distributed parameter model. The choice of an event-based model was considered appropriate given the results of the water quality studies

undertaken by Bramley *et al.* (1996). Essentially a shell in which a number of sub-models are coupled together in a series of loops, AGNPS estimates runoff, erosion and nutrient movement across a matrix of uniform cells (grid) with output at the cell level and at the catchment outlet. AGNPS has thirty core parameters, which describe land use, land cover, management practices, soil, geomorphology of the landscape and hydrology.

The model outputs at two levels, for the whole catchment at a selected outlet point and for an individual cell. Output's were grouped into hydrology (e.g. runoff volume and peak runoff rate), sediment (e.g. sediment yield, upland erosion and deposition) and chemical (e.g. nitrogen and phosphorus concentrations and sediment associated mass). Outputs were produced in tabular form and through the integration with GIS. The integration with the GIS also allows users to perform spatial analyses on model outputs.

Calibration was undertaken for each component of AGNPS (hydrology, sediment and nutrients) for nine storm events of varying degrees of intensity and duration over the last 20 years. The events represent a typical selection of storm conditions ranging over a number of days and with a variety of intensities. Results of the calibration produced R^2 values in excess of 0.9. Following calibration, model output was validated using a further four storm events. These events covered a range of conditions in the catchment including low and high soil antecedent moisture conditions, high upper catchment rainfall and long time duration.

Key results of applying the model to a range of scenarios in the Herbert River catchment were:

- *Sediment Yield*
    - Approximately 65% of the sediment is generated in the middle section of the catchment, 21% in the upper catchment and 9% in the lower catchment.
    - The contribution of sediment from *Eucalyptus* dominated land cover patterns is approximately 61%. Areas used for cattle grazing contributed approximately 21% of sediment generated in the catchment. Sugarcane areas contributed approximately 1% of the total sediment yield in the catchment. Plantation forestry areas contributed approximately 1% of the sediment yield at the catchment level.

- *Nutrient Yield*
    - Average soluble nitrogen contributions per unit area for the main land cover types averaged over five storm events showed that sugarcane and urban land uses both contributed approximately 0.05kg per hectare. Grazing contributed the least at 0.01kg per hectare of soluble nitrogen.
    - Values for total soluble nitrogen ranged from less than 0.01 kg/ha to 2.79 kg/ha. The application of fertiliser on agricultural areas strongly influences the spatial distribution of soluble nitrogen. Caneland areas are associated with areas of high nitrogen values. Urban land uses, on average, were responsible per unit area for contributing the same as sugarcane. Interestingly, rainforest areas generated significantly more nitrogen than *Eucalyptus* dominated cover. As with the values for total soluble nitrogen, the distribution of cane land is closely linked to the distribution of soluble nitrogen concentration values (ppm).

- *Phosphorus*
    - Sediment attached phosphorus source areas are more widely distributed across the catchment than for soluble nitrogen. The highest levels of sediment attached phosphorus are generated in the zone of high erosion in the middle of the catchment.

- *Temporal changes in non-point source pollution*
  - The result of land use changes at the catchment scale has been an overall increase in discharge and sediment yield, with an average increase of 20% for peak flow and 9% increase in total sediment yield since European settlement.
  - A decrease in both modelled discharge and sediment yield occurs from 1977 to 1996 as a result of the introduction of green cane harvesting in sugarcane areas.

- *Changes in Land Management Practice: Green Cane versus Burnt Cane Farming Systems*
  - Changes to farming practices, especially those associated with sugarcane have had a considerable positive impact on non-point source pollution in the lower catchment area of the Herbert River.
  - Green cane harvesting has been responsible for a reduction in nutrient export from cane areas.
  - Under the burnt cane harvesting system, nutrient output from individual cells reached as high as 3.8 kg/ha, whilst under green cane harvesting no cell in the area produced greater than 0.8 kg/ha of soluble nitrogen.

Overall the AGNPS model performed within expectations, however our research has shown that it has a number of key limitations which should be considered when using it in the future in a decision support capacity. Within its limitations, the model is a useful tool and given further testing especially in the area of nutrient pollution loads, AGNPS has potential as an operational tool for catchment management.

Tools for decision support

While acknowledging the value of new research, research *per se* rarely solves natural resource management problems, but it clearly can contribute to their solution. In response, our approach in this Project to the development of decision support tools was to:
- understand the context of decision-making;
- understand and seek to facilitate the processes of analysis and synthesis for natural resource management; and
- seek to facilitate the integration of research outputs into these processes.

These requirements have underpinned the development in this Project of an advanced decision support environment (or toolkit) for natural resource management called NRMtools. The toolkit is designed to provide the flexibility of application demanded by users in combining and recombining analytical functionality to meet the demands of particular tasks. As such, NRMtools is a powerful environment in which to package and deliver research outputs. NRMtools provides a mechanism whereby decision-makers can make use of quantitative models. It also provides a means of delivering qualitative or semi-quantitative knowledge and guidelines by developing knowledge based systems (most familiar in the form of expert systems) that can be integrated into decision support tools.

As a result of this Project, NRMtools is available for use over the Internet, so that hardware, software and data storage requirements for clients are kept to a minimum. These resources are held, maintained and updated on our server at the Davies Laboratory in Townsville. This innovative way of delivering our research has allowed us to provide our clients in the Herbert River catchment with the latest tools and models as they are developed. While NRMtools has

been developed in the context of resource management in the Herbert River catchment, it is readily transferable to other regions. In other words, site or issue specific data and analytical functionality can easily be added and removed from the system. Implementation of the system in a new context would require identification of that part of the existing analytical functionality that is relevant to the new context; and identification of functionality not previously available that is required for the new context. This new functionality might well be provided by existing models or might be rapidly developed using knowledge-based systems technologies on the basis of published research results, codes of practice or similar industry guidelines. As such, NRMtools provides a powerful mechanism for integrating and making full use of a range of existing methods and research outcomes.

Building stakeholder capacity

In mid 1993, staff from this Project initiated discussions with key stakeholders in the Herbert catchment with the aim of acquiring essential base data at a scale of 1:10 000. The costs of acquiring this data exceeded the individual financial capacity of any one of the interested stakeholders. In response, a joint venture (the Herbert Mapping Project or HMP) was brokered by the Project's Principal Investigators between 11 organisations (industry, community, state, local and federal government) to fund the acquisition of digital orthophotography, cultural data (e.g. utilities, farm boundaries), natural features (e.g. streams, topography) and cadastral data for the lower Herbert catchment. The HMP was completed in July 1996.

As the HMP neared completion, it became evident to many stakeholders that the utility of the data collected could only be maximised through advanced analysis of the HMP outputs in digital form. GIS provided the best means of satisfying their requirements for data analysis and presentation. A further collaborative joint venture, the Herbert Resource Information Centre (HRIC) was therefore proposed by the Project's Principal Investigators and a needs analysis and a cost-benefit analysis conducted by the Project team.

The needs analysis involved the use of a four-part questionnaire to assess perceptions of the opportunities and constraints associated with GIS should it be adopted within the stakeholder groups. The results of the needs analysis clearly demonstrated that a collaborative GIS facility was commensurate with the organisational background, organisational requirements and operational characteristics of the potential participating organisations and provided the basis for designing a detailed business plan. This in turn provided the basis for a cost:benefit analysis that indicated an overall ratio of discounted benefits to discounted costs of 8.8:1. The results suggested that the collaborative GIS was both an attractive public and private investment. Full details of the needs analysis and cost:benefit analysis can be found in Johnson and Walker, 1997.

Having demonstrated the appropriateness and viability of a collaborative approach, six stakeholders in the catchment agreed to begin negotiations with a view to establishing a formal agreement. Four of these stakeholders (CSR Sugar Mills, Herbert Cane Protection and Productivity Board, Hinchinbrook Shire Council and Canegrowers Herbert River Executive) represent local industry and community while two (Queensland Department of Natural Resources and CSIRO) represent state and federal government respectively. In August 1996, a 10-year collaborative agreement was signed by the six stakeholders to formally establish the HRIC. The agreement secures the financial and non-financial (in-kind) support of the

stakeholders and binds them to support the HRIC's foundation philosophy of being a non-profit, community-based collaborative GIS facility designed to support both economic and ecologically sustainable development in the Herbert catchment.

The HRIC is staffed by 2 full time GIS specialists, whose role is to provide expertise and skills to facilitate the collection, storage, maintenance and analysis of natural resource data and to ensure the products of these activities are delivered to HRIC stakeholders. As such, the HRIC offers a bureau service to its stakeholders, providing GIS consultancy and project management skills and acting as a conduit for the transfer of relevant R&D products. Furthermore, HRIC staff undertake a core function in assisting relevant stakeholders to implement GIS as part of their business operations. An additional function is to promote an environment for the facilitation of improved communication and collaboration between the HRIC stakeholders.

Within each of the stakeholder organisations, GIS groups were formed to facilitate the planning and implementation of GIS within their host organisation (although the state and federal government stakeholders already had significant GIS capability at the time of HRIC formation). Capacity building had begun, without being recognised as such, within the HMP in so far as participation in the HMP lead to an understanding of the need for GIS through user identification of a need and technical input providing options. Capacity building within the HMP, the HRIC and stakeholder organisations has therefore enabled rapid adoption of GIS, a technology unknown to many of the participants three years ago.

After the two and half years of formal operation of the HRIC, the HRIC and the partners to the HRIC have collected, collated and synthesised a high quality spatial database for the catchment. The database has been underpinned by the products of this research Project. The resources in the HRIC had been widely used by individual partners for routine activities in planning infrastructure developments, assessing the resource bases and integrating monitoring activities. Direct (private) benefits had accrued to each of the joint venture partners. In some cases these benefits were already substantial while in others, substantial benefits were anticipated in the near future. A formal evaluation of the HRIC's operation to date has clearly demonstrated the fundamental and critical role that the Project team played in the centre's inception and subsequent successful implementation.

Summary

In summary, in each of the four core R&D activities, the Project Team has met, and in many cases exceeded, the original Project objectives. As such, we have not only addressed water quality issues in the Herbert River catchment, but have also facilitated the development of a residual natural resource management capability in the catchment through the provision high quality data, tools analysis and synthesis. In addition we have facilitated a capacity to use these data and tools locally at the Herbert Resource Information Centre. This enhanced capability provides an improved basis for the sugar industry and its partners in the Herbert to plan for a sustainable future.

2.   BACKGROUND

The coastal zone remains a major focus of competition between alternative uses of resources which poses serious threats to its future economic, environmental, social and cultural potential. Sustainable land and water resources management is best achieved through the informed action of individual users and managers of these resources. As a major user of land in the coastal zone of northern Australia, the sugar industry is, and must increasingly be seen to be, concerned about sustainable land management and about minimising any adverse effects of the industry on the environment. By understanding the problems and having the tools to assist in managing these issues, the industry stands to benefit economically in the short term, and protect its substantial investment in the coastal zone in the longer term. The existing knowledge base (e.g. data, expert knowledge, and models) resides in a wide range of agencies and in a variety of data forms (e.g. raster, vector attribute, scanned). This Project was initiated in response to both expressed and perceived needs to develop tools at a range of scales to integrate this knowledge base.

This Project arose out of concerns for the apparent increase in nutrient and sediment contaminant loads in Queensland coastal waters since European settlement (e.g. DEAP Report, 1992). At the time of Project inception, the origins of this increase had yet to be defined and quantified, however, the sugar industry was considered to be a likely contributor because of the large (and increasing) areas of sugarcane involved and the relatively high fertiliser inputs per unit area. Preliminary results from another SRDC-funded project (CSC2S) had also shown that losses of fertiliser nitrogen applied to sugarcane were significant.

There was, therefore, a need to develop practical tools to integrate existing information and spatially model, at the catchment scale, nutrient and sediment losses from agricultural land. It was the Project teams' intention to provide tools to analyse important issues/questions relating to the sustainable management of existing and potential sugarcane production lands of the Herbert River catchment.

3. AIMS AND OBJECTIVES

The core aims of the Project were to develop computer-based decision aids and tools to assist user(s) to evaluate the spatial distribution of nutrient losses from agricultural production systems in the Herbert River catchment. These tools were expected to:

1. Integrate spatial data from diverse sources;

2. Analyse the spatial distribution of nutrient losses at several scales;

3. Provide the results of the analysis in a variety of formats to assist end users to identify and promote land use policies and land management strategies that are sustainable in the long term;

4. Produce a prototype from which a more "generic" system that is applicable to a wider range of coastal catchments can be developed in the future.

These aims were expected to be achieved by:

a) Surveying potential end users to evaluate individual information needs in relation to sustainable catchment management;

b) Assessing the availability and utility of existing and potential sources of spatially-referenced data (e.g. natural resource, land use, economic);

c) Evaluating spatial information systems technologies for their utility for integrating and synthesising data from diverse sources; and,

d) Producing a spatial modelling system for the Herbert River catchment that meets the needs of a variety of stakeholders (e.g. canegrowers, millers, ICM Committees, advisory and regulatory bodies).

The Project was also expected to provide the spatial modelling capability for a Decision Support System (DSS) for catchment management being built by CSIRO as part of its multi-divisional Coastal Zone Program. In the sections that follow we report on the level of achievement against agreed objectives. We demonstrate that not only have all original Project aims and objectives been met, but that the Project team has significantly overachieved in a number of areas and facilitated outcomes in the Herbert River catchment that were not anticipated at Project inception.

4. ACHIEVEMENTS AGAINST OBJECTIVES

4.1 Data Collection and Integration

A core component of this Project involved the collection and integration of a diverse range of natural resource data to support decision making in the Herbert River catchment. Initial activities focussed on identifying, acquiring and evaluating the available spatially referenced natural resource data. In co-operation with relevant State, Federal and Local agencies, a large number of data sources were acquired and evaluated and data rated as satisfactory by the evaluation were incorporated into an operational GIS for the Herbert River Catchment. The sections that follow briefly describe the core data sets held in the Herbert River Catchment Spatial Database (Johnson and Murray, 1998b).

4.1.1 Soils

Information on the soils of the Herbert River catchment was acquired from the Queensland Department of Natural Resource at 1:100 000 scale for 85% of the catchment. Soils information for the remaining 15% of the catchment area (in the rangelands of the upper Herbert) was acquired from the CSIRO Atlas of Australian soils at a scale of 1:1000000. Soils information was collected at 1: 8000 scale as part of the CSR Soil Survey supervised by Dr. Wood. As an outcome of this Project, this unique data set which includes detailed measurements of soil physical and chemical properties for 60% of the area under sugar cane cultivation, is now held in digital format. Following completion of the Herbert Mapping Project, the original digital data set was revised so as to improve its spatial accuracy. These improvements have resulted in stakeholders the Herbert River catchment being able to access the most comprehensive soils database in the Australian sugar industry.

4.1.2 Land cover

Land cover of the Herbert River catchment was mapped from aerial photography acquired in 1943, 1961, 1970, 1977, 1988, 1992, 1993, 1994 and 1995. SPOT Panchromatic and MSS imagery were used to map land cover in 1996. Land cover boundaries were mapped onto a

geo-referenced digital base in ARCINFO GIS. Classification drew heavily on previous DOE vegetation surveys and QDNR soil surveys. Validation of mapping units and mapped boundaries was conducted by vehicle and foot traverses. Classification of units and boundaries not inspected was undertaken by extrapolation from equivalent photographic units. In addition to mapping observed land cover, an estimate of land cover prior to European settlement (circa 1860's) was derived from observed relationships between remaining stands of native vegetation and the known distribution of soils, topography, relief, hydrology and rainfall. Johnson *et al.* (1998b) report in detail on the whole of catchment study (Figure 1).
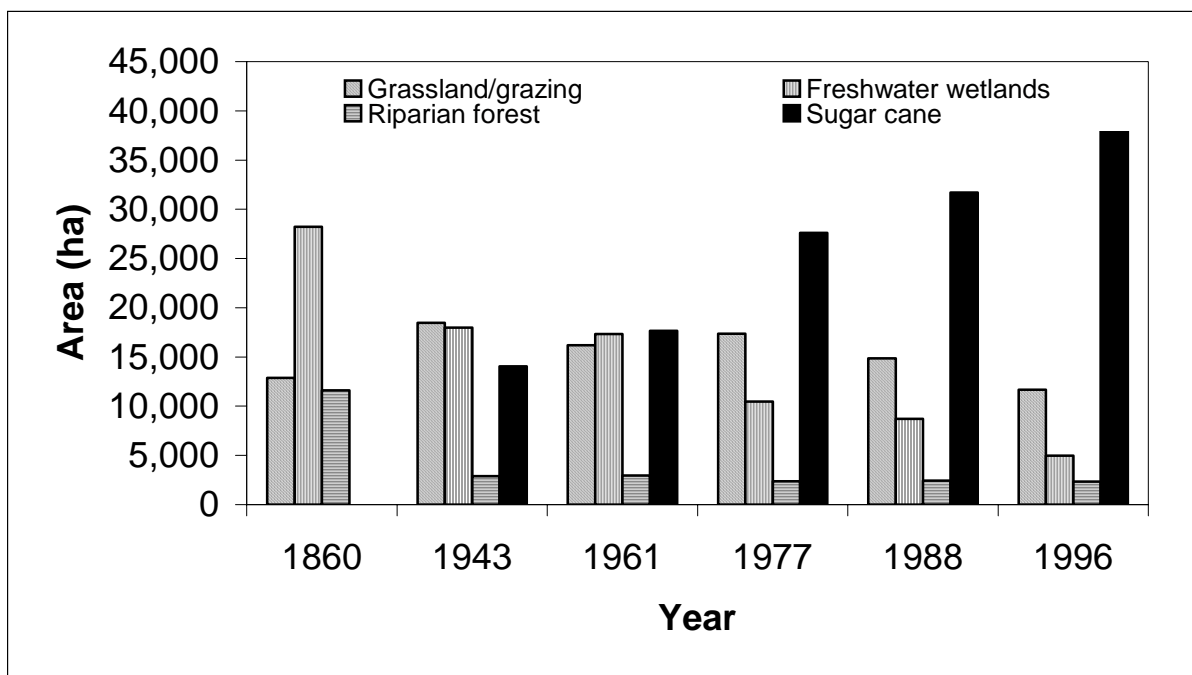

Figure 1. Area of key land cover classes in the lower Herbert River catchment since European settlement.

A focussed case study was also undertaken on the coastal floodplain that investigated land cover changes, with an emphasis on changes in the spatial and temporal distribution of freshwater wetland and riparian forest areas (Johnson *et al.,* 1998a). Although mapping was conducted for the entire Herbert catchment, this case study investigated land cover changes on the coastal floodplain below an elevation of 13m (ie the zone of seasonal inundation with direct influence on estuarine wetlands and the adjacent Great Barrier Reef Marine Park). A time series was developed to elucidate spatial and temporal change in land cover. An

analysis of floodplain landscape pattern, emphasising the dynamics of riparian and wetland "islands" was also undertaken.

The case study clearly demonstrated the following in terms of land cover change on the floodplain of the Herbert River catchment:

- A rapid decline in the area of freshwater wetlands and riparian forest since European settlement in the 1860's;

- A 60% decrease in the area of freshwater wetlands (including a 40% decrease since 1943);

- A 50% decrease in the area riparian forest since 1943;

- Riparian forest areas becoming narrower with time;

- The number of riparian forest and freshwater wetland islands increased after 1860, however mean island area decreased;

- Aggregation of freshwater wetland and riparian forest islands on the floodplain between 1943 and the present;

- A decline in Diversity and Evenness indices for the Herbert floodplain as the area of sugarcane increases; and

- A more uniform/less diverse landscape now exists on the Herbert coastal floodplain when compared with historical patterns.

4.1.3 Terrain

One of the principle limitations in the past to improved management of natural resources on the Herbert River floodplain was the absence of comprehensive and spatially accurate terrain data. Terrain data is essential for the success of modelling of nutrient flowpaths, and the evaluation of the impacts of land use on nutrient loads. In response to these needs, aerial photography was acquired for the entire lower Herbert as part of a joint venture agreement between CSIRO, CSR, CANEGROWERS, QDNR, QDE, QDOT, Herbert Productivity Board, BSES and Hinchinbrook Shire Council. Project staff initiated, planned, brokered and coordinated this major exercise. The photography formed the basis of a collaborative effort between all stakeholders that produced 69, 1:10000 orthophotos (both digital and hardcopy) for the lower Herbert. From the orthophotos, a comprehensive digital terrain model of the

lower Herbert was developed with a minimum spatial resolution of 1m. This data set is unique in the sugar industry and has had a major impact on natural resource management activities in the catchment. Section 5 provides evidence for the dataset's utility based on an evaluation of stakeholders in the catchment.

4.1.4 Rainfall

Rainfall regimes with extreme spatial and temporal variation are characteristic of regions where sugarcane is grown in Australia. Regimes vary considerably over short distances because of changes in local topography, including the height and orientation of mountain ranges and the direction of the coastline with respect to the prevailing winds. Although networks of rainfall stations exist, there remains a very poor understanding of the spatial and temporal distribution of rainfall in cane growing regions.

An enhanced knowledge of rainfall distribution in both space and time has the potential to deliver significant economic and environmental benefits to the sugar industry. From an economic perspective the efficiency of both growing (e.g. on-farm management) and milling sectors (e.g. harvest scheduling) could be improved. An improved understanding of rainfall is also essential for developing enhanced estimates of surface runoff and surface erosion, and as a key input parameter for stream flow. Johnson and Murray (1998b) report on the application of an innovative technique for estimating mean annual rainfall in the Herbert River catchment that incorporate both location and elevation as independent variables to estimate rainfall distribution over an area of approximately 795 000 ha.

The ANUSPLIN suite of programs was used to implement partial thin plate smoothing spline algorithms for the lower Herbert River district. ANUSPLIN allows readily available topographic and point source weather data to be used for modeling climate and bioclimate. ANUSPLIN utilises point source (and potentially incomplete) weather station records, as well as topographic data (from the Herbert Mapping Project) to construct continuous gridded climate surfaces. ANUSPLIN's robustness and hence utility, lies in that it can accommodate large data variations (such as observed in rainfall data) across locations within close spatial proximity. Furthermore, ANUSPLIN is able to use rainfall records with high temporal

variability (including stations with very short records) by weighting each point as a function of its record length and data variance.

The results of this case study demonstrate that the method can be applied successfully within the domain of data routinely available in cane growing regions and hence its relevance to a broad range of decision-making activities in the Australian sugar industry (Figure 2).
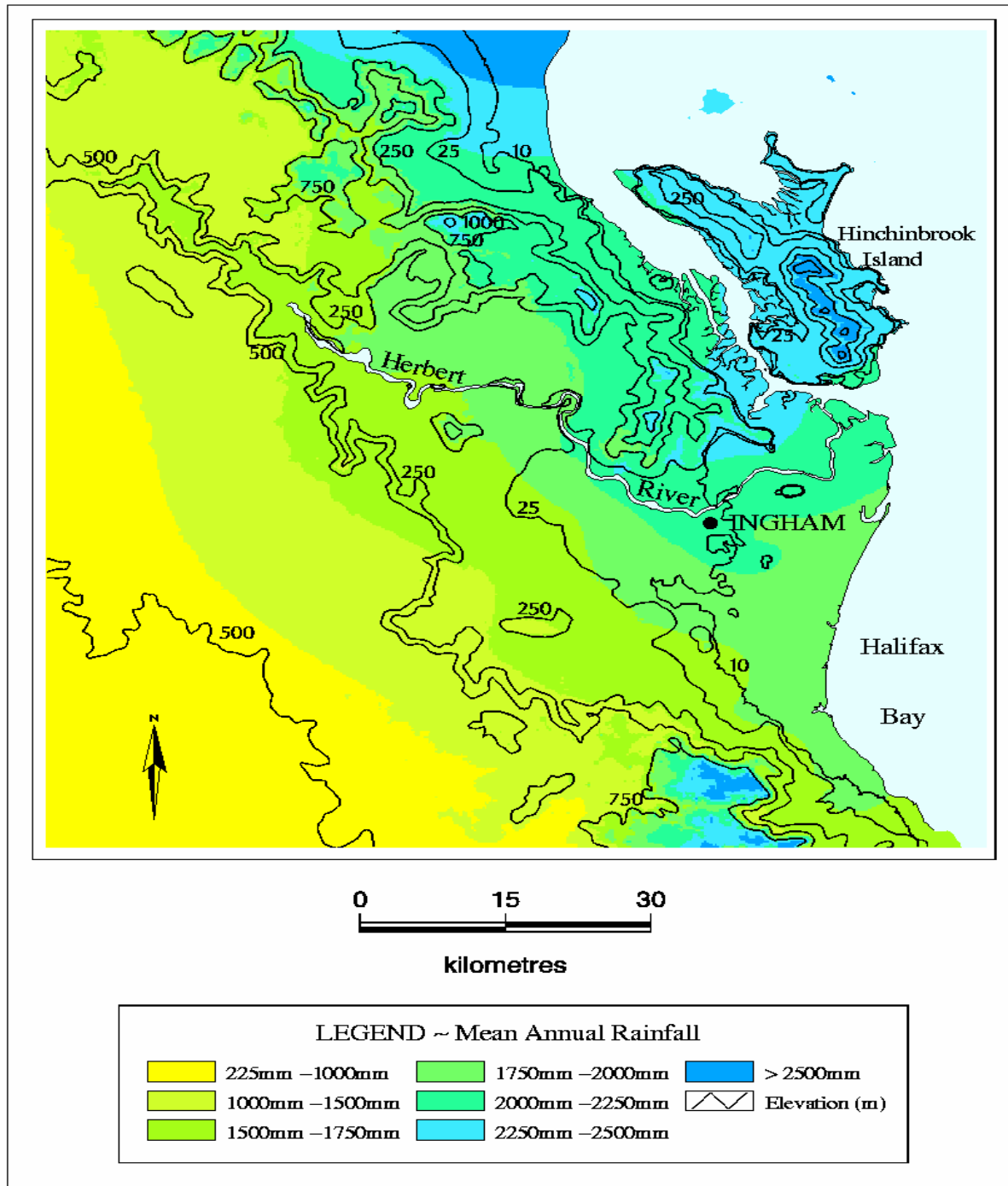

Figure 2. Interpolated mean annual rainfall surface for the lower Herbert River district.

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4.1.5   Land Use and Management Practices

An understanding of the nature and spatial distribution of land use and management practices in the Herbert River catchment over time is vital to the development of contaminant export budgets from different land uses.   The development of contaminant export budgets is essential for the calibration and validation of models and tools that evaluate the spatial distribution of contaminant loads from the catchment to the marine environment. In response to this issue, current and historical nitrogen (N) and phosphorus (P) usage practices on rural lands in the Herbert River catchment were determined within the context of changes in land use (Johnson, 1995).   Johnson (1997) has also estimated usage rates of a range of other agro-chemicals and hydrocarbons in the catchment.

Land use trends

Agricultural and pastoral production are the largest users of land in the Herbert River catchment. Agriculture contributes approximately 80% of the catchments GDP, with the main industries being sugar, beef and dairy cattle, vegetables and tropical fruits. In terms of arable agricultural production, the sugar industry located in the lower catchment is dominant, with approximately 65000 ha of land supplying cane to two sugar mills. Lands not used for arable agriculture are mainly under native vegetation or for extensive beef cattle production. This is especially the case in the upper catchment. The catchment also supports a substantial commercial and recreational fishery. Forestry has declined in importance since the World Heritage listing of the rainforest resource, with timber production now primarily focussed on exotic softwood plantations. Small areas are utilised for mining (in the upper catchment only) and industrial activities or alienated for urban development. Approximately 18000 people reside in the catchment, of which 75% are located in the lower catchment.

Since European settlement, the lower catchment has undergone 3 major phases of rural land use change. These phases were associated with expansions in the sugar industry in the 1960's, 1970's and late 1980's - early 1990's and the establishment of large areas of exotic pine plantations in the late 1980's. In contrast, rural land use (predominantly grazing of unimproved pastures) in the upper catchment (areas upstream of Nash's Crossing) has remained relatively constant.   More detailed descriptions of land cover change in the catchment are provided in Section 4.1.2.

Nitrogen and Phosphorous fertiliser use

Total fertiliser N and P use in the catchment has increased with time, however it is important that these increases are placed in the context of changes in land use (Figure 3). Johnson (1995) showed that the total area of land fertilised in 1994 to be approximately 7% of the total catchment area (approximately 10000 km^2), 5.5% of which was sugarcane cultivation.
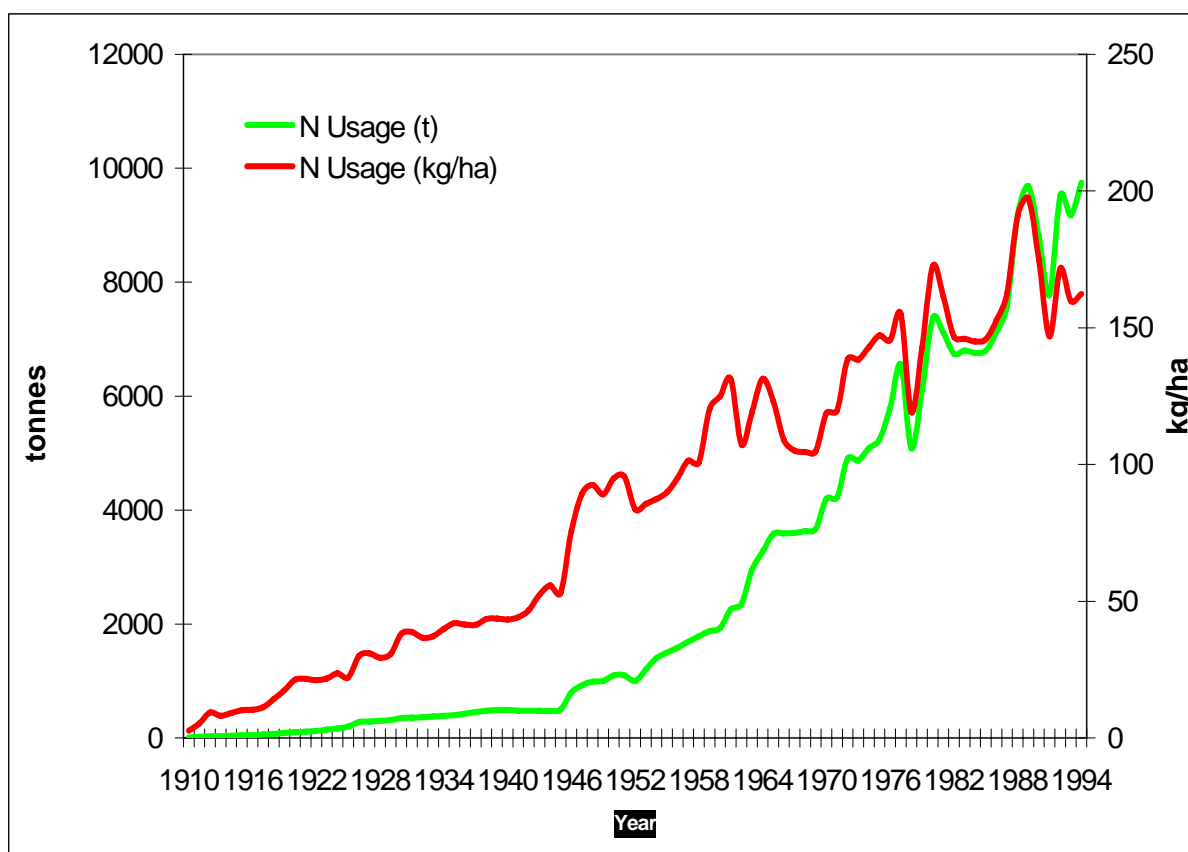

Figure 3. N and P usage in the Herbert River catchment.

As the area of sugarcane cultivated has continued to increase with time, N fertiliser inputs (kg ha^{-1}) increased, reaching a peak in the late 1980's. Early indications are that this trend may be declining as sales of fertiliser post 1990 have declined and current BSES fertiliser recommendations for the Herbert River district advocate reduced rates of N (R. Beattie *pers comm*). P fertiliser inputs (kg ha^{-1}) have increased over time as the area of cultivated land increased, although both rates and total use declined for a period in the 1970's due to the removal of the government fertiliser subsidy and the energy crisis (M. Probert *pers comm*). The area of improved pastures increased until the late 1970's and remained constant until the early 1980's when pasture land was converted to sugarcane production. Inputs of N and P to

pastures increased during the 1980's. The area of exotic pine plantations has increased since establishment in the 1970's, although additions of N and P (kg ha^{-1}) have decreased since the late 1980's. The area of horticulture and small crops in has varied with time, although N and P usage (kg ha^{-1}) has remained relatively stable.

Agrochemical usage

Johnson (1997) and Johnson and Brunskill (1998) quantify current and historical agrochemical usage practices on rural lands in the Herbert River catchment in the context of changes in land use. Quantities of herbicide and insecticide used in infrastructure maintenance (eg roads, railways, drains, electricity poles) pest and weed control on government and leasehold lands, and government forestry plantations were obtained from historical records maintained by the relevant state or local government agency. Data for insecticides used in the sugar industry were obtained from historical records held by the Herbert Cane Protection and Productivity Board. Insecticide usage for crops other than sugarcane as well as herbicide and fungicide usage for all agricultural activities was estimated by combining data collected at 4 levels: statistical divisions and local government boundaries (in the Herbert River catchment local government boundaries have remained relatively constant since 1900, and are closely associated with the boundaries of chemical company sales districts and of the catchment itself); the original sales areas of chemical companies (these correspond in the Herbert River catchment to the sugar mill areas); individual dealer records for sales districts of fertiliser companies; and interviews with individual agricultural producers. Chemical allocations were developed on a crop basis (i.e. the known area of each crop multiplied by the rate of usage), and then summed for the catchment over time. Allocations of sales area data to the catchments were confirmed in discussions with industry personnel and by visits to the catchment. Agrochemicals for which usage data were collected included:

- *Organochlorines* (Aldrin, BHC, DDT, Dieldrin, Heptachlor, Lindane, Methoxychlor);
- *Organophosphates* (Chlorpyrifos, Ethoprophos, Fenaphimos);
- *Alophatic acids* (Dalapon, Glyphosate, TCA);
- *Aromatic acids and esters* (Dicamba, Picloram);
- *Nitroanilines* (Trifluralin);
- *Phenoxys* (2,4-D (amine), MCPA, 2,4,5-T);
- *Triazines and triazoles* (Ametryn, Atrazine, Simazine);

- *Ureas* (Diuron);

- *Bipyridyliums* (Paraquat);

- *Mercurial Fungicides* (Shirtan);

- *Azoles* (Flusilazole, Prochloraz, Propiconazole); and

- *Rodenticides* (Thallium sulfate).

The area of rural land receiving regular inputs of pesticides in 1994 was shown to be approximately 7% of the total catchment area. With increasing land area for sugarcane, inputs of pesticides and hydrocarbons have increased with time (Figure 4).
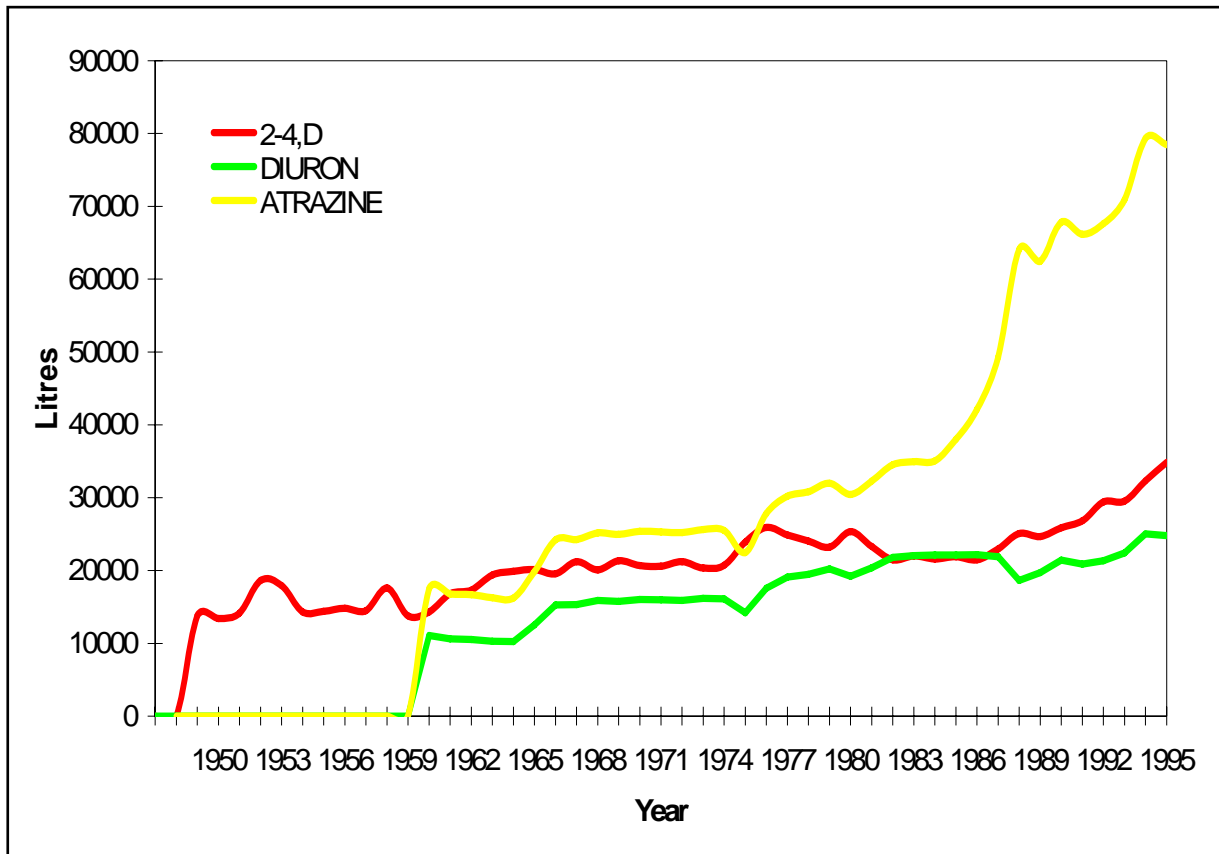

Figure 4. Inputs of selected pesticides in the Herbert River catchment over time.

Hydrocarbon usage

Estimates of fuel consumption were obtained by combining data collected for each ABS statistical division and local government area, as well as individual dealer records for sales districts of fuel companies. Vehicle movements in the catchment were developed based on estimates of annual average daily traffic flow (AADT) provided at key locations by the Queensland Department of Transport. Fuel consumption for each vehicle class was estimated from data supplied by ABS. Usage allocations were developed for each fuel type (i.e. the known number of vehicles types multiplied by an estimate of the distance travelled in the catchment), and then summed for the catchment over time. Johnson (1997) shows changes in hydrocarbon usage over time in the lower Herbert catchment.

Canegrower perceptions relating to nutrient management

A large gap exists in knowledge and understanding of the attitudes which Australian sugar producers have toward risk and variability as they affect farm management activities. Information concerning risk perceptions and management responses from producers in the Herbert River district was collected by Johnson (1995). The survey was conducted in May 1994 using a common survey instrument. Dillman's Total Design Method was used to develop the questionnaire's format and a Likert scale was selected for ranking producers' responses. Local research and extension personnel from the BSES and CSR Technical Field Office provided input into the survey design. The sample selected represents a cross section of producers in the Herbert River district and was designed to incorporate a range of biophysical conditions, geographic regions and management skills. A total of 120 producers were interviewed in person. These interviews were followed up with telephone contacts if required. Producers were asked to rank the importance of various sources of variability which create risk in their farm operations. Respondents were also asked to assess the importance of various management responses to variability and to indicate whether they used the method or tool. Respondents were asked to consider the farm as a whole as well as providing specific answers that pertained to their nutrient and chemical management strategies, as well as other farm cultural practices (i.e., cultivation). Additional socioeconomic data were also obtained from each canegrower.

Canegrowers indicated that weather was the most important source of variability impacting on nutrient management strategies. Soil type ranked second, however producers also ranked

(in decreasing order of importance) variety, input costs, cane price, crop class, the impacts of major technical innovations, the effects of government regulations, equipment availability and a small number of other effects as being important. Between-region differences ($P<0.05$) were found in the degree of importance that producers attached to the effects of weather and cane variety. No significant differences were found in attitudes between regions for the other variables identified.

Timing of fertiliser application was considered the most important managerial response to risk. Trash retention was given a high rating, followed closely by fertiliser type, drainage practices and method of fertiliser application. Strategies such as weed control, green manuring, length of crop cycle were also considered to be important, while irrigation was considered to be relatively unimportant across most regions in the district. Between-region differences ($P<0.05$) were found in the degree of importance that producers attached to drainage, irrigation, trash retention, weed control and fertiliser type. No significant differences were found in attitudes between regions for the remaining variables.

Results indicated that responding producers consider a wide range of sources of variability to be important. The absence of a significant difference in attitudes between regions for variables other than weather and cane variety is indicative of the uniform recognition given by producers to the importance of alternative sources of variability.

Producers viewed weather as the most important source of variability in relation to nutrient management. However, the degree to which producers viewed the influence of weather varied significantly between regions. This response is not unexpected given the large variation in climatic conditions that exist across different regions of the Herbert River district. This response is also consistent with results reported from other similar studies. Producers in the Herbert did not place a high importance on cane price effects, although the slightly higher value for input costs does reflect an attitude that excessive fertiliser costs are unacceptable. This is an important outcome given that existing industry fertiliser recommendations are explicitly related (and attach a high importance) to the price of sugar.

The high ranking that producers in all regions gave to soil type as a major source of variability is also an important result. Again, this is not unexpected given the inherent spatial variability of soil types in the Herbert. However, while producers gave a high importance to

soil type, only 35% performed routine soil testing on their farm, although 90% indicated that they had performed soil tests at some time in the life of the farm. Of the 35% that performed routine tests, only 28% (i.e., 10% of the total number) varied their application rates across the farm to accommodate variations in soil type. In most cases this was in the form of trace element additions, with little variation in application rates of nitrogen, phosphorous and potassium.

Nearly all producers indicated that they relied on on-farm experience as their primary source of expertise to develop nutrient management strategies. However, BSES, CSR and other extension and agribusiness personnel were considered to be useful sources of information. Less than 10% of producers indicated that they placed a high importance on information obtained from neighbours. Interestingly, only 38% of producers followed existing industry fertiliser recommendations, while 87% of farmers considered that farm specific recommendations would significantly improve on-farm productivity. These results suggest that more effort needs to be placed in developing farm specific recommendations.

In terms of management responses to variability, producers considered timing of fertiliser operations to be the most important response to variability across all regions.   Other responses such as trash retention, fertiliser type, weed control, farm drainage, and fertiliser type were also considered to be important, however levels of importance varied across regions. Again, many differences can be attributed to the spatially heterogeneous soil and climatic characteristics of the Herbert River district. For example, producers in wetter regions such as Macknade-Halifax placed more importance on drainage and weed control than producers in drier areas such as Upper Stone. Conversely, producers in drier areas placed more importance on trash retention and irrigation than producers in wetter areas. These responses confirm observed behavioural patterns. The high ranking given to fertiliser type is notable in that many producers expressed a desire for the development of economically viable, slow release fertilisers.

Some other insights were also obtained from the survey. In their informal responses during the survey process, in many instances producers articulated a "philosophy of life" which they followed in decision making rather than some economic optimisation criterion. Emphasis in their responses was commonly placed on the short-run rather than intermediate or long-run

concerns. Many producers also indicated what could be interpreted as "safety first" considerations in making decisions that relate to nutrient management.

These results suggest that researchers concerned with measuring the risk attitudes of sugarcane producers and developing effective risk management strategies should consider a wide range of sources of variability. This is especially relevant to the development of risk efficient nutrient management strategies. These results have interesting implications for the design of educational programs, policy analysis and formulation, research, and the dissemination of information designed to enhance decision making. They also enable for the first time in the sugar industry, the generation of hypotheses that can not only challenge the present understanding of farmer behaviour but also challenge conventional approaches to risk analysis.

Hence there is strong evidence to suggest that a number of criteria used by producers to develop nutrient management strategies vary across geographic regions within a sugar-growing district and amongst farms within each geographic region. Risk modelling and management strategies should be adapted to the unique conditions of the research domain because standardised formulations can be misleading. Producers' responses strongly indicate that single NPK recommendations for the whole Herbert River district are unsatisfactory. The design of fertiliser recommendation strategies and extension programs must, therefore, account for geographic variability at a higher spatial level than presently exists. In many cases this will require the development of farm specific recommendations if producers needs are to be met.

Risk models and resultant management strategies which consider only sugar price and yield variability, underestimate the importance of other sources of risk in the decision making process. Again, there are important implications for fertiliser recommendation strategies and extension programs in that the existing practice places a particularly high importance on cane price. In response, a range of considerations such as soil type, cane variety, crop class and cultural practices must be integrated explicitly, if a realistic decision making framework is to be developed. In understanding risk in relation to the use of nutrients, management tools must acknowledge and if possible accommodate the importance that producers place on optimising lifestyle rather than net farm income. This must occur within a multiperiod business environment where "safety first" considerations are emphasised.

It is critical that a rigorous understanding of the effects of variability be developed if more effective research, development, extension and policy activities are to be achieved. This must be done not only for the Herbert River district, but also for all sugar production regions. Further research is required if risk perceptions and management responses of producers in other regions are to be quantified and improved management strategies developed. This activity is crucial not only for nutrient management, but also for a range of other issues that have a direct effect on both industry profitability and natural resource sustainability.

4.1.6   Water Quality

Between 1992 and 1996 surface grab samples of water were collected at monthly intervals from up to 30 sites throughout the lower part of the Herbert River catchment (Bramley *et al.*, 1996). The sites were chosen to reflect the different land uses, soils, drainage and sub-catchments. Samples were also collected in response to rainfall events exceeding 50 mm d^{-1}. Following collection, the samples were refrigerated (3^0C) for transport to the laboratory for determination of pH and EC, filtration and storage (-15^0 C) prior to analysis for total soluble N and P, and fractions of NH_4 and NO_3-N, *ortho*phosphate (P_i) and potassium (K). Sub-samples were also filtered for gravimetric determination of the suspended sediment load. These analyses, together with river discharge information, were used to estimate the effects of land use on water quality and to make a preliminary assessment of the efficacy of wetland/riparian zones as mitigators of nutrient export downstream.

Nutrient concentrations in creeks associated with the dominant Herbert land uses were generally below the ANZECC target levels for freshwater (Figure 5). Exceptions occurred during wet season peak flow events when river discharge was closely correlated with rainfall, as expected. Thus Bramley *et al.* (1996) found that nutrient loss in the Herbert River catchment is predominantly event-based, and is insignificant outside the wet season months.
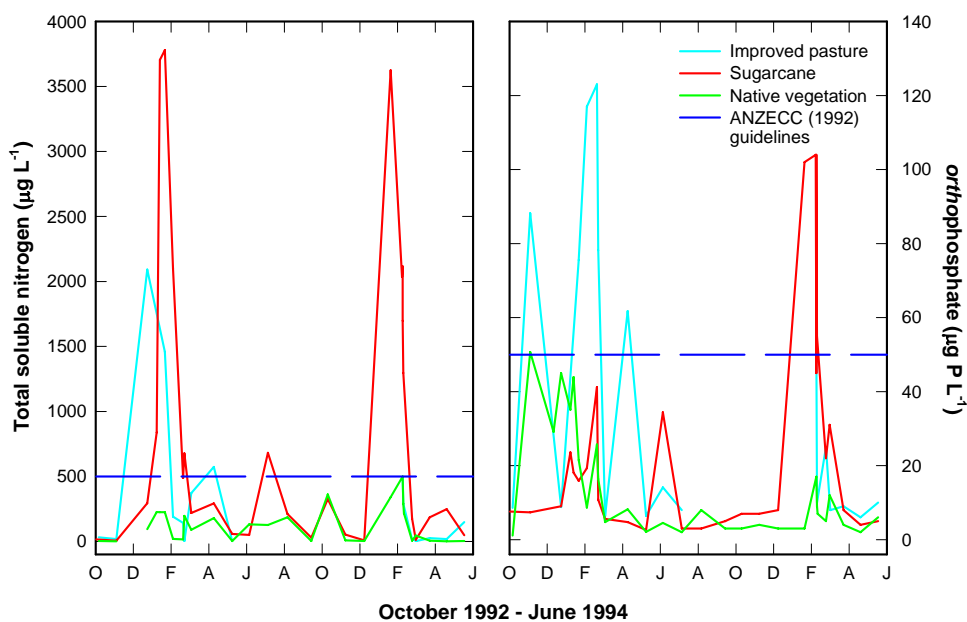
Figure 5. Concentrations of inorganic N and P in some lower Herbert streams draining different land uses (Data of Bramley and Johnson, 1996).

For example, at the end of January 1994, heavy rain associated with tropical cyclone Sadie (approximately 600 mm in 2 d) resulted in a peak Herbert River discharge at Ingham of 254,440 ML d^{-1}, peak concentrations of soluble N and P_i of 649 micrograms N and 38 micrograms P L^{-1}, and an estimated peak export of these soluble nutrients moving downstream from Ingham of approximately 120 t N and 9 t P d^{-1}. The peak load of suspended solids (SS) during this event was 904 mg SS L^{-1}. This contrasts with typical dry season flows of less than 500 ML d^{-1} and concentrations of soluble N and P_i of the order of 50 micrograms N and 8 micrograms P L^{-1}. Nutrient concentrations in streams associated with sugar cane production were generally greater than in those associated with other land uses, and any differences between these were only seen during wet season peak flow events.

In general, Herbert River discharge was only significantly greater at downstream sites (eg. Ingham) compared to upstream sites (eg. Abergowrie) during the wet season. This difference

reflects the contribution of water during this period from the Stone River in particular, and also from Dalrymple, Elphinstone and Hawkins Creeks which drain the ranges on the north bank of the Herbert between Ingham and Abergowrie. Bramley *et al.* (1994) have shown that riverine nutrient concentrations are higher at Ingham compared to Abergowrie suggesting that this increase is associated with drainage from agricultural land (Figure 6). Thus, when nutrient export from the land draining into the Herbert between Abergowrie and Ingham was estimated as the difference between the sum of discharge and concentration at these two sites, it was seen to be event based, and insignificant outside the wet season months.
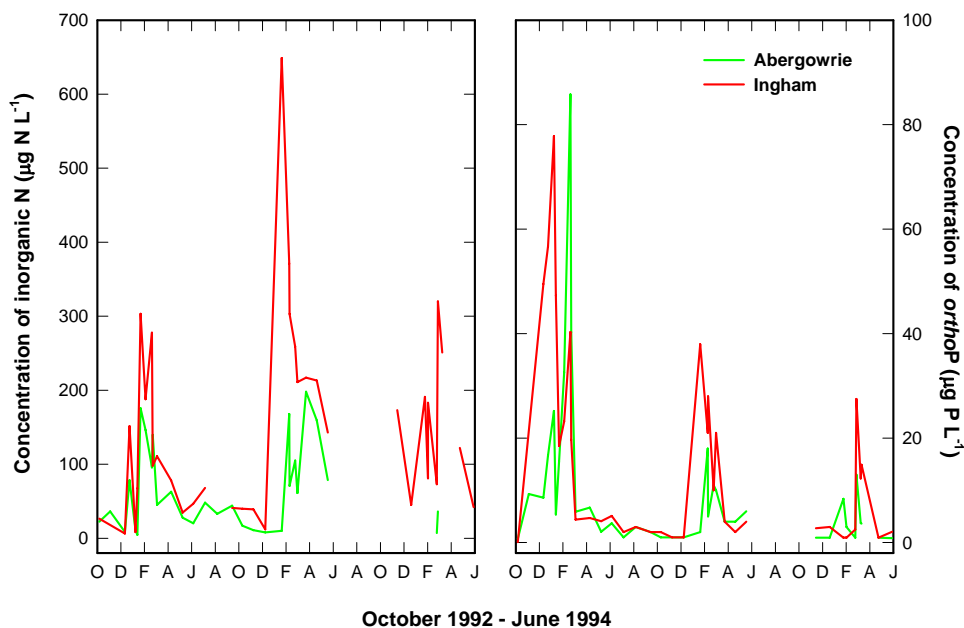

Figure 6. Concentrations of inorganic N and P at Ingham and 32 km upstream at Abergowrie (Data of Bramley *et al.*, 1994).

The results, like those obtained by other agencies working in other north Queensland rivers, suggest that the downstream effects of agricultural production in the tropics is governed to large degree by the climate, in particular its seasonality, and the volume and intensity of rainfall. Within individual catchments, climatic spatial and temporal variability may also be significant. The results suggest that nutrient loss (kg ha^{-1} y^{-1}) from land under intensive agriculture is likely

to exceed that from other land uses irrespective of the type of intensive agricultural production undertaken. Thus, it is the general nature of intensive agricultural land use and the relatively high inputs that such land use involves, rather than the specific production system employed (for example, sugar cane compared to maize), which results in an increased export of nutrients downstream relative to that from lower input land uses such as rough grazing or forestry. Minimisation of nutrient loss off-farm is therefore likely to depend on carefully matching actual land use to land use suitability. In the tropics, the latter is governed largely by drainage characteristics and position within the catchment. However, because the extent to which nutrient export impacts on ecosystems downstream has not been quantified and may be location-specific, and given that the concentration of nutrients in stream water is generally below levels that have been deemed acceptable, motivating the agricultural community to minimise the export of nutrients and other agro-chemicals downstream remains largely a question of economics. To date, the costs of ameliorating environmental degradation, real or perceived, have not been considered to be costs of production in Australian agriculture. These results also suggest that the ANZECC target guidelines for nutrients in rivers ought to take account of river flow in addition to nutrient concentration - the current basis for judging the environmental impact of agricultural practice on water quality.

4.1.7   *Herbert River Catchment Spatial Database*

All digital spatial data developed or acquired for the Herbert River catchment have been integrated into the Herbert River Catchment Spatial Database. Johnson and Murray (1998) developed a Spatial Database Directory that describes data currently held in the database. A detailed listing of dataset descriptions are given in order of scale and theme. The Directory provides a range of information about each dataset (or coverage) in the database and a standard coverage description was developed to enable consistent storage of information about coverages held within the database. Correct interpretation of information content, accuracy, and intended applications is dependent on this type of reference information.

The Database structure is designed to improve data management and access for users by providing an intuitive, logical framework for data storage. The top-level directory has been structured to separate major components and activities involved with the maintenance and analysis of the database. This framework encourages users to locate programs, coverages,

and other data in a logical directory. The major benefits of this approach are improved stakeholder access and use of data and reduced data duplication. This framework is also flexible and responsive to future stakeholder needs.

In addition to the publication of a Spatial Database Directory, the Project has facilitated stakeholder access to natural resource data relating to the Herbert River catchment through the publication of a Herbert River Atlas (Johnson and Murray, 1997). The Atlas was produced in collaboration with the Herbert River Catchment Coordinating Committee (ICM) and Herbert River CANEGROWERS. The Atlas was received with wide acclaim and in response to significant demand for additional copies in the community, was re-released in CDROM format. Over 800 copies of the CDROM have been distributed to stakeholders both within the Herbert River catchment and in other cane growing regions.

All data held in the database is stored and maintained at CSIRO Davies Laboratory in Townsville. A copy is also kept at Cunningham Laboratory in Brisbane and the Herbert Resource Information Centre in Ingham. Copies of the Herbert River Catchment Atlas (Hard Copy and CDROM versions) are also available from the same locations.

4.2   Spatial Analysis of the Impact of Land Use and Management on Water Quality

A key objective for this Project was to spatially model the distribution of sediment, nutrient and water from non-point (ie diffuse) sources in the Herbert River catchment. The need for non-point source pollution modelling arose in part from the requirements of natural resource managers to make decisions within the context of limited data and demanding time pressures. In practice, time pressures often do not allow for adequate field research and models have been seen as a tool to help achieve decisions with a level of certainty that could not otherwise be achieved. Springer (1998) provides a detailed account of the spatial modelling activities undertaken in this Project. The sections that follow briefly outline the key components of this work.

4.2.1 Model Selection

Numerous models are available for assessing non-point source pollution. Model taxonomy varies, but essentially models originate from the USA and Europe. Most currently available non-point source pollution models are based on hydrologic models and draw some of their fundamental equations from observations and assumptions made over 150 years ago. Hydrologic modelling has evolved over the last couple of decades, moving from modelling runoff volumes and peak flows, through soil erosion, transportation and deposition, to include nutrient movement and crop growth.

The list of models available for non-point source pollution modelling continues to expand and decisions about which models to use are becoming increasingly difficult. Determining an appropriate model is non-trivial, as many variations exist in model structure and design. Model scale, time frame and study area locality, all play a role in decisions about the choice of model. Evaluation of models is often objectively based on the quantitative ability of the model to perform in a study area. Some researchers have proposed a more holistic approach to model evaluation using subjective elements to assist in decision-making processes. Elements such as model documentation and support, input and program utility, model sensitivity and model output all play a role in the evaluation of the model. Researchers at the CRC for Catchment Hydrology have listed ten criteria that would make up the ideal

catchment model. Whilst considering a full combination of these impossible, they felt that models should contain three basic attributes; generality, realism and precession.

Apart from the quantitative assessment of model outputs, objective evaluation should also include evaluation of model calibration, model validation and time use. Assessment of models has predominantly been based on performance against other models in achieving higher accuracy, however we argue that other facets of using a non-point source pollution model need to be considered. Many of these considerations have also been raised in other research as non-point source pollution models have moved from the purely scientific research realm into that of the natural resource management. Barnes *et al.* (1997) reviewed the role and function of models for decision support at the catchment level, discussing the different role of models from hypothesis testing through to specific management models. Citing the difference between the various functions, Barnes *et al.* (1997) felt that models for DSS should be simple and adaptable to commonly available data rather than dictating the quality and quantity of data, as done by research models.

Barnes *et al.* (1997) were also critical of the increasing model complexity and the ability for users other than model developers to adequately calibrate the model. This point has been broadly supported in the research community, where there has been concern that models were becoming overly complex and beyond the scope of most resource management organisations. The data requirements were far greater than the knowledge base of most organisations requiring years of preliminary research to create a data set suitable for modelling and if current trends in scientific research continue it is unlikely that such data collection will be a high priority.

This Project required a number of key features for a suitable non-point source pollution model. Apart from containing sediment and nutrient components, the model needed to have spatially distributed outputs, which allowed tracing of pollution to source areas and the mapping of pollution fluxes across the catchment. Importantly the model needed to have the ability to be linked or integrated into a geographical information system. Other considerations included the scale of the model both in aerial coverage and time frame. Some models use a continuous time step, modelling daily flows over extended periods such as crop rotation cycles and estimate output on daily monthly and yearly time steps. Other models work on short time frames modelling single rainfall events. Currently there are a limited

number of models that address both time scales, usually specialising in one scale and the resulting outputs reflect the model's time frame. The ability of the model to handle the large spatial coverage of the Herbert River Catchment was another issue in choosing the model. Both software and hardware limitations also constrained the choice of an appropriate model.

Given these considerations, the AGNPS model developed by USDA was chosen for use in this Project. The model compared favourably in the evaluation, with good levels of model documentation and published papers, improved model data entry tools through GIS and suitable model outputs. On the negative side, potential problems exist in relation to the models assumptions and their applicability to the Herbert River, the ability to find adequate input data with some parameters not commonly researched in Australia and the ability of AGNPS to handle a large rainfall gradient across the catchment.

4.2.1.1 Agricultural Non-Point Source Pollution Model - AGNPS

AGNPS is an event based, distributed parameter model. The choice of an event-based model was considered appropriate given the results of the water quality studies undertaken by Bramley *et al.* (1996). Essentially a shell in which a number of sub-models are coupled together in a series of loops, AGNPS estimates runoff, erosion and nutrient movement across a matrix of uniform cells (grid) with output at the cell level and at the catchment outlet. Being a single rainstorm event model, AGNPS was initially designed for events up to 24 hours although it has been successfully applied to periods up to 3 days. AGNPS is not capable of long-term assessment as is possible with models that estimate pollution on an annual time frame.

The hydrologic sub-model of AGNPS is based around the USDA Soil Conservation Service Curve Number method, with runoff calculated for each cell and accumulated for the whole catchment. The sediment sub-model is based on a modified version of the Universal Soil Loss Equation, using complex routing and deposition equations to model sediment movement through the catchment and estimating total yield for the whole catchment. The nutrient transport sub-model utilises the concept of enrichment ratios and extraction coefficients to estimate movement of nitrogen, phosphorus and COD (Chemical Oxygen Demand) through the catchment.

AGNPS has thirty core parameters, which describe land use, land cover, management practices, soil, geomorphology of the landscape and hydrology (Table 1). In additional to these parameters, AGNPS has a number of non-essential parameters that give the user options for more detailed input data.

Table 1. AGNPS Input Parameters.

Catchment Characteristics	Slope Shape Factor
Watershed Identification	Average Field Slope Length
Cell Area	Average Channel Slope
Total Number of Cells	Average Channel Side Slope
Precipitation	Manning's Roughness coefficient
Precipitation Duration	Soil Erodibility Factor (K)
Energy Intensity Value	Practice Factor (P)
USDA Storm Type	Cropping Factor (C)
Precipitation Nitrogen Concentration	Surface Condition Constant
Runoff Calculation Method	Chemical Oxygen Factor
Cell Characteristics	Soil Texture
Cell Number	Fertiliser Indicator
Number of the cell into which it drains	Pesticide Indicator
Flow Direction	Additional Erosion Sources
SCS Curve Number	Impoundment Indicator
Average Land Slope	Channel Indicator

The model outputs at two levels, for the whole catchment at a selected outlet point and for an individual cell. Output's can be grouped into hydrology (e.g. runoff volume and peak runoff rate), sediment (e.g. sediment yield, upland erosion and deposition) and chemical (e.g. nitrogen and phosphorus concentrations and sediment associated mass). Outputs can be viewed in tabular form, or through the integration with GIS, outputs can be mapped and viewed graphically. The integration with GIS also allows users to perform spatial analysis on the outputs.

The model has several limitations that have hindered its development from a research model into the field of decision support. Apart from problems with the use of USLE and SCS Curve Numbers, AGNPS has problems in terms of transportability. Default extraction coefficients and enrichment ratios based on research and observations in the USA are not overly suited to

conditions in many areas outside where they were derived. Another criticism is the use of the USLE for individual storm events. USLE was designed to estimate soil loss from long term averaged data rather than for short-term events. There have also been questions raised about the balance of the model between empirical relationships and the sub-model components (Barnes *et al.*, 1997). The relationships between the models' components are complex and result in difficulties in achieving optimum calibrations. Such complexities are becoming more common as models evolve and represent a greater number of processes and ultimately reflect the complexity of the natural environment. This however is making the models less user-friendly and beyond the resources of many natural resource management organisations.

These limitations aside, AGNPS has a number of advantages over other models. The distributed input and output allows for accurate pollution tracking and makes the model more suited to integration with a GIS. Many of AGNPS's core parameters are widely used in other models. AGNPS does not require the excess crop growth and ground water information, thus it requires significantly lower quantities of data than other models. AGNPS requires thirty parameters with twenty-two parameters for each cell to run as opposed to other models like SWAT that requires over 100 parameters per unit area to run (Arnold et al. 1995).

4.2.2 Model Calibration and Validation

Calibration of AGNPS was necessary to ensure the validity of model output. Calibration involved adjusting model parameters to achieve a more accurate model output. To better estimate input parameters, calibration was carried out on hydrology, soil erosion and sediment transport components of the model based on known catchment outputs and adjustments made based on the scale of model output errors.

Using this information and the process described in Figure 7, adjustments were made to the parameters to minimise error and to achieve an acceptable outcome (ie $R^2 > 0.9$). Calibration was undertaken for each component of AGNPS (hydrology, sediment and nutrients) for nine storms of varying degrees of intensity and duration. The storms were recorded over the last 20 years and represent a typical selection of storm conditions ranging over a number of days and with a variety of intensities.

Results of the calibration are displayed in Figures 8 and 9. From these it can be seen that in general, AGNPS over-estimates peak flow and total sediment yield. This can be considered an excellent result, however, as AGNPS does not have an over-bank flow component in its calculations.
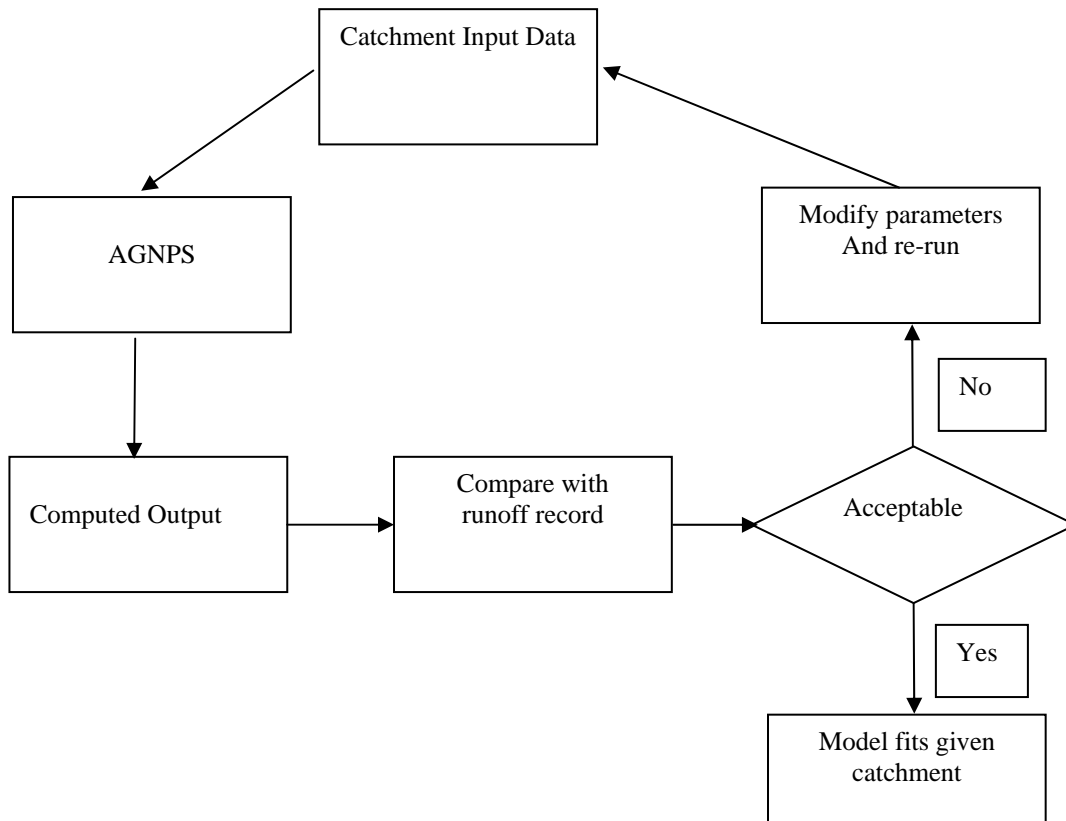

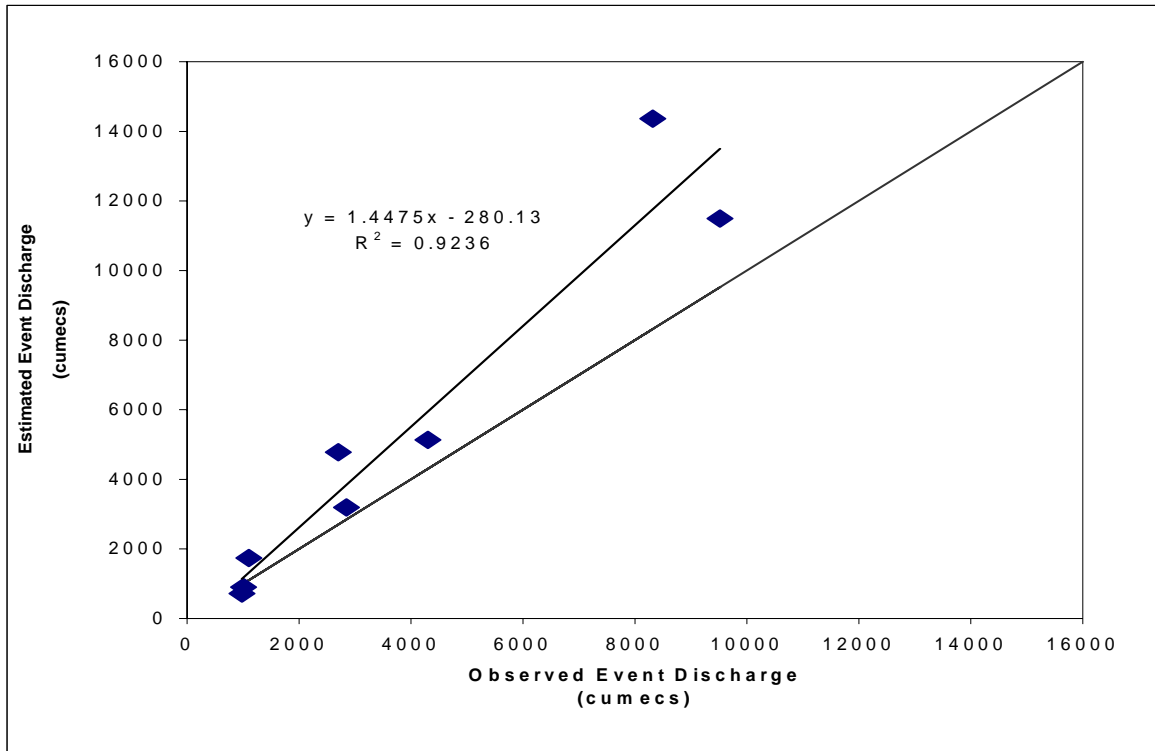**Figure 7. Procedure used to calibrate the AGNPS model.**

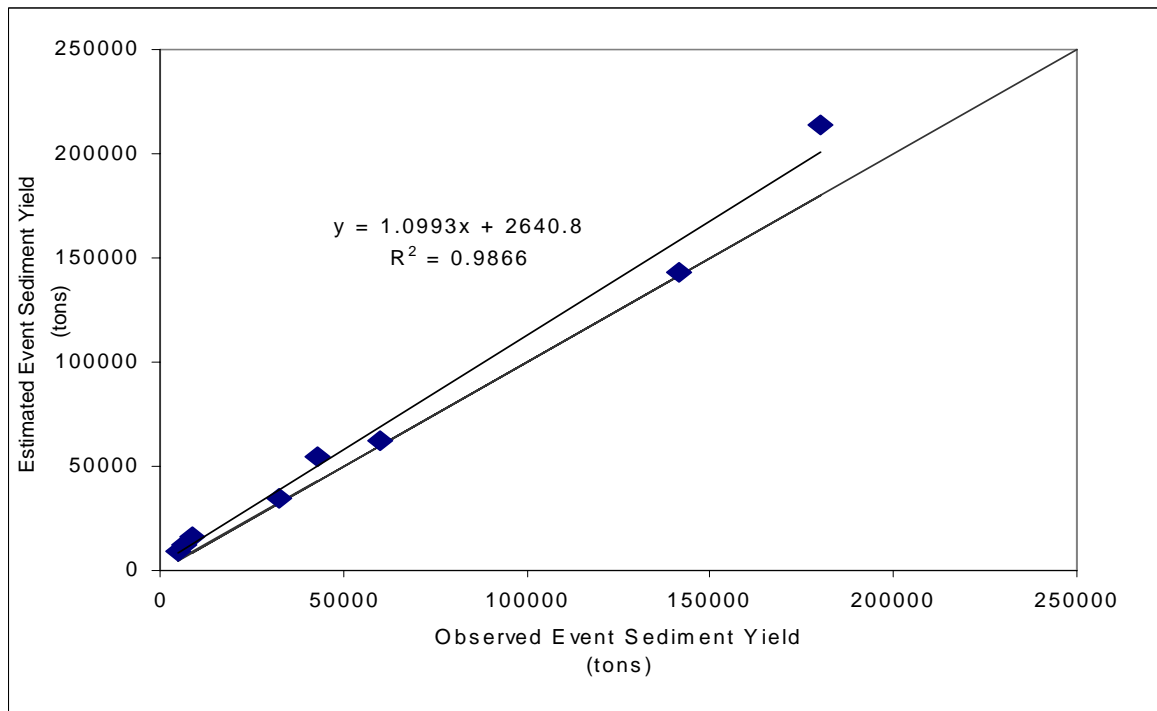**Figure 8. Calibration results for of event discharge.**

Figure 9. Calibration results for event sediment yield.

Data for calibrating the nutrient component of AGNPS was limited with the majority of nutrient data collections recording ambient water conditions rather than those experienced during high flow. Only three events in 1993 and 1994 were collected and from this data only two AGNPS nutrient outputs were measured, soluble nitrogen and soluble phosphorus concentrations. Table 2 displays the observed values and estimated outputs from AGNPS. Measured in parts per million, the concentrations in the Herbert River were measured at John Row Bridge and at Abergowrie. AGNPS limits outputs to two decimal places and in the event of values smaller than this limit an output of zero is displayed.

Table 2. Calibration results for soluble nitrogen (N) and soluble phosphorus (p) concentrations (ppm).

Date	Observed				Estimated			
	Abergowrie		John Row Bridge		Abergowrie		John Row Bridge	
	N	P	N	P	N	P	N	P
18th Feb 1993	0.367	0.04	0.403	0.019	0.00	0.00	0.00	0.00
2nd Feb 1994	0.395	0.005	0.473	0.034	0.00	0.00	0.00	0.00
21st Feb 1994	NR	0.01	NR	0.021	0.00	0.00	0.00	0.00

Following calibration, model output was validated using a further four storm events. These events covered a range of conditions in the catchment including low and high soil antecedent moisture conditions, high upper catchment rainfall and long duration storms (Table 3).

Table 3. Validation results for three selected storm events.

			Observed		Predicted	
Event	Rainfall Depth (mm)	Duration (h)	Peak Flow (m3/s)	Sediment Yield (tonnes)	Peak Flow (m3/s)	Sediment Yield (tonnes)
13-17 Feb 1988	146.81	120	1030	6070	2365	32630
17-21 Feb 1991	284.98	120	10939	362421	19149	114298
15-18 Feb 1994	94.48	96	550	2728	794	6934
22-25 Feb 1994	82.80	96	1764	25675	1809	28106

4.2.3. Results

Having calibrated AGNPS, the model was used to predict non-point source pollution based on a range of different decision making criteria, which are detailed in the sections that follow.

4.2.3.1 Sediment Yield

Contribution of catchment divisions

As discussed previously, the Herbert River catchment can be divided into three distinct sections, upper, middle and lower. The lower catchment can be further sub-divided into 2 divisions, lower and coastal. The lower division is confined to those areas that flow directly into the Herbert River, the coastal division are those sub-catchments which flow into the Coral Sea but are included in the definition of the Herbert River catchment (eg Cattle Creek, Trebonne and Palm Creeks and Seymour River).

Figure 10 shows the relative mean sediment contributions for different sections of the catchment for a range of storm events. It can be seen that 65% of the sediment is generated in the middle section of the catchment. The next highest contributor to sediment loads is the upper catchment area, providing 21% of the total sediment load. Significantly, the lower catchment section including Stone River sub-catchment contributed only 9% of the total sediment load.
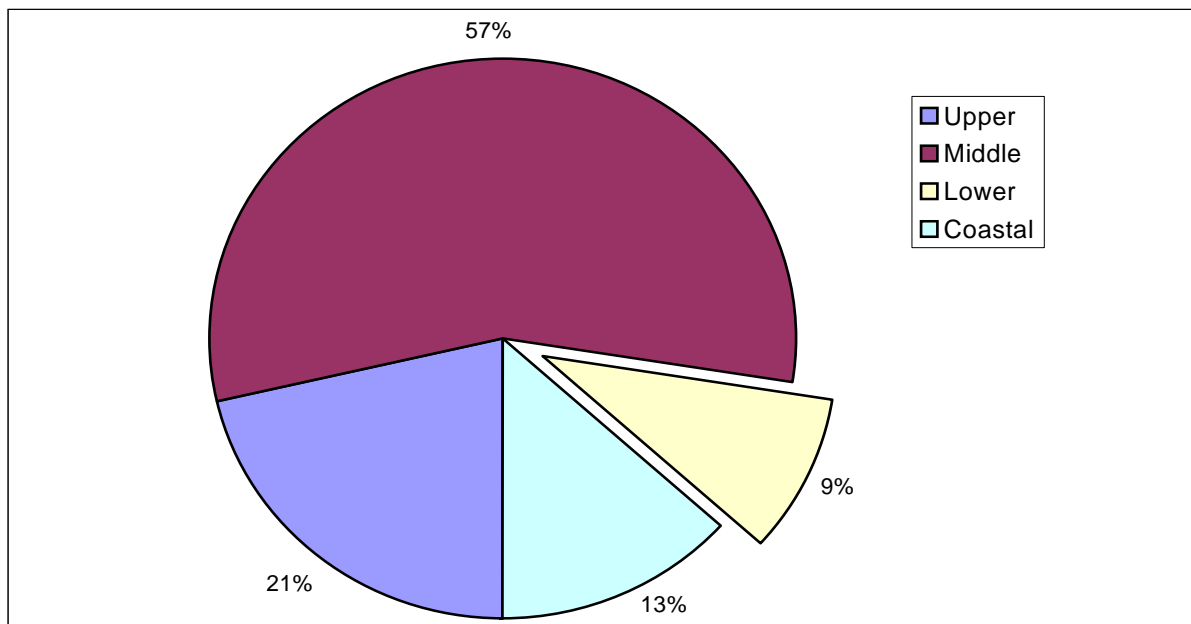

Figure 10. Average Event Sediment Yield Contributions by Catchment Area based on 5 recorded events.

Contribution of different land cover types

Figure 11 details mean sediment contribution for a range of land cover types in the catchment. It can be seen that the contribution of sediment from eucalyptus dominated patterns is approximately 61%. This value is heavily influenced by the location of this land cover type, with large sections occurring on the steeper slopes of the middle and lower catchment. Areas used for cattle grazing contributed approximately 21% of sediment generated in the catchment. Located predominantly in the upper catchment, grazing activities are rangeland oriented with limited pasture improvement and low stocking rates. Sugarcane areas contributed approximately 1% of the total sediment yield in the catchment. Plantation forestry areas contribute approximately 1% of the sediment yield at the catchment level.
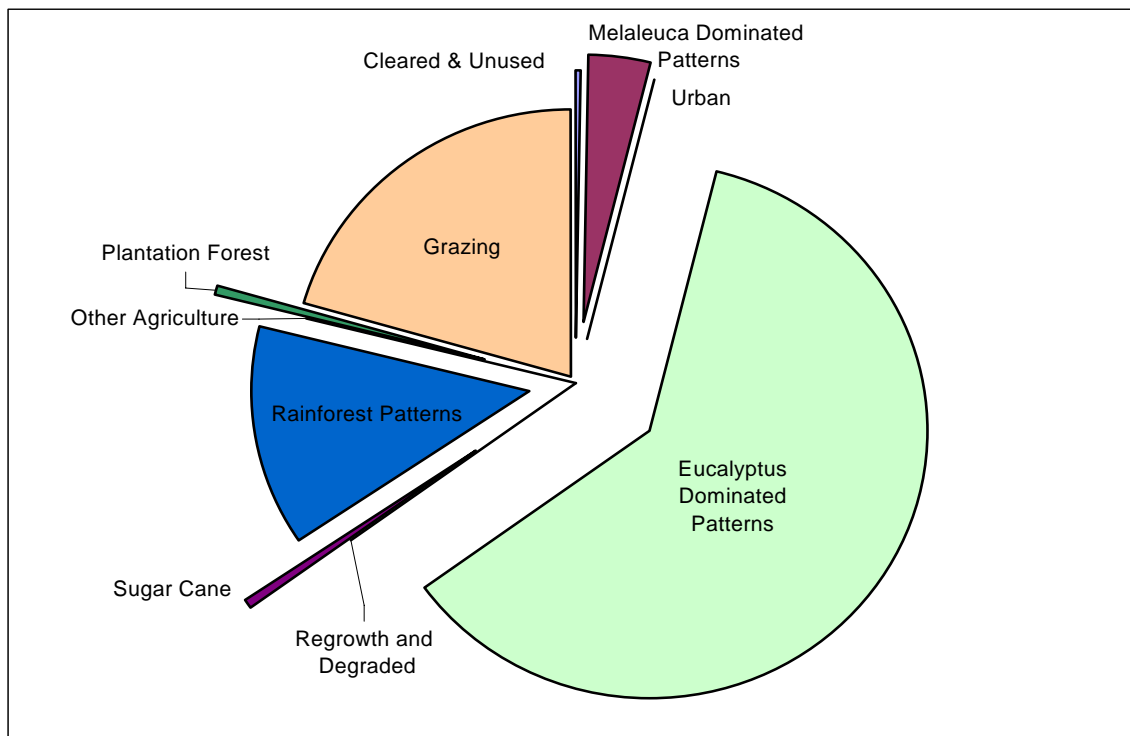

Figure 11. Average Sediment Contribution by Land Use Type based on 5 recorded events

Visualisation of sediment distribution and deposition

*A*s discussed above in the previous section, over half of the total sediment yield is generated in the middle catchment area. Figure 12 displays the total cell erosion for the Herbert River catchment at Ingham based on a rainfall event which occurred over the period 7th-11th March 1983. Total cell erosion is the total amount of sediment transported within each cell before deposition, measured in tons per hectare. The largest amounts of cell erosion occurred in those areas designated in red, with the areas in dark green undergoing the least amounts of erosion. The band of high sediment movement follows the steep slope areas, which bound the floodplain in the lower catchment and form the Herbert Gorge upstream of Abergowrie.

Figure 13 shows, total sediment deposition for the Herbert River catchment at Ingham, for the same event. Total deposition represents to amount of sediment that is deposited within the cell from the total amount of sediment being transported within the cell. Displayed as a percentage, negative values denote scouring by larger sediment particles and the formation of rills and gullies. Values approaching 100% indicate high levels of deposition where the majority of sediment generating or entering the cell is deposited within the cell.

Displayed in red and orange, areas of high negative deposition or gully erosion are closely associated with stream channels and represent areas of high stream bank erosion. The floodplain areas along the Herbert River channel show high levels of deposition, with the majority of sediment generated deposited within the cell of generation. The contributions of sub-catchments to the total sediment discharge at Ingham are displayed in Figure 14 for the Herbert River Catchment at Ingham for the storm event over 7th-11th March 1983. It can be seen that the upper catchment contributed approximately 7585 tons of sediment, but at Abergowrie the Herbert River had more than tripled its load to 26933 tons. Contributions of the remaining tributaries in the lower catchment bought the total sediment yield at Ingham to 31206 tons.
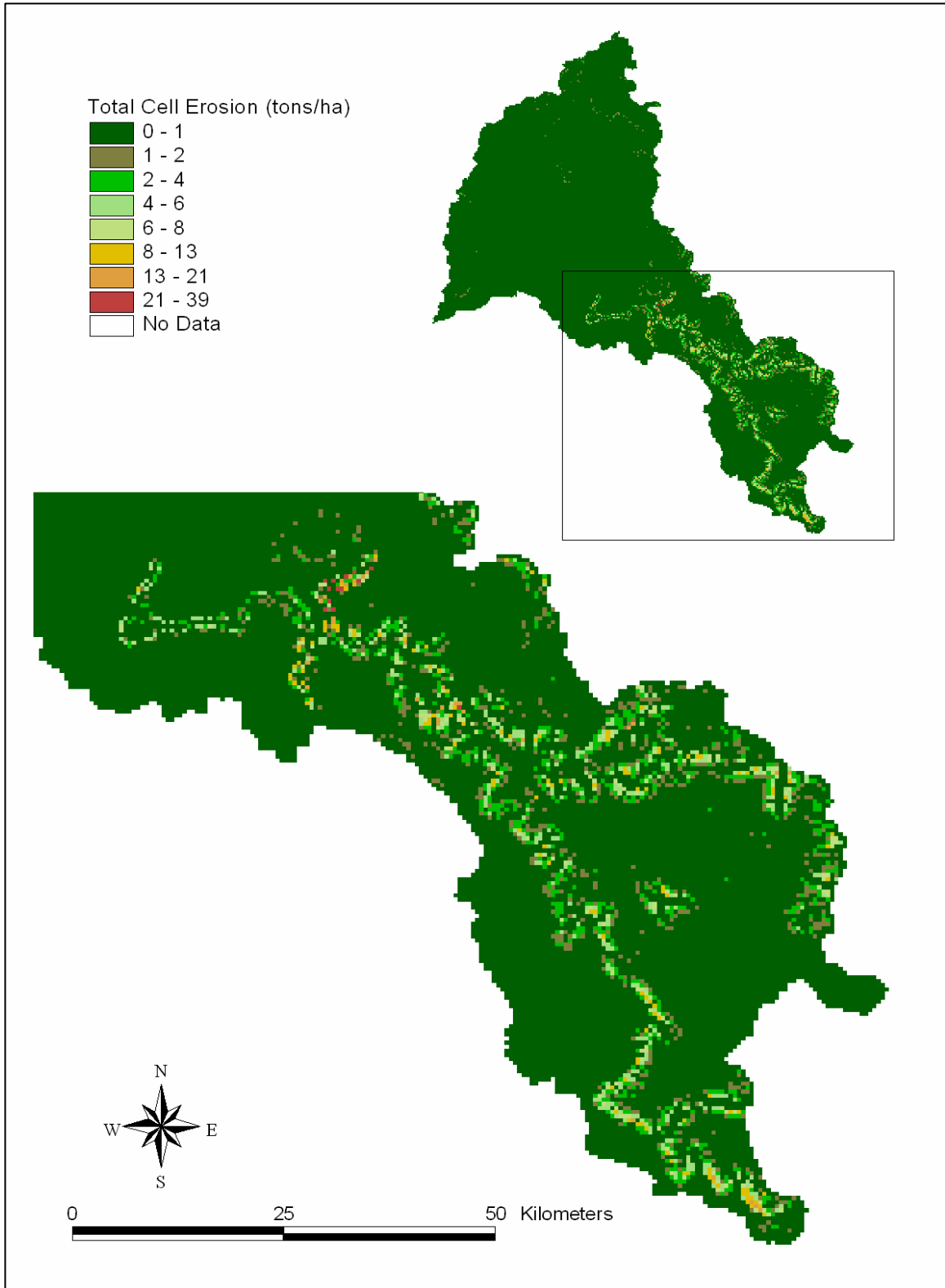
Figure 12. Total Cell Erosion for the Herbert River Catchment at Ingham. For the event 7th –11th March 1983.
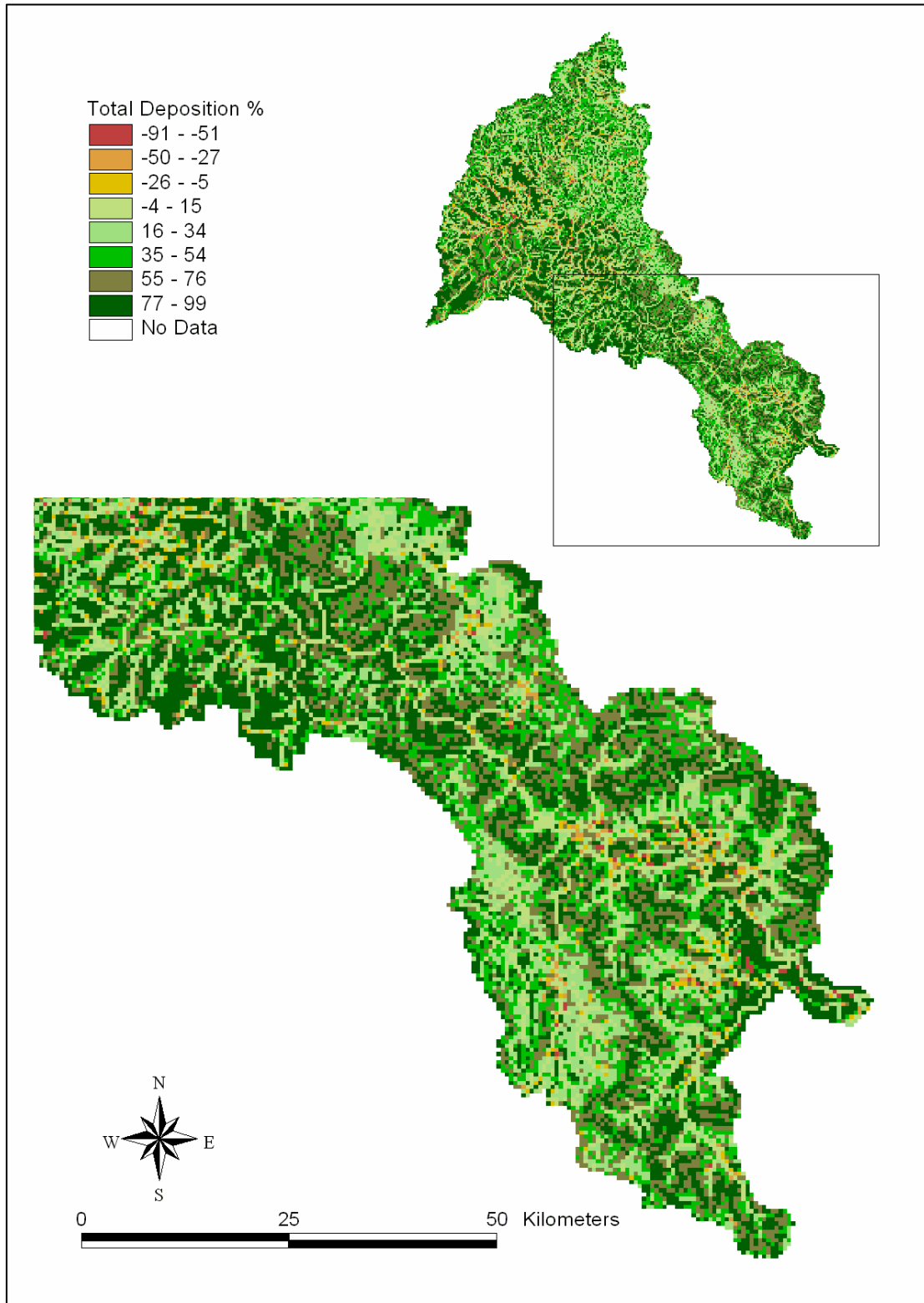
Figure 13. Total Deposition for the Herbert River Catchment at Ingham for the event 7th –11th March 1983.
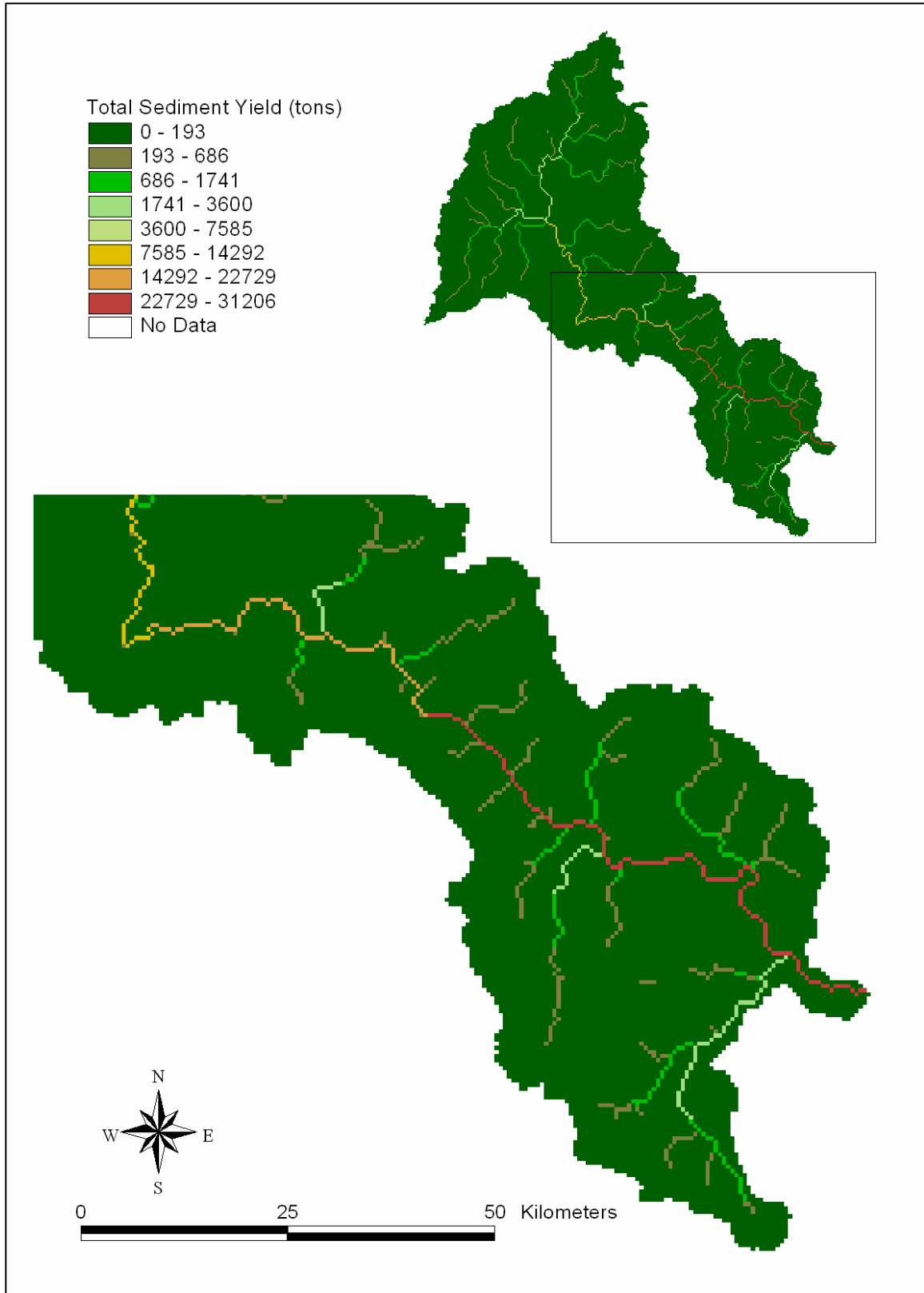
Figure 14. Total Sediment Yield for the Herbert River Catchment at Ingham for the event 7th-11th March 1983.

4.2.3.2 Nutrient Yield

Nitrogen

Figure 15 displays the average soluble nitrogen contributions per unit area for the main land cover types averaged over five storm events. Sugarcane and urban land uses contributed the most, both at 0.05kg per hectare. Grazing contributed the least at 0.01kg per hectare of soluble nitrogen.
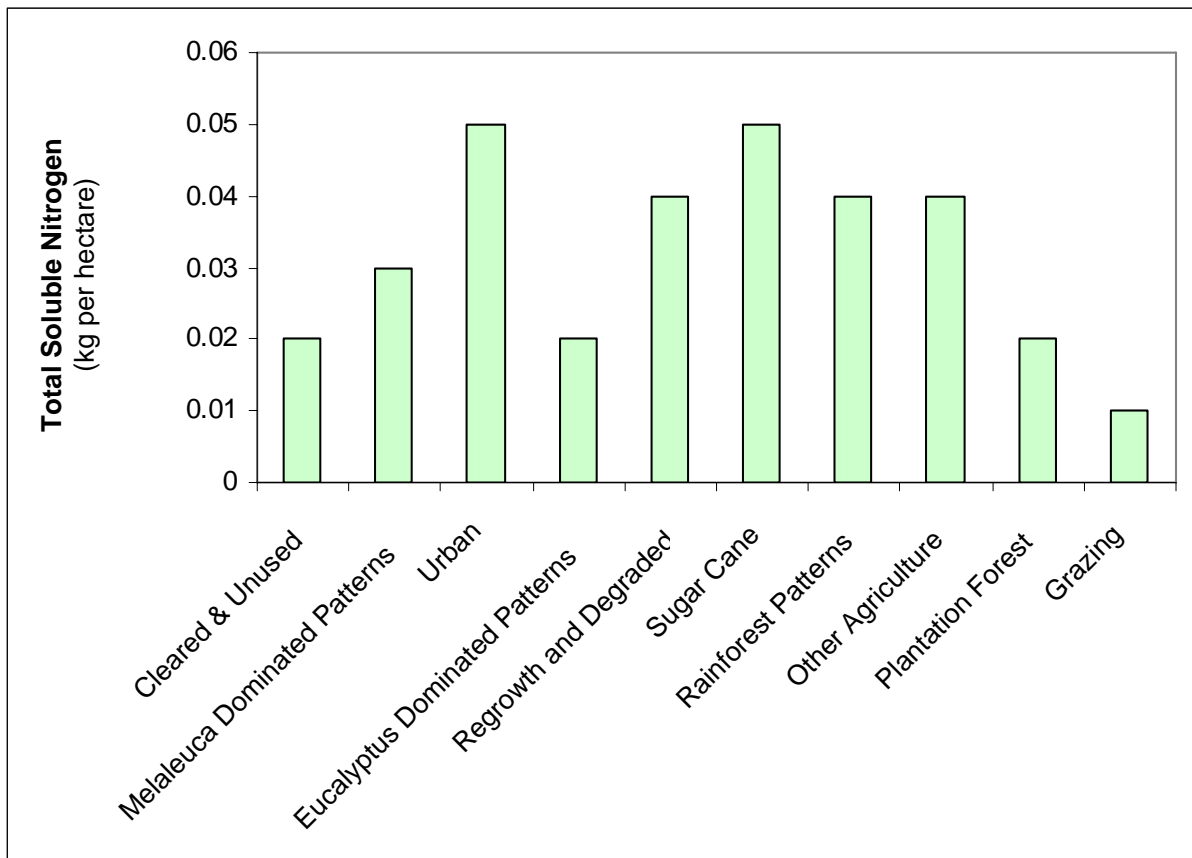

Figure 15. Average Soluble Nitrogen Contributions per unit area by land use category for the Herbert River Catchment, for the event modelled, 7th-11th March 1983.

Figure 16 displays the Total Soluble Nitrogen generated for the event over 7th-11th March 1983. The values range from less than 0.01 kg/ha to 2.79 kg/ha. The application of fertiliser on agricultural areas strongly influences the spatial distribution of soluble nitrogen. Cane land areas are associated with areas of high nitrogen values. Urban land use areas on average were responsible per unit area for contributing the same as sugar cane. Interestingly, rainforest areas generated significantly more nitrogen than eucalyptus dominated cover.

Figure 17 displays the soluble nitrogen concentrations as estimated by AGNPS for the event on 7th-11th March 1983. As with the values for total soluble nitrogen, the distribution of cane land is closely linked to the distribution of soluble nitrogen concentration values (ppm).
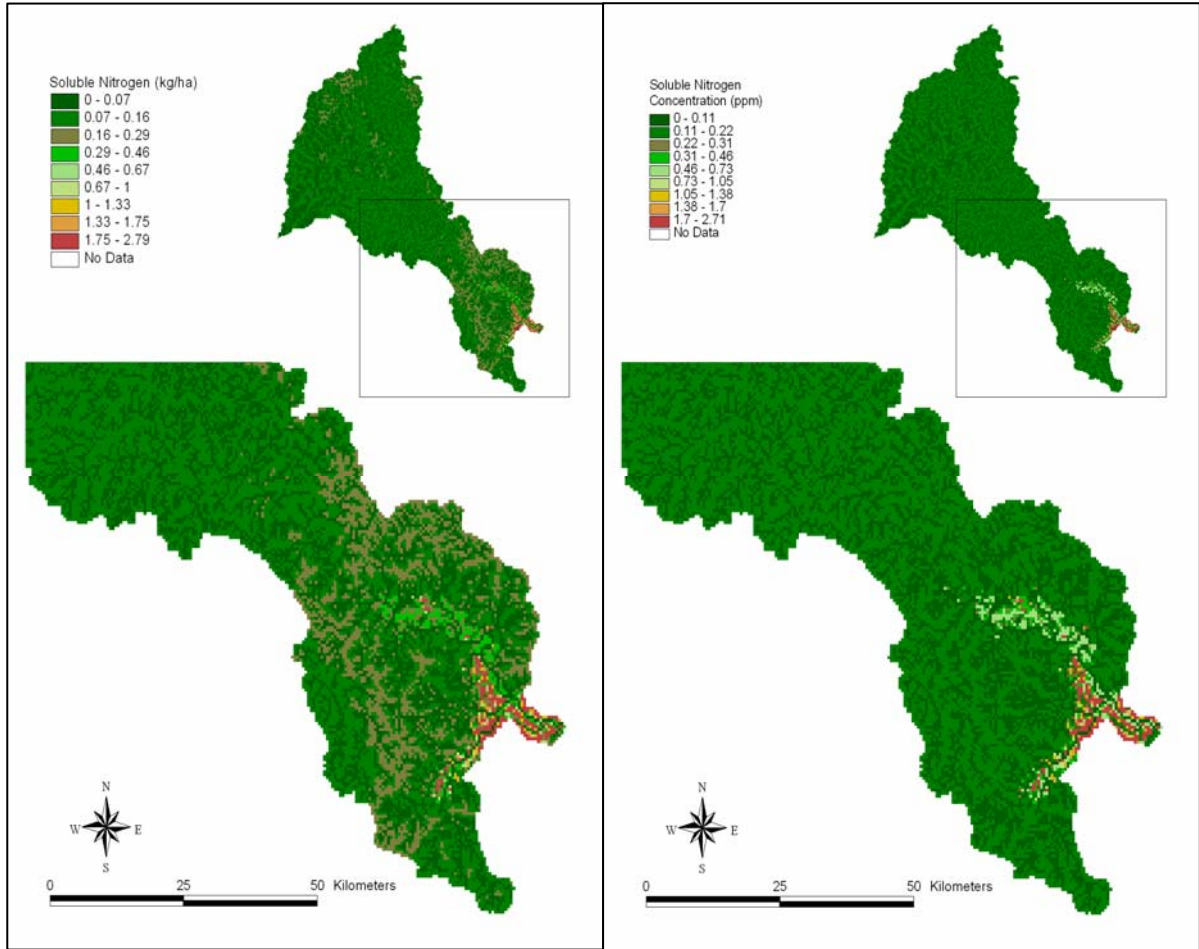

Figure 16. Total Soluble Nitrogen.   **Figure 17. Soluble Nitrogen concentration**
(Herbert River at Ingham, for the event modelled 7th-11th March 1983)

Phosphorus

Phosphorus behaves differently to nitrogen, with the majority of phosphorus pollution being sediment bound rather than soluble. While AGNPS can estimate soluble levels of P, the work of Bramley *et al* (1996) has shown that it is more important to study sediment attached phosphorus outputs. Figure 18 displays the estimated sediment attached phosphorus for the event 7th-11th March 1983. Measured in kilograms per hectare, the sediment attached phosphorus source areas is more widely distributed across the catchment than the soluble nitrogen. The highest levels of sediment attached phosphorus are generated in the zone of high erosion around the middle of the catchment.
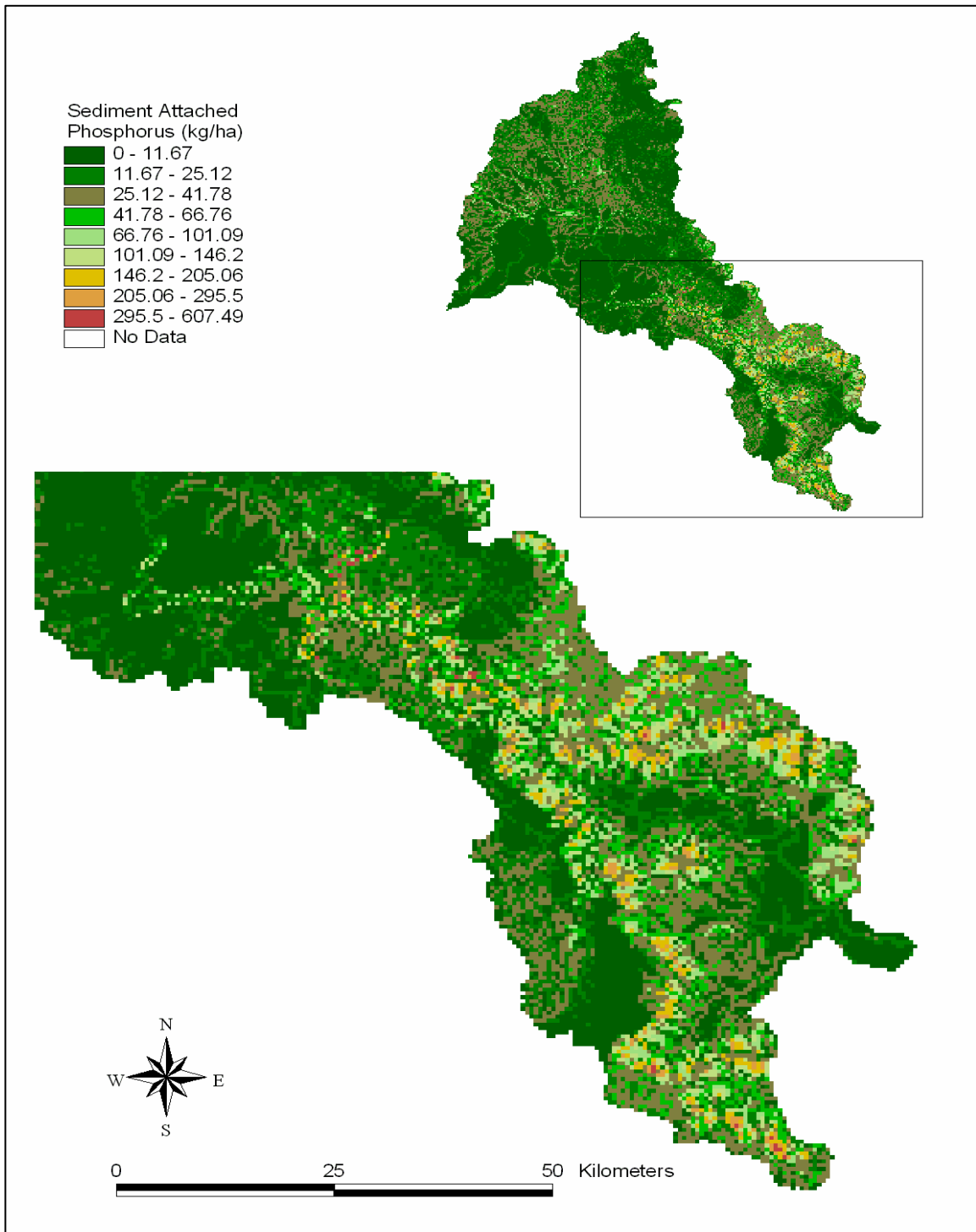
Figure 18 Sediment Attached Phosphorus for the Herbert River Catchment at Ingham, for the event modelled 7th-11th March 1983.

4.2.3.3 Temporal changes in non-point source pollution

Using land cover data sets described in section 4.1.2, changes in sediment loads and discharge in the Herbert River catchment over time were modelled. Figure 19 displays the peak flow and total sediment yield for the Herbert River at Ingham for three rainfall scenarios at 4 point in time. The low rainfall scenario had an average of 15mm of rainfall over 24 hours across the catchment, the medium scenario an average rainfall of 48.26mm, and the high rainfall scenario an average 149.86 mm of rainfall. The high rainfall scenario represents a typical rainfall event associated with a rain depression or tropical cyclone.
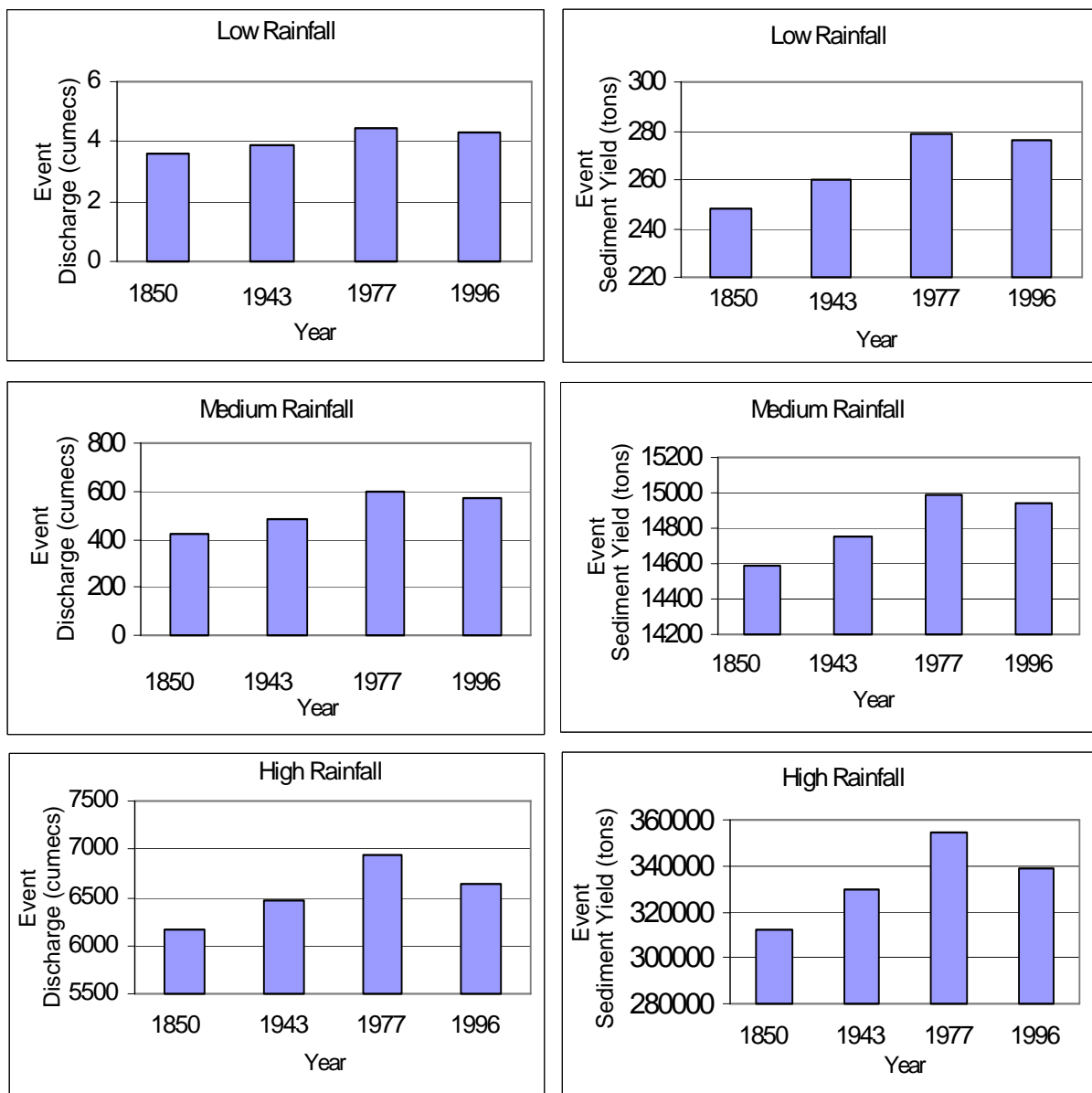

Figure 19. Sediment yield and discharge in the Herbert catchment for a range of rainfall events over time.

For the three rainfall scenarios modelled, the result of land use changes since European settlement at the catchment scale has been an overall increase in discharge and sediment yield, with an average increase of 20% for peak flow and 9% increase in total sediment yield. It can also be seen that a decrease in both discharge and sediment yield occurs from 1977 to 1996 as a result of the introduction of green cane harvesting in sugarcane areas. Further analysis carried out at the sub-catchment level revealed similar trends in the model output for the four years (Springer, 1998).

A typical summer storm event was modelled in sub-catchment of the lower Herbert and the results displayed in Figure 20 for discharge and Figure 21 for total sediment yield. The impacts of land use change between 1977 and 1850 were considerable in all catchments, with an average increase of 34% across the four sub-catchments for discharge and 10% for total sediment yield. In all of these sub-catchments there has been a decrease in discharge and sediment yield since 1977 with the effects of green cane harvesting and other conservation measures greatly improving the outputs of many streams during this period. Lannercost Creek represents an exception to this trend, with both discharge and sediment yield increasing from 1977 to 1996. This can be attributed to the growth in plantation forestry in the catchment. Forestry areas occur on steeper slopes in the catchment and often have reduced ground cover, resulting in higher runoff rates and rainfall erosivity.

The introduction of conservation farming practices in Trebonne and Palm Creeks and Seymour River has resulted in an overall decrease in both discharge and sediment yield when compared to pre-European estimates. This is the result of conservation farming practices on cane lands. The increase in ground cover provided by the cane trash and the dense cane crop results in decreased runoff rates and reduced soil erodibility even compared to the natural vegetation.
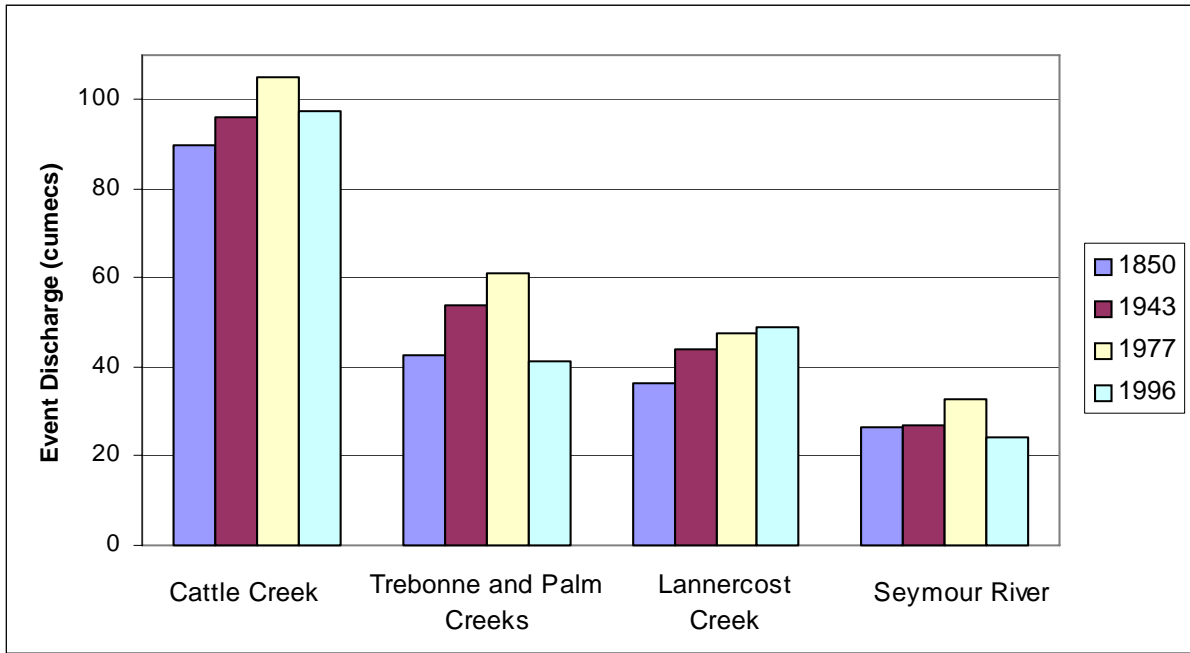
Figure 20. Temporal changes to event peak flow for four sub-catchments of the Herbert River.

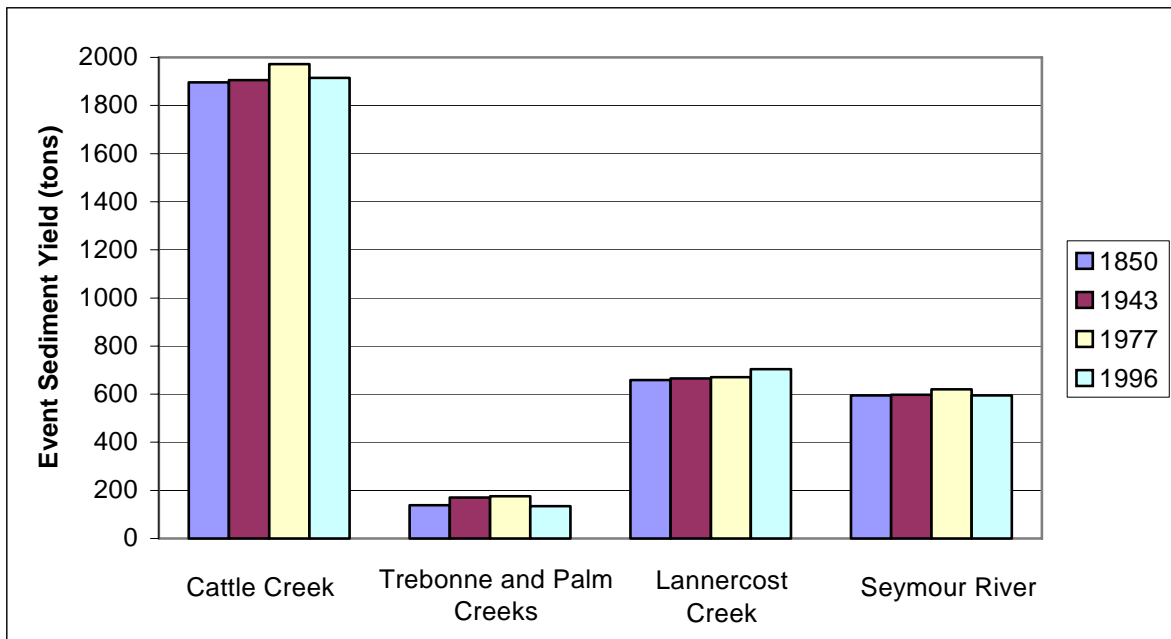**(Based on an average storm event of 149mm of rain over 24 hours with EI^{30} of 19.47)**

Figure 21. Temporal changes to event sediment yield for four sub-catchments of the Herbert River.

(Based on an average storm event of 149mm of rain over 24 hours with EI^{30} of 19.47)

4.2.3.4 Changes in Land Management Practice: Green Cane versus Burnt Cane Farming Systems

As discussed in the previous section, changes to farming practices, especially those associated with sugarcane, have had a considerable impact on non-point source pollution in the lower catchment area of the Herbert River. Using AGNPS to model the changes in farming practices, it is possible to gain an understanding of the degree to which green cane harvesting affects individual areas of the catchment and the catchment as a whole. Averaged across the four sub-catchment areas, green cane harvesting has decreased sediment yield by almost 10%.

Every sub-catchment area modelled except Lannercost Creek, showed a decrease in sediment yield. Lannercost Creek has seen an increase from 1977 to 1996 and as mentioned earlier the expansion of plantation forestry is a contributing factor to this increase. AGNPS estimations for Trebonne and Palm Creeks and Seymour River (Figures 20 and 21) showed a total decrease in discharge and total sediment yield to below levels prior to European settlement in 1996 as shown in Figure 17 and Figure 18.

Green cane harvesting is also responsible for a reduction in nutrient export from cane areas. Figure 22 displays an area of Trebonne Creek and Palm Creek Catchments and the estimated total soluble nitrogen generated in each cell for a single storm event. Under the burnt cane harvesting system nutrient output from individual cells reached as high as 3.8 kg/ha, whilst under green cane harvesting no cell in the area produced greater than 0.8 kg/ha of soluble nitrogen.

At the catchment scale, this results in a significant decrease in soluble nitrogen being transported around the catchment and pollution waterways. Similarly with sediment attached nutrients, as there are lower rates of erosion under green cane harvesting there is also a reduction in sediment attached nutrient rates being generated from cane lands.

Figure 22. Effects of green cane harvesting on total soluble nitrogen in Trebonne and Palm Creek Catchments. (Based on event with 48.26 mm over 24 hours with EI^{30} of 19.47)

4.2.3.5 Discussion and conclusions

Overall AGNPS performed within expectations, however this research has shown that there are a number of key limitations with the AGNPS model and these should be considered when using the model in a decision support capacity (Springer, 1998). Using the model within these limitations, it is a useful tool and given further testing especially in the area of nutrient pollution loads AGNPS has potential as an operational tool.

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Runoff and sediment yield predicted by AGNPS compared favorably to observed values in a number of storm events. However, the model's inability to effectively model over-bank flows remains a significant constraint. Furthermore, more detailed event based runoff data for a series of sub-catchment areas would greatly improve its usefulness.

The results of land use change in the catchment have been responsible for an overall increase in discharge, sediment and nutrient export in the Herbert River. The impact of conservation farming techniques for sugarcane are significant at the catchment scale as they have resulted in decreased runoff and sediment yield from cane lands. At the sub-catchment scale, green cane harvesting has in most instances resulted in a net reduction of both discharge and sediment yield from some areas.

Using AGNPS it has been possible to model the affects of land use change at the catchment scale and determine pollution source areas. Further analysis could include the predicting the impacts of future land use change including expansion of cane lands and plantation forestry or the impacts of re-establishment of riparian vegetation buffers between stream channels and agricultural areas. Apart from the limitations discussed above AGNPS performed within expectations. Achievement R^2 values for peak flow of 0.92 and 0.98 for sediment yield is encouraging. However, there is a clear need for a more localised and adaptable model tool to model non-point source pollution under tropical floodplain conditions.

4.3   Tools for Decision Support

Throughout the Project, a significant investment was placed in ensuring operational application of research findings within a land use planning context. It was anticipated from the outset that a decision support system (DSS) potentially provided an appropriate means of facilitating such application. Hence, the creation of a DSS was one of the key objectives of the project. This section of our report relates research activities in relation to this objective. It was recognised that, in the context of natural resource management and planning, a DSS can:

- help resource managers make effective use of existing information in making defendable decisions in natural resource management;

- integrate outputs of research for efficient use in decision-making; and

- provide a focus for integrated, multi-stakeholder consideration of natural resource management issues.

Specific roles for such systems include problem formulation and task analysis (helping the user to identify the issues meriting analysis), data analysis (including information retrieval and analysis; exploration of 'what-if' scenarios etc.) and enabling exploration of issues across stakeholder groups. In the natural resource management context such systems can integrate spatial and non-spatial data analysis technologies (e.g. GIS, statistical techniques etc.), simulation models (e.g. hydrological models), expert systems (e.g. for assessing land use suitability) and other knowledge-based approaches (e.g. resource allocation according to guidelines). Sources of input into a DSS might include existing data resources within agencies and externally; existing resources for data analysis; community / stakeholder input; evolving legislation and policy and research outputs.

Decision support systems have been most successfully applied in engineered systems or simplified, intensively managed systems and in addressing highly defined and well structured domains. In such contexts, system functioning and the problems addressed in management are relatively well understood. By contrast, natural resource management for sustainability, particularly at a catchment or landscape scale, is typically characterised by consideration of complex interactions which are only partially understood and about which limited data are available. These challenges were assessed in some detail as part of the research reported here and were published in Walker and Lowes (1997). As a consequence, the Project team were

committed to the potential utility of developing a DSS but recognised that the development and implementation of an appropriate (i.e. operationally relevant) DSS within the current context was a significant challenge.

Our response to these challenges has been to implement an innovative decision support toolkit environment named NRMtools. NRMtools is a flexible, distributed decision support environment. It is targeted at natural resource professionals (i.e. it is designed to be used by decision-makers rather than IT support staff). A range of decision support tools developed within the NRMtools framework are supplied with the toolkit, however, its central feature is that users can also specify and implement new tools. Execution of a decision support tool within NRMtools results in fully documented output to encourage defendable recommendations on the basis of available information. These key design features are justified in the following sections and implementational detail is provided.

4.3.1   *NRMtools – background and specification*

While many of the technical constraints to effective decision support have been overcome in recent years through advances in information technology, many decision support systems have failed to fulfil their initial promise and achieve operational application. We believe that this failure can, in large part, be ascribed to development being technology-centred rather than user-centred. In consequence, the development of NRMtools was based on extensive consultation with potential users.

In 1994, an exploratory user survey was undertaken comprising interviews with 24 potential system users, ranging from primary producers to top level managers in state government (Bellamy and Johnson, 1994). This work revealed that decision-making in the context of catchment management was characterised by the occurrence of many occasional or one-off tasks rather than routine, frequent and standardised processes. As a result, planning and action tended to involve the intuitive and highly flexible combination of available data and understanding, and use of techniques for synthesis and interpretation to meet a broad range of objectives. A DSS on the focused solely on the impact of land use change on water quality was seen to be of limited relevance in that it only provided a means of addressing one issue amongst many. Furthermore, a broad range of spatial and temporal scales was considered

relevant and a complex and evolving legislative environment was described. As a consequence, while a potential role for decision support for helping to deal with this complexity was evident it was not clear that a single system would meet a useful proportion of requirements. As a result, the Project team proposed that rather an a DSS specifically and restrictively focussed on water quality issues, an attempt should be made to develop a broader and more flexible toolkit-based approach in which a DSS on water quality could be developed and flexibly applied but also providing the opportunity to tackle other key challenges to the sugar industry in the Herbert catchment. A more detailed assessment of the options was required before considering system design.

As a consequence, a 'needs analysis' process was instituted. This involved a further look at the activities of potential DSS users in State Government Agencies, local government and industry. The key objective was to test whether a toolkit-based approach was appropriate and viable. It also provided the opportunity to establish 'active partnership' with key users in system design and creation

The needs analysis involved semi-structured interviews with practitioners in State Government, local government and the sugar industry. These interviews sought to understand the key natural resource planning problems tackled by the individuals interviewed. The analysis of functional requirements was divided into three steps.

Step 1 - Task description - Eliciting a set of contrasting decisions for which decision support may be appropriate and details of the institutional context of that decision.
Step 2 - Context description - For each of the tasks elicited, exploration of its context of use and institutional context and categorisation according to topic and functional category.
Step 3 - Task analysis - For each of the decisions elicited, characterising the stages in the decision-making process that would be demanded of a decision support tool for that task.

Through this process, 38 distinct tasks that might be tackled by DSS were identified. This list was neither exhaustive nor stable – it simply captured key activities of the people interviewed at the time of interview. From a DSS perspective, 40 analytical, data handling or display functions were identified as being necessary to facilitate these tasks using a DSS. Many of these functions were very generic while they were specific to particular issues.

This analysis provided a range of key insights for the DSS design process. It was concluded that no planning tasks were sufficiently significant, frequent and stable to warrant development of a DSS targeted solely at addressing that task. However, there was a broad range of tasks for which development of a decision support tool within a toolkit was of interest. These tasks were predominantly infrequent or one-off and generally unstable (i.e. the tasks might be expected to change faster than DSS's could be implemented and adopted). However, most resources that might be used for any one task were also relevant for other tasks. This made adoption of a toolkit approach viable. This needs analysis process has been reported in detail in Walker and Johnson (1996a).

On the basis of this analysis, work was undertaken to develop a DSS toolkit environment – named NRMtools. As outlined above, the fundamental objective of this work was to create an operationally relevant DSS. It was decided that *flexibility* of application and *accessibility* were likely to be the key determinants of success. Flexibility of functionality was <u>the</u> key design criterion. Flexibility was achieved by creating a high level programming language within NRMtools (called the 'task language') that is used to write new tools or modify existing tools. Additionally, an innovative internet-based delivery approach has been pioneered to ensure accessibility. The design of the system as a whole has been reported in an international journal paper (Walker and Johnson, 1996c). The internet-based approach to delivery was reported, by invitation, at the Third Annual Asia Pacific Distributed Solutions Event (Walker and Brebner, 1997). The toolkit is described in more detail at our website (http://nrmtools.tag.csiro.au) from which the software required can be downloaded and run. The current structure of the NRMtools software is illustrated in Figure 23.
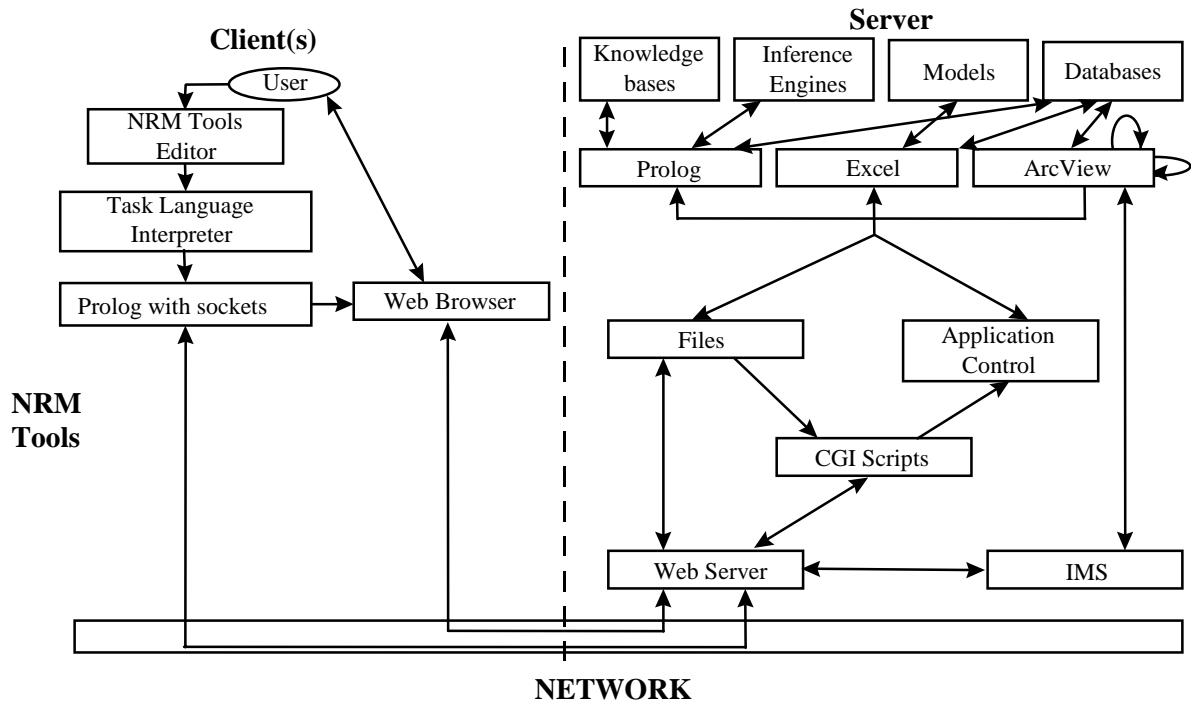
Figure 23. The architecture of NRMtools.

Applications using NRMtools

A variety of decision support tasks have been tackled within the NRMtools framework. These have included a range of approaches to considering the hydrological impact of land use change, consideration of the relationship between geomorphological processes to land use, scheduling water licenses, assessing run-off susceptibility, land use suitability for cane, allocating land uses (cane production, aquaculture and habitat conservation) and valuing riparian vegetation management options in canelands. In particular, four tools were developed as part of a prototyping exercise (described below). While not delivered to the users *per se*, these 'proof of concept tools' served to demonstrate the flexibility of the toolkit environment developed and provided an important validation of the toolkit-based approach.

Having completed this 'proof of concept' process and undertaken the necessary software development to refine the toolkit environment, four tools were completed and have been maintained for user access within NRMtools :

- modelling the impacts of land use on water quality and quantity;
- options for riparian zone management;

- land-use allocation (with data sets and rule bases to apply this tool to cane assignment, aquaculture assignment and habitat conservation); and

- map building tools – allowing user to access and explore the extensive data sets in the Herbert including, for example, the land use change data.

Development of these tools, which represent a range of types of analysis, allowed the Project team to help to fulfil some quite different needs as identified by system users.

The 'Proof of Concept' exercise

The following tasks addressed in the proof of concept exercise were directly selected from the tasks characterised during the needs analysis exercise described above.

- *Land suitability.* The Queensland Department of Primary Industry (QDPI) Land Suitability criteria provide a means of evaluating comparative land use suitability for a range of crops in the humid tropics on the basis of a range of biophysical data (Anonymous *Guidelines for agricultural land evaluation in Queensland.* (Land Resources Branch, Queensland Department of Primary Industry, Brisbane, 84 pp. 1990)). Deriving a land use suitability for a location is a key criterion used in land use planning and extension. Land Suitability classification is a comparatively data intensive operation and time consuming where undertaken manually. However, both data access and classification are highly amenable to automation.

- *Land use allocation.* This tool considered development of a hypothetical reserve allocation strategy for conservation purposes within the Herbert catchment (which has high conservation as well as production value) derived from data about the catchment and a set of policy guidelines for reserve allocation.

- *Hydrological impacts of land use change.* An implementation of a tool for exploring the impacts of land use change on water quality and quantity in the Herbert was developed using a prototype model developed by collaborators in CSIRO Land & Water (Barnes *et al*., 1997)

Demonstration tools designed to help the user to address the above tasks were created in the prototype toolkit environment. These tools illustrate the range of functionality and tasks that might be addressed within a flexible toolkit environment. They were developed for the purposes of illustration only. Each of these tools is outlined below. The tool definition (i.e.

the actual program) for the third tool is also presented as an illustration of the NRMtools 'task language'.

- *Land suitability.* This tool derived the land suitability for sugar cane for a specified UMA (Unique Mapping Area - Basinski, J.J. "General Report - Volume 1". in *Land use on the south coast of New South Wales - A study in methods of acquiring and using information to analyse regional land use options*, ed. J.J. Basinski. (CSIRO, Melbourne, Australia, pp. 65-9, 1978)) or set of UMAs by applying the QDPI land suitability criteria for the Wet Tropical Coast. UMAs were selected from a map of the catchment. The information required for each UMA in order to calculate land use suitability was retrieved from a database. The user had the opportunity to review and modify these data (this enabled the user to update information, e.g. by using more detailed local knowledge/inspection of the site and to explore scenarios e.g. the impact of modifying the drainage characteristics of a site on land use suitability). The land use suitability was then derived and an explanation of the basis for the Land Use Suitability for any UMA is provided - including, for example, the factors not considered due to missing data.

- *Land use allocation.* In this example, a hypothetical reserve allocation strategy for the Herbert catchment was derived from a set of rules and data about the catchment stored in a GIS. The procedure is based on a reimplementation of work described by Goldsborough and Robertson (Goldsborough, D.G., and D. Robertson. "Representing the structure of reserve selection arguments using logic programs". In*: GIS '94, Proceedings of the Eight Annual Symposium on Geographic Information Systems in forestry, environmental and natural resources management*, (Vancouver, Canada, February 21-24, pp.283-290. 1994), itself based on work on computational reserve allocation undertaken by Cocks and Baird (Cocks, K.D. and Baird, I.A., "Using mathematical programming to address the multiple reserve selection problem: an example from the Eyre Peninsular, South Australia" (1989) *Biological Conservation* 49, 113-130).

In the example undertaken, the objective was to provide a reserve allocation strategy for four vegetation communities / habitat types. The proposed reserve allocation strategy was derived from the rules presented in Walker and Johnson (1996b). These were applied to the 16 000 sites in the digital cadastral database of the lower Herbert Catchment (i.e. any site is considered to be a potential reserve), each overlaid with information on vegetation and current ownership.

- *Hydrological impacts of land use change.* This tool explored decision support using simulation models. The tool was based on an application of a model of water and sediment yield in the Herbert Catchment (Barnes *et al*., 1997). The tool derived water and sediment yield between two user specified points in the catchment given current land use and provides the user with a variety of alternate mechanisms for altering model parameters in order to specify alternate land use scenarios. Cumulative discharge and turbidity loads under current conditions and one or more land use scenarios were presented graphically. For example, this tool might have been used to explore the potential impacts of significant expansion of cane production into areas currently under native vegetation.

Some specialist functionality was demanded in implementing the tools described: for example, an algorithm to generate reserve allocation strategies across the catchment on the basis of explicit reserve selection criteria. Nevertheless, generating a new data transformation element, in this case an inference engine, for inclusion as a primitive in the task language resulted in much more expedient development of a decision support tool than developing an entire tool from scratch.

The programming code used to implement the land use change and hydrology tool in the task language is presented in Box 1. While understanding or generating this code places some demands on the user it is considerably less complex and more intuitive than implementing the tools from scratch in the underlying programming languages (in this instance Prolog, Avenue and C).

Box 1. The land use change and hydrology proof of concept tools as implemented in the task language.

```
fire_tool,

get_area_between_points(Catchment),

get_site_characteristics(Catchment,Site_characteristics),

get_rainfall(Catchment,Rainfall),

calculate_water_yield(Site_characteristics, Rainfall, Current_water_yield),

calculate_sediment_yield(Site_characteristics,                    Current_water_yield,
Current_sediment_yield),

graph_results(Current_water_yield),

graph_results(Current_sediment_yield),

get_scenarios(Catchment, Scenario),

calculate_water_yield(Scenario, Rainfall, Scenario_water_yield),

calculate_sediment_yield(Scenario, Scenario_water_yield, Scenario_sediment_yield),

graph_results(Scenario_water_yield),

graph_results(Scenario_sediment_yield),

close_tool.
```

Demonstrating the flexibility of the toolkit-based approach.

The principle justification for the development and application of the toolkit based approach was that this enabled flexible adaptation of existing tools or the creation of new tools to meet new or evolving needs of the targeted users - professional natural resource managers or planners rather than information technology specialists. Although some new functionality had to be added to the task language in order to implement the three tools described above, creating each of these new tools was considerably less time consuming than if each had been generated individually from scratch. However, to illustrate the flexibility of the task language approach, the functionality in the three tools described above was integrated into a single tool. This tool looked at potential areas for expansion of the sugar industry within the Herbert Catchment and looked at some of the off-site impacts that might accompanied that expansion. It prompted the user to specify a sub-catchment from a map. It then calculated land use suitability for all the UMAs within that area; found those UMAs with a land use suitability for cane of 1, 2 or 3 (i.e. appropriate for cane production); found those areas within

this area that are not currently under cane; and removed from this area of potential expansion for cane any cadastral units that fall into the reserve allocation strategy previously described. Having therefore identified the potential area for expansion, the hydrological model was used to explore the potential impacts of such expansion on water and sediment yield from the sub-catchment. This tool integrates the functionality of the three tools previously combined. Furthermore, it could be further modified or extended easily by a user with clear objectives but limited computing skills.

Having performed this 'proof of concept' exercise, it was presented to a workshop of key stakeholders and potential users, receiving clear endorsement. The Project Team then undertook the significant software development necessary to create an operationally applicable toolkit. A set of default tools was then developed for the Herbert. These are described in the following sections.

4.3.1.1 Modelling the impacts of land use on water quality and quantity

The use of AGNPS for modelling water quality and quantity was described in Section 4.2. In order to enable the use of this modelling work by stakeholders in the catchment, the integrated ArcView/AGNPS model was incorporated into NRMtools. There were a number of issues associated with incorporating the model into NRMtools, including model demands, model complexity and end user knowledge.

AGNPS was initially designed to work on microcomputer technology of the late 1980's. Through reprogramming, the model can now be run on current personal computers and Unix workstations. Early use of the model was limited to a small number of cells, which took considerable amount of time to compute compared with today's technology. Even today the model still requires high specification hardware to run acceptably. The model requirements have increased as the number of model cells increases. Initially the model was used for up to 100 cells but with reprogramming AGNPS can now take an unlimited number of cells and is largely limited by hardware and storage capacity. In this research, the model was tested to levels above 300 000 cells with computer RAM as the limiting factor. AGNPS requires about 1kb of ram for each cell and for a catchment with over 300 000 cells the required

amount of RAM including memory for the operating system is around 400mb. This is beyond the resources of a majority of personal computers.

The time required to run the model was also a limiting factor in successful incorporation into NRMtools. From starting the model run process to viewing output grids can take as little as a couple of minutes or, if a detailed catchment area is selected (in excess of 150 000 cells) model runs can take several hours (depending on available hardware resources). NRMtools users were likely to use AGNPS in an exploratory, rather than detailed analytical, capacity. This meant that long model runs were likely to be a major deterrent to use.

This problem was addressed through the creation of a data bank of AGNPS runs which incorporate a range of temporal land use, climatic and management scenarios. Approximately 400 AGNPS outputs were created and presented in NRMtools. Users are given a series of options, the output grids are displayed and the user can analyse the data with tools from the DSS.

Providing users with a predefined set of outputs eliminates a number of potential problems. AGNPS is a reasonably complex model and requires a fair understanding of geographic and hydrologic processes to ensure that the model is being used sensibly. If used incorrectly, the model's outputs could be mis-interpreted, providing the inexperienced user with inaccurate information. Supplying users with predefined outputs also limits potential problems with users causing an overload on the Internet server by selecting an overly detailed model run.

If specialist model outputs are required an off-line version of the integrated model can be run within NRMtools providing users with the required outputs and not causing problems with the overloading the Internet server. The video included in the CDROM accompanying this report provides an example of the use of the AGNPS tool within NRMtools. It illustrates the selection of the range of input parameters required from the user and the form of output as well as the comprehensive report created by NRMtools.

The tool can also be run live by through use of the NRMtools software (provided on the CDROM accompanying this report or available from http:\\nrmtools.tag.csiro.au).

4.3.1.2 Options for riparian zone management

This tool was developed to facilitate the assessment of options in the management of riparian vegetation. It is an example of an application developed in direct response to stakeholder needs at a locally appropriate scale and based on locally defined perceptions of key issues.

Riparian vegetation management is a contentious issue for the sugar industry in the Herbert. Consultations with the ICM co-ordinator and Chair (also the Chair of River Improvement Trust) and others provided a basis for identifying key issues in relation to riparian vegetation management and the most appropriate options for a tool to facilitate debate.

On the basis of these discussions, it was decided that a tool was required that enabled a landholder to explore the private costs and benefits of various riparian vegetation management options. This was achieved through development of a framework for cost-benefit assessment of options in establishing, retaining and removing riparian vegetation. The intention was that the framework developed would enable future extension to allow consideration of the public costs and benefit associated with these management actions

The analysis included consideration of private costs and benefits including: value of cane production (gained or foregone); establishment costs for riparian vegetation; changes to rat damage in cane as a consequence of changes on owl populations; and harvestable timber values from riparian areas. Provision was also made for users to provide estimates of values in relation to public costs and benefits including environmental services such as bank stabilisation, aquatic habitat, sediment trapping and aesthetics as well as, for example, options for rate rebates for environmentally benign management.

The cost-benefit model was implemented in Microsoft Excel. Input data was accessed from the Herbert Catchment GIS and collected specifically for this exercise from a range of sources. Importantly, a number of input values into the spreadsheet can be modified by the user, thus enabling the user to explore the implications of particular assumptions in the model. The flow of execution allows the user to select the particular farm block of interest, consider modifying input values into the spreadsheet model and view the output as tables and graphs, which are accompanied by an explanation of all input.

The video in the accompanying CDROM provides an example of use of the riparian vegetation management options tool in NRMtools. The tool can be run live by through use of the NRMtools software (provided on the CD accompanying this report or available from http:\\nrmtools.tag.csiro.au).

4.3.1.3 Land allocation tools

Both in catchments in which the sugar industry is expanding (such as the Herbert) and in areas where cane land is under significant pressure from alternative land uses (such as the Maroochy), options for land allocation are a significant challenge for the industry. Approaches to exploring the implications of differing policies and constraints in relation to the allocation of land for cane production and for competing alternative land uses may make a significant contribution to enabling the industry to take a strategic approach to these issues. For this reason, a generic tool was created within the NRMtools framework for exploring the implications for specified areas of particular criteria for rejecting sites as being unsuitable for a particular land use and, given a set of suitable sites, identifying an allocation strategy that meets strategic allocation targets.

Conceptually, the tool operates in two stages. First, each site in a set of sites selected by the user from a GIS is assessed against a set of rules to establish whether, in the light of these rules, it is an appropriate site for the land use in question. If not, it is rejected. In the second stage, the resulting set of potentially appropriate sites are used to identify an allocation of those sites that meets a set of strategic objectives. The program uses a set of selection conditions to select the most appropriate site from the set of unallocated sites. The complete set of allocated sites to date are then tested against a set of 'terminating requirements'. These are rules that, if violated, mean that the entire allocation strategy fails to meet a strategic objective (e.g. the total area of cane in an area should not exceed at specified area in hectares – possibly a consequence of crushing capacity). Violation of any one of these terminating conditions means that there is no allocation of land use in the area in question that complies with the criteria laid out in the rule bases. Assuming that terminating conditions are not violated, the program checks the set of allocated sites against 'necessary conditions' these are the conditions that must be met for the allocation to meet key strategic objectives (e.g. the minimum area of cane in a specified area – which may be dictated by economic imperatives

in keeping a mill competitive). Once all the necessary conditions are met, the set of selected sites allocated constitute an allocation that meets the strategic requirements specified in the selection criteria (note – the allocation strategy is the first the program can identify it is not necessarily the optimal solution).

The rules or criteria applied to the allocation can be enabled or disabled by the user (allowing them to explore the implications of including/excluding particular criteria) and the values for those criteria (e.g. maximum area of cane) can be modified by the user. The generic structure of the tool (from the user's perspective) is outlined in Box 2 the implementation of this structure in the NRMtools task language is presented in Box 3.

Rule-bases and data sets were then developed to enable this generic tool to be run in relation to three land uses, namely cane allocation and allocation to two important competing land uses in the Herbert, aquaculture and habitat conservation. Currently, these allocations are undertaken independently (as outlined below). However, supervision of an Honours student at James Cook University has enabled the Project team to explore options for integrating allocation of multiple land uses into a single tool.

Example sets of criteria for caneland allocation, aquaculture allocation and allocation for habitat conservation are presented in Boxes 4, 5 and 6. These sets of criteria can be easily modified to enable exploration of the implications of different criteria.

Box 2. A description of the land use allocation tool.

1. User defines the geographic extent of interest.
2. Allow user to read in predefined list of sites for land use (e.g. existing enterprises, applications or the results of some previous analysis)
3. Allow user to modify preselected list (interaction with a map interface)
4. Open knowledge base used to reject unsuitable sites for land use and modify as required (changing values or turning rules off).
5. Retrieve data for eliminating illegal / non-viable areas for land use from GIS for all the DCDB sites within the specified extent plus a buffer.
6. Using rules & data reject unsuitable sites.
7. Open knowledge base used to devise suitable distribution of land use and modify as required (changing values or turning rules off).

8. Retrieve data for strategy for land use from GIS for all the DCDB sites within the specified extent plus a buffer.

9. With the non-illegal pre-selected sites as a starting list try to devise a list of sites for land use that satisfies a range of strategic requirements.

10. Map the results and present an explanation of those results.

11. Ask the user whether they want to accept the results and therefore terminate the session

12. If not, allow them to modify the selected sites on the map manually and return to step 7.

Box 3. The land use allocation tool as implemented in the NRMtools task language.

```
open_herbert_gis([nil],[nil]),

define_geographic_extent([herbert],[Sites]),

if

        ask_user_yes_no([`Do you want to load an existing list of selected sites?`],[yes])

then

         map_results(['\programs\preselection\presel.txt'],[nil]),

open_and_edit_knowledge_base([`\programs\reject_sites\rejection_rules.pl`],[RejectRules]),

get_site_characteristics([Sites,[tenure,landuse,distance]],[Data1]),

reject_sites([Sites,'\programs\preselection\presel.txt', Data1, RejectRules],[RejectedSites, RejectionExplanation]),

map_results([RejectionExplanation],[nil]),

list_difference([Sites, RejectedSites],[AvailableSites]),

get_site_characteristics([AvailableSites,[area, x_coord, y_coord]],[Data2]),

repeat

        (open_and_edit_knowledge_base([`\programs\select_sites\selection_rules.pl`],[SelectionRules]),

        select_sites([Data, SelectionRules],[SelectedSites,SelectionExplanation,Status]),

        message([Status],[nil]),

        map_results([SelectionExplanation],[nil]),

        manual_include_exclude([nil],[nil]))

until

        ask_user_yes_no([`Do you want to further modify this strategy?`],[no]).
```

Box 4. Example criteria for caneland allocation.

A site can legitimately be added to the list of proposed cane assignments if :

- The site is not current cane assignment
- None of the site lies below 3 m. AHD
- The slope of the land is not greater than 3%
- The site does not occur within a national park;
- The site is not zoned 'urban';
- The site is not zoned ' high density residential';
- The site is not subject to a vegetation protection order
- The site is not under mangrove or wetland vegetation
- The site does not have a land use suitability for cane of 4 or 5.

- The site is not more than 50 km from a mill.

- The site does not have a perimeter : area ratio > X1

- The site is the largest remaining site falling into the highest land of land use suitability class 1, 2 or 3.

In the final strategy :

The total area of the allocation should be >X2 ha but <X3 ha

The total number of sites should be > N1 but < N2

Box 5. Example criteria for aquaculture suitability.

A site can legitimately be added to the list of proposed cane assignments if :

- The site does not occur within a national park;
- The site is not zoned 'urban';
- The site is not zoned ' high density residential';
- The site is not subject to a vegetation protection order
- The site does not have a slope > 5%
- The site does not have a mean AHD > 20 m
- The site is not under mangrove or wetland vegetation
- The site is not > 5 km from the coastline
- The site is not > 2 km from a water source
- The site is not < 3 km from an urban area

- The site is not > 100 km from an urban area

- The site is over 200 ha. And is the furtherest away from any site already selected of the sites already allocated.

In the final strategy :

The total area of the allocation should be >X2 ha but <X3 ha

The total number of sites should be > N1 but < N2

Box 6. Example criteria applied in deriving a proposed reserve allocation strategy

A site can legitimately be added to the list of proposed reserves if :

- it is already a National Park; or

- it has the largest area of the remaining cadastral units and has at least one of the communities at the site; or

- it is a remaining cadastral units in which the community least represented in the list of reserves occurs; or

- it is a site on which one of the communities occur ; or

- it is an existing state forest reserve; or

- it is an existing lowland forest reserve.

In the final strategy :

each community should occur at least 4 times;

the number of state forest reserves must exceed 10;

the number of lowland forest reserves must exceed 10;

all existing reserves appear in the list of selected reserves;

the sum of the area of all the reserves should not exceed 15 000 ha; and

the total number of reserves should not exceed 50.

Screen Camera videos of execution of the land use allocation tool for each of these three land uses are available in the accompanying CDROM. These tools can also be run within the NRMtools software.

4.3.1.4. Map building tools

The final tool currently available to users of NRMtools in the Herbert is a mapping tool. This allows the users to select layers of data from the Herbert GIS maintained by the research team and combine these sets of data into mapped output. While this is a trivial application from a DSS perspective, it is of considerable utility to users in the catchment, giving them easy, internet-based access to data sets on the Herbert across the internet.

4.3.1.5. The application of NRMtools - Summary

The development of NRMtools has been a strategic investment in developing a decision support capacity for catchment-scale resource use planning for the sugar industry. Implementationally, the development of a specific decision support focussed solely on the impact of land use change on water quality would have been significantly more straightforward. However, the needs analysis process strongly suggested that such a system would have a very limited 'shelf life' and appeal to users and would probably, therefore, not have merited the implementational investment. By contrast, the investment in the development of NRMtools provides a long-term capacity for the sugar industry. NRMtools was built from the ground up over a three-year period and makes use of some advanced IT technologies and was, therefore, a significant (but strategic) investment. It provides a capacity for rapid response to further decision support requirements. For example, the development of the decision support tool for riparian vegetation management was developed rapidly. It required the original idea (from users), collection of the core knowledge from stakeholders, experts and the literature, some data manipulation and adaptation of some pre-existing software before the tool was written in the NRMtools task language. Such tools can now be developed in a matter of days or weeks.

**4.4   Building Capacity to Plan for Sustainable Use of Natural Resources
          in the Sugar Industry – The Herbert Resource Information Centre**

Decision-makers in both the private and public sectors are increasingly faced with the challenge of maximising the dual goals of economic efficiency and ecological sustainability. Decision-making frequently demands consideration of a range of issues across varying spatial and temporal scales. The physical environment is complex, and understanding is often inconsistent, incomplete and constantly being updated. In addition, the Australian legislative environment in which decision-making must occur is both complex and evolving.

The Herbert River catchment, like many other parts of Australia's coastal zone, is a major focus of competition between alternative uses of resources. The need for an integrated approach to resource management to avoid the environmental and social damage sustained by conflicts in land use has gained prominence, with government agencies in most Australian states responding with the introduction of Integrated Catchment Management (ICM) or similar programs. These approaches aim to foster joint action from stakeholders and in particular require significant involvement and ownership by the local community, who in turn rely predominantly on technical advice from government agencies.   However, the effectiveness of these activities is often constrained by a poor understanding of key issues in sustainable resource use, a paucity of data at spatial and temporal scales relevant to decision making, poor coordination or communication between participating stakeholders and limits to the data processing and analytical capabilities of participants in the decision-making process. These constraints are further magnified within many rural regions.

A Geographic Information System (GIS) has a demonstrated capability to improve decision-making and lead to more efficient administration through the display, manipulation and analysis of spatial data. While GIS has been readily adopted in many metropolitan and large municipal areas, implementation of GIS in rural areas has been and applications addressing broader integrated resource management issues or utilising more advanced GIS capabilities in a planning context have not been widely reported in the literature. In many instances, full acceptance of GIS technology has been constrained by a combination of factors, including a lack of appropriate data and perceived costs in collecting data which are not currently available. There have also been perceptions that the technology is expensive and does not justify the financial and human resource inputs that are required. Furthermore, there has been

little published information quantifying both costs and benefits to investing in GIS technology in rural areas.

Johnson and Walker (1996) and Johnson *et al.* (1997) describe an approach used to facilitate the development and implementation of a collaborative GIS facility involving industry, community, government and research agencies in the Herbert River catchment of north Queensland – the Herbert Resource Information Centre. It describes the use of a framework to determine the appropriateness and feasibility of a collaborative, community based GIS and a method to evaluate non-quantifiable impacts. In doing so, a strategic approach that is broadly applicable for use in other rural contexts is provided.

Formative Events

The path to formation of the HRIC was preceded by a number of events that had a significant impact on its development. Like many rural catchments, effective resource management in the Herbert catchment was constrained by an absence of essential data at a spatial scale relevant to decision making. In mid 1993, CSIRO initiated discussions with key stakeholders in the catchment with a view to acquiring essential base data at a scale of 1:10 000. The costs of acquiring this data exceeded the capacity to pay of any one of the interested stakeholders. In response, a joint venture (Herbert Mapping Project or HMP) was developed between 11 agencies (industry, community, state, local and federal government) to fund the acquisition of digital orthophotography, cultural data (eg utilities, farm boundaries), natural features (eg streams, topography) and cadastral data for the lower catchment. The HMP was completed in July 1996 and was a watershed for integrated resource management activities in the lower Herbert River catchment.

On completion of the HMP, it became evident to many stakeholders that the utility of the data collected could only be maximised through advanced analysis of the digital data. GIS provided the best means of satisfying their requirements for data analysis and presentation. Following the formation of a group of interested stakeholders in late 1994, two activities were undertaken that were central to the development and implementation of the HRIC; a needs analysis and a cost-benefit analysis. The methods used to perform the needs and cost-benefit analyses, and the accompanying results are briefly presented and discussed below. A comprehensive description of the methodology is presented in Johnson and Walker (1997b).

Needs Analysis

Representatives from each organisation were asked to complete a four-part questionnaire addressing their perceptions on the opportunities and constraints associated with GIS should it be adopted within their organisation. The first three parts of the questionnaire were designed to elicit information describing the institutional and operational environment within which each organisation/department operated. The final part asked respondents to indicate the demand that their organisation would have for a broad range of GIS functional capabilities.

Results of the needs analysis demonstrated that existing and potential applications of participating organisations were reasonably well defined. Although the majority of organisations did not have adequately skilled staff, most considered hiring new staff for a collaborative facility and retraining of existing staff within the home organisation to be feasible courses of action. Further, it was perceived that adequate financial resources were available for the development of the HRIC. In terms of the participants' organisational requirements, most organisations had potential use for a range of GIS functionality. Also, there was significant interest in the full range of GIS functionality presented in the questionnaire. Operational characteristics, as expected, varied between organisations, however, most applications identified by each organisation occurred frequently and had response time requirements ranging from days to weeks. While all organisations processed a moderate volume of "sensitive" material, matters of a legally significant or commercial in confidence nature were unlikely to inhibit a GIS. Hence, the results of the needs analysis clearly demonstrated that a collaborative GIS facility was commensurate with the organisational background, organisational requirements and operational characteristics of the potential participating organisations.

Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a standard method for economic analysis. However, use of CBA has remained problematic in the GIS context and the analytical problems associated with determining the benefits and costs of these systems are perceived to be substantial by users. In response to these considerations, an analytical framework was developed.

The analysis consisted of five steps: (1) specify the objective or desired outcome of the activity and determine all relevant impacts; (2) use identified impacts to define all costs and express these in dollars of the base year; (3) identify positive impacts (benefits) occurring over time and assign dollar values for the base year; (4) discount benefits and costs distributed over many years into the future to the base year using a discount rate to capture the time value of money; (5) calculate net present value (NPV) by subtracting the present value of costs (PVC) from the present value of benefits (PVB). Two alternatives were examined; a *status quo* alternative and a collaborative GIS implementation alternative. The *status quo* alternative assumes that the existing way of doing business would continue without the implementation of GIS.

Benefits were estimated to be $5.9M greater for the collaborative GIS alternative. Similarly, costs were expected to be $1.02M greater for the GIS alternative. As with many large projects, costs were heavily weighted in the early stages of the project and full benefits were assumed to be fully realised in years 4 to 10. The analysis showed that an investment in GIS was estimated to realise a net benefit to the district over 10 years of $8.6M in 1995 dollar terms. This figure represents a 230% improvement on existing activities. Furthermore, the net result represents an overall ratio of discounted benefits to discounted costs of 8.8. The results suggested that the collaborative GIS was both an attractive public and private investment.

Implementing a Collaborative GIS

Having demonstrated the appropriateness and viability of a collaborative approach, six stakeholders in the catchment (CSR Sugar Mills, Herbert Cane Protection and Productivity Board, Hinchinbrook Shire Council, Canegrowers Herbert River Executive, CSIRO and the Queensland Department of Natural Resources) agreed to begin negotiations with a view to establishing a formal agreement. In 1996, a 10-year collaborative agreement was signed by the six stakeholders to formally establish the HRIC. The agreement remains the central tenet upon which HRIC continues to function. The agreement secures the financial and non-financial (in-kind) support of the stakeholders and binds them to support the HRIC's foundation philosophy of being a non-profit, community based collaborative GIS facility designed to support both economic and ecologically sustainable development in the Herbert catchment.

The HRIC is staffed by 2 full time GIS specialists, whose role is to provide high level expertise and skills to facilitate the collection, storage, maintenance and analysis of natural resource data. Their role is also to ensure the products of these activities are delivered in an efficient and timely manner to HRIC stakeholders. The HRIC does not currently resource data collection programs in the catchment. As such the HRIC offers a bureau service to its stakeholders, provides free GIS consultancy and project management skills and acts as a conduit for the transfer of relevant R&D products. Furthermore, HRIC staff undertake a core function in assisting relevant stakeholders to implement GIS as part of their business operations. A spin-off function is to also promote an environment for the facilitation of improved communication and collaboration between the HRIC stakeholders.

HRIC staff report to a Board of Directors, comprised of one senior representative from each stakeholder (CSIRO Tropical Agriculture, CSR, CANEGROWERS, Herbert Productivity Board, Hinchinbrook Shire Council and QDNR) plus an independent chairman appointed from the local community. The Board's role is to provide strategic direction to HRIC activities, to determine HRIC work priorities and associated management of HRIC resources. The Board and HRIC staff are also assisted by a voluntary Technical Advisory Committee (TAC) comprised of relevant GIS and natural resources experts within the region.

Within each of the stakeholder organisations, GIS groups were formed to facilitate the planning and implementation of GIS within their host organisation (although the state and federal government stakeholders had significant GIS capability upon HRIC formation). Hence, by building capacity within both the HRIC and stakeholder organisations, the long-term sustainability of GIS as a core management tool within the catchment is assured.

5.   EVALUATION OF IMPACT

Typically, 'traditional' clients for the outcomes of R&D projects have had a requirement for scientific solutions that have meaning in a real world management context. Traditionally this requirement has been conceptually disjoint from the domain within which planning, initiation and development of R&D products has occurred. Most activities in the fields of agronomy or soil science for example, have been conducted largely with a focus on the individual farmer and property, or on a single industry.   However, in this Project, the client base was significantly broader and included not only cane growers but also a multinational company such as CSR, government at all three levels, and the broader community.   This shift raised fundamental methodological and institutional issues as to how we undertook the Project, what constituted an outcome, who controlled the agenda and our accountability to others.   In particular, it also challenged the way we in which we communicated both internally and externally, and the role of communication and communication R&D in the conduct of our work.

As has been discussed in previous sections, consideration of the needs of stakeholders formed an integral part of the research process continuum from design to inception and from development through to delivery.   In this Project, participative processes provided an extremely powerful means of responding to stakeholder needs. In particular, they: acted as a statement of stakeholder and R&D provider philosophy; stimulated the sharing of knowledge; provide a learning experience; provided a sense of ownership for users/clients; increased the usefulness of research products; fostered improved client/stakeholder relations; and fostered the develop of change skills.   The participative approach taken also optimised the contribution of research to decision-making by helping the Project team to better understand the context of decision-making and to facilitate the integration and adoption of research outputs through the development of facilities such as the Herbert Resource Information Centre. In summary, our approach attempted to:

- better characterise and analyse stakeholders;
- facilitate inter-organisational collaboration to promote people-oriented R&D; and
- facilitate interaction between different levels of organisations in agricultural and natural resource systems where there are constraints to innovation and change

In implementing a participatory approach, it is critical to monitor and evaluate the impact of the R&D to enable scientists and stakeholders to analyse critically their own practices and to enter into dialogue with each other in terms of Project outcomes. In the sections that follow we report on the results of an independent evaluation of the impact of the CSIRO Tropical Agriculture R&D team in the Project as well as the results of an evaluation of the impact of the Herbert Mapping Project and the HRIC.

5.1   Impact of CSIRO R&D

As discussed, much of the research reported here has required highly participative approaches, including significant interaction with key stakeholder groups, most notable in the establishment of the HMP and the HRIC. Anecdotally, this interaction has had a range of important impacts above and beyond immediate research objectives. In order to assess these, and to provide insights into the efficacy of the participatory approaches to capacity building used, an independent evaluation of the impact of CSIRO's research in this Project was commissioned. This work was undertaken by Dr Alison Cottrell of James Cook University. Her full report is appended on the CDROM provided. Some of the key outcomes are summarised below:

- Stakeholders strongly valued the technical inputs from members of the Project team.
- The Project team provided motivation and leadership, as well as helping stakeholders with the necessary learning.
- Without the Project team the HMP and HRIC would not have occurred.
- The Project team had the vision and skills to assess the needs of the catchment to acquire data sets to greatly increase information and help in decision-making processes.
- The Project team's activities achieved great efficiencies and benefits to the Herbert district.
- The Project team worked hard to achieve a collaborative effort.
- Both participants in the HMP and HRIC clearly viewed the Project team's involvement in facilitating establishment and implementation as being fundamental to the success of these ventures.

5.2   Impact of the Herbert Resource Information Centre

A broad assessment of the impact of the HMP and HRIC was undertaken in collaboration with staff from James Cook University. As outlined in Section 4.4.1, the HRIC evolved as a direct consequence of the successful completion of the HMP. It was evident to the HMP participants that contiguous with realising the Project's primary objective, participation had made a significant impact on the way that they went about their business in relation to resource management in the catchment. Participants felt they had gained a sophisticated view of the nature of spatial data, its uncertainties, limitations and potential range of application. Furthermore, collaboration seemed to have fostered a new spirit of understanding and co-operation between agencies.   It was anticipated that the HRIC would likewise have significant impacts. In order to be able to demonstrate these impacts rigorously and derive lessons from the HRIC in establishing best practice for community-based resource information centre's, a 3 year evaluation program was established.

The objectives of the HRIC can be summarised as:

- improved quality of data available for the Herbert catchment;

- improved access to data;

- better informed decisions in planning and implementing data collection and use projects;

- better informed decisions in natural resource management; and,

- improved collaboration.

These objectives were explicitly addressed in the evaluation but there was also provision for the evaluation of less tangible aspects in relation to changed perceptions, attitudes, understanding & behaviour, particularly in relation to collaboration between groups, as a consequence of involvement in the HRIC.

Methods

The evaluation was conducted using qualitative research techniques. Individual, face-to-face interviews using a semi-structured interview schedule were conducted with key participants in the HRIC each year over three years. Nineteen people were interviewed in February 1996 (6 months before completion of the joint venture agreement and employment of HRIC staff), follow-up interviews were conducted in February 1997 (19 interviewees) and March 1998 (17 interviewees).   Each interview took approximately 90 - 120 minutes and was tape-recorded. There was some change in key participants such that a total of 41 individuals were

interviewed over the three years with a core group of 7 individuals being interviewed at each of the three times. The issues addressed in the survey are summarised in Walker *et al.* (1998). In the first round of interviews, anticipated impacts were elicited. In the second and third rounds, anticipated and actual impacts to date were elicited. After each set of interviews, interviewee responses were transcribed and collated. At the end of the three year period, the entire data set was entered into the NUD*IST qualitative data analysis package and tagged against key evaluative criteria providing a basis for the qualitative analysis reported here.

Outcomes

After the two and half years of formal operation of the HRIC covered by this evaluation, the HRIC and the partners to the HRIC have collected, collated and synthesised a high quality spatial database for the catchment. The resources in the HRIC had been widely used by individual partners for routine activities in planning infrastructure developments, assessing the resource bases and integrating monitoring activities. Direct (private) benefits had accrued to each of the joint venture partners. In some cases these benefits were already substantial while in others, substantial benefits were anticipated in the near future.

The extent and speed of operational impact across the range of activities in partner organisations is illustrated in Figures 25 and 26. As well as providing detailed descriptions, interviewees were asked to rank both predicted and actual impacts against the range of criteria discussed above, both for their own organisation (25) and for all the others (26). It is interesting to note that predictions tended to be higher for others than for self-assessment. This may reflect the inevitable concerns about equity in a collaborative venture but may also reflect a more accurate understanding of the informants' own agency than of others – leading to assessments that are more informed and better reflect reality. The graphs do not provide any evidence for any period of disillusionment, so often associated with ventures based on a new technology. It is likely, however, that the annual time step of the evaluation has simply failed to capture short-term crises of confidence that were reported anecdotally by the partners. Furthermore, it is possible that the capacity building outcomes of the HMP equipped participants with more realistic expectations of timelines and outcomes possible in such a project. Predicted impacts were generally stable or climbing over the three years. Equally, impacts perceived to have occurred were high and climbing up towards anticipated levels of impact – demonstrating that the venture had started to meet expectations very rapidly.
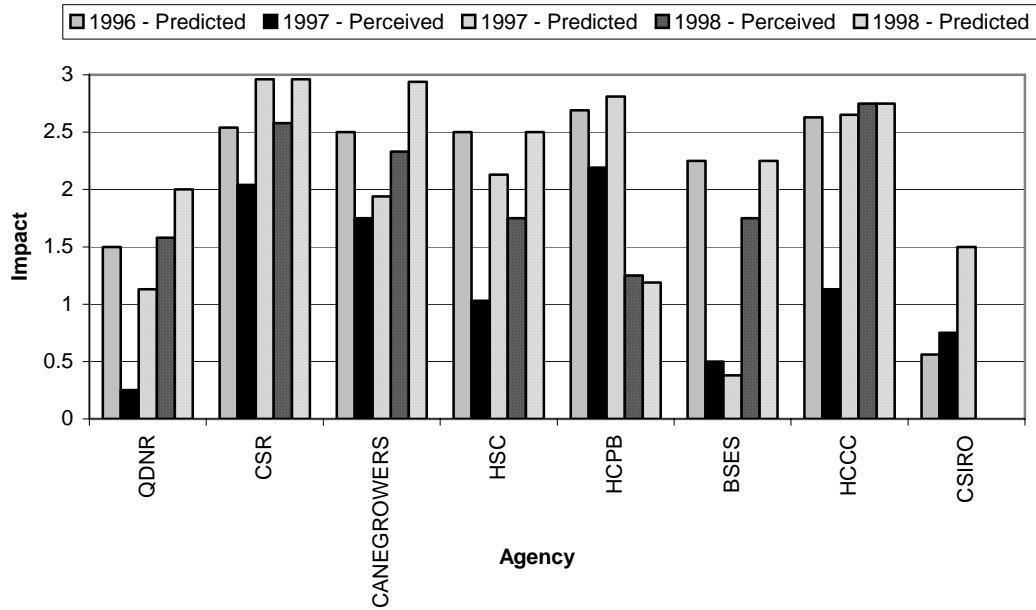
Figure 25. Results for self assessed impact (0 = no impact, 3 = very significant impact).
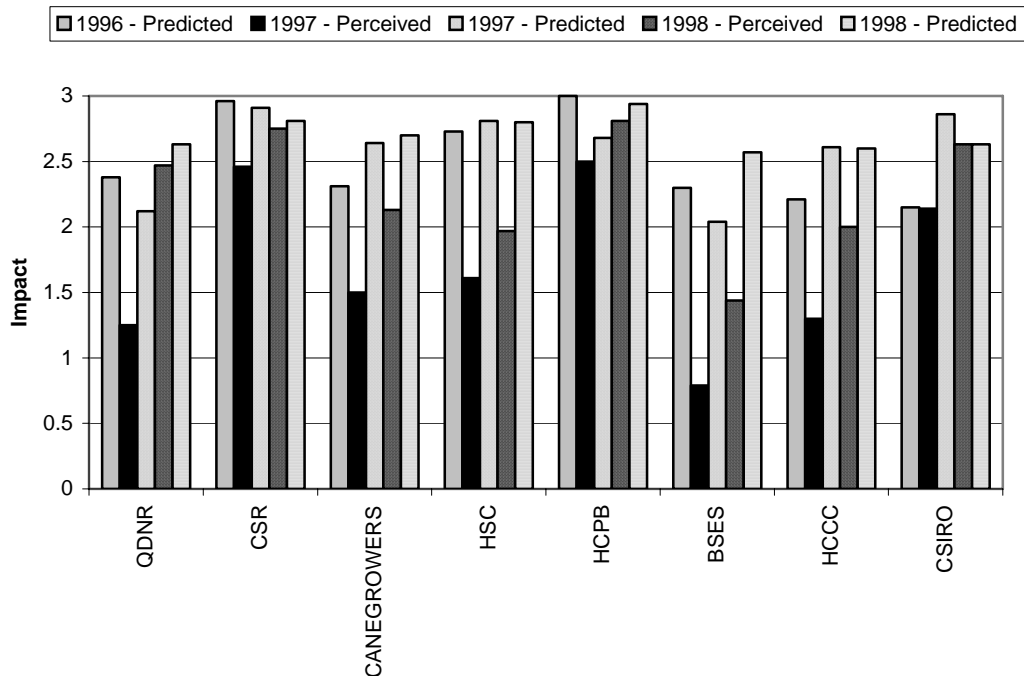

Figure 26. Predictions by all partners of the HRIC's impact (0 = no impact, 3 = very significant impact).

Specific outcomes against the HRIC objectives were as follows:

- **Improved quality of data available for the Herbert catchment and improved access to that data**. Data access improved dramatically with participants becoming more aware of the range of data available and having access to all but that which was 'commercial-in-confidence'. There were still significant differences in perception between individuals of the general quality of data available in the Herbert, particularly between active users and less active users. Nevertheless, many participants had come to better understand the limitations of key data sets, including, for example, an increased understanding of the implications of scale on use, as well as limitations of the data. Paradoxically (or at least unexpectedly), this had made them more confident in use of that data (although it may be that this rise in confidence is confounded by improved access to better data sets). This understanding of the data in combination with a knowledge that all parties were operating with common data resulted in higher levels of confidence in using the data.

- **Better informed decisions in planning and implementing data collection and use**. While processes for data collection were only moderately impacted for most parties, compatibility with other data had become a significant criteria such that data storage and management collectively and individually had been significantly impacted. Furthermore, for some activities, radical changes in data collection (e.g. from field survey to orthophoto and satellite imagery) had been instigated. In general, while the interviewees saw compatible data collection and storage as important, and indeed the project would fail if it did not occur, other factors were seen as more important. Common 'ownership' of the HRIC generated agreed, common and trusted data sets. In this context, issues of absolute data accuracy might, perhaps, be less significant than the opportunity to discuss differences in interpretation of the meaning of those data sets.

- **Better informed decisions in resource management**. Formal spatial analyses were being used in planning decisions, often with a substantial cost saving and resulted in decisions perceived to be as good as, and frequently better than, would have been achieved with previous processes. GIS-based products were increasingly being used in negotiations regarding resource-use. However, improved consideration of complex resource management issues that cut across sectors and stakeholders resulting in more efficient and better quality decisions were still anticipated but not yet achieved. There was, however, a general perception that achieving this objective was a question of time

rather than a function of more fundamental constraints, although it had become increasing apparent to participants that data itself does not make decisions.

- **Improved collaboration**. In terms of motivation for involvement and strategic direction, many initially saw the HRIC as a data source and a means of cost sharing in data collection. However, a shifting emphasis towards a role in skills development, skills sharing and project brokering was unanimously supported. The HRIC was increasingly seen as a significant force for changing planning processes rather than a technical service. Certainly, the key assumption that collaborative joint venture was an appropriate mechanism for fostering broader uptake of GIS technologies in the catchment was perceived to have stood the test of time. An initial mixture of optimism and uncertainty was replaced over the three-year period by a very positive view of the HRIC and a sense of real pride in what had been achieved. For the people interviewed, involvement in the HRIC has meant additional work, meetings and a requirement to quickly develop new skills in emerging fields. In some cases it has also meant developing working relationships where none would have existed previously. However, all participants saw this as a positive experience both for themselves and their community. Equally significantly, the collaborative nature of the initiative had important impacts. Willingness to work together increased amongst the partners to the HRIC and external use of the HRIC by businesses and the broader community began to occur (although issues of user payment for HRIC services and third party data remained a complex challenge). Improved collaboration between agencies was not reported for all the combinations of partners however, in no case were relationships reported as having become worse. Some concern was expressed, however, about groups that did not become formally involved in the HRIC becoming somewhat marginalised in key developments in the area.

Key contributions to success

The evaluation presented here demonstrates that from the participants' perspective, the first three years of the HRIC have been a success. The interview material demonstrates that the participants in the HRIC believed that certain key features of the catchment and the agencies involved were important in the success of the establishment of the HRIC, namely:

- **Skilled professional staff**. Although the capacity of hardware and software was a necessary base from which to operate the HRIC, the interviewees tended to attribute a significant proportion of the success of the HRIC to the qualities and skills of the staff

employed by the HRIC. The importance of the HRIC staff was recognised from the outset, with the Board making a conscious decision to provide attractive terms and conditions in order to recruit staff with the mixture of negotiation/facilitation, management and technical skills required. The change in HRIC Manager at the end of the second year of operation had consequences that provided further evidence of just how critical these appointments were. While only two staff are employed by the HRIC, one of their key roles has been to build capacity in the partner agencies through the provision of training courses and high level support for staff in those organisations. As a consequence, some 40 people have received formal GIS training over the course of three years with several of those now spending a significant proportion of their time on GIS-based work within their organisations. This has meant that the HRIC staff have played an increasingly strategic role in support of a growing range of individuals, thereby avoiding overload in the face of burgeoning use of GIS within the catchment. The qualities and skills of the staff have certainly facilitated the success of the HRIC. Nevertheless, while it is reasonable to argue that the HRIC staff might, had they been less competent, have caused the failure of the HRIC, it does not follow that their skills in themselves totally explain the HRIC's success.

- **Common goals**. The overwhelming dominance of the sugar industry in the catchment meant that, while not always in agreement, key players had very significant interests in common – none of the partners are, for example, competitors in terms of resource use.

- **Existing infrastructure**. Similarly, the fact that GIS infrastructure and investment within the catchment (as opposed to the Government agencies involved) was negligible meant that there were no vested interests within agencies to overcome in designing and implementing a collaborative venture.

- **Location**. The 'neutrality' of the HRIC was also important in avoiding conflicts of interest. The HRIC and its staff are not viewed as being overly aligned to any one of the partners in the venture (although an early arrangement whereby the HRIC was located within the offices of one of the agencies was viewed as a problem from this perspective and was changed at the earliest possible convenience).

- **Credibility**. Having established a structure that avoided potential barriers to effective collaboration, the success of the HRIC depended on establishing credibility as rapidly as possible in order to maintain and enhance commitment to the joint venture agreement and associated financial contributions. Early projects that clearly demonstrated benefits to

partners were therefore very important early in the HRIC's operations. Outcomes of broader collaborative or public benefit were not required immediately, however, there was significant pressure for benefits to accrue to individual partners early in the process to maintain commitment.

- **An evolutionary history**. The evolution of the HRIC from the Herbert Mapping Project was very significant. The completion of the HMP meant that the HRIC started with a high quality base to which the data provided by partners could be rectified relatively rapidly such that it wasn't necessary to spend a substantial period at the outset collecting data. More importantly, many of the participants in the first round of interviews stressed that involvement in the HMP had provided them with experience and understanding that was invaluable in the early stages of the HRIC in that it provided them with practical experience in a successful joint venture and demonstrated that they could work together effectively for mutually beneficial outcomes. Even so, a highly evolutionary approach to establishing the HRIC (and a great deal of good will) was required at the outset. Interestingly the importance of this evolutionary approach was not widely acknowledged amongst participants in the third round of interviews. Many informants felt that in establishing the HRIC again, they would seek to employ staff, generate a strategic plan and so on at the very outset. Consideration of the interview material from the first two years suggests that this would not have been realistic.

Despite overall success, some significant threats had been encountered, as follows:

- **Issues of intellectual property**. In so far as significant problems and threats to the HRIC had been encountered, many related to issues of tightening data access policy, both amongst partners and external (particularly within Government agencies) and related issues of Intellectual Property and liability. These remain a significant challenge.
- **'Head office'**. Another significant set of threats that had to be carefully managed by the participants was the need to ' sell' the initiative within their own organisations. While individuals and local offices were enthusiastic and committed participants, it was necessary for all those agencies to sell continued involvement and financial contribution very carefully to other parts of their organisations in order to be able to protect their continued involvement from cuts associated with general 'resource squeeze' in their parent agencies.

- **Over-commitment**. As awareness of what the HRIC could offer spread, demand for the HRIC's services grew rapidly. As a result, prioritisation of tasks and effective restriction of access to services was necessary to avoid serious over-commitment and the danger of failing to meet critical objectives.

5.3.   Lessons from the Evaluation – the Applicability of the HRIC Model to Other Cane Growing Regions

We are not aware of equivalent data sets to the evaluation reported here for other initiatives in Australia. Nevertheless, the evaluation of the HRIC presented in the previous section provides an appropriate means of considering key issues that may need to be addressed in the establishment of Information Centres in other cane growing regions. These can be listed as follows:

- The HRIC provides access to integrated data sets but also plays a project brokering and capacity building role. How does the impact of this dual approach compare with initiatives solely targeted at information provision?
- The HRIC has a tight regional focus covering a rural catchment dominated by a single population centre and by a single industry. What implications might a wider geographical area of mandate or more complex community structure have?
- The relative socio-economic homogeneity of the catchment means that the individual goals of the partner organisation to the HRIC and the common goals of the HRIC are highly compatible; there are no dominant resource use conflicts between partners. Would the HRIC have succeeded in a more complex environment with more substantive conflicts?
- The HRIC evolved from the Herbert Mapping Project, an initiative with a very specific and tangible technical objective. In the early rounds of evaluation this evolutionary approach was seen as critical to success. Could a similar HRIC have been established without this initial focussed output?
- Although initially facilitated by Project staff, the HRIC has a high (and growing) level of local ownership. Furthermore, the initiative was seen as being 'neutral' rather than the associated with any particular local agency. All stakeholders agreed that this was key to the success of the venture, that the HRIC was seen as an independent broker of

information for the explicit reason that all parties had a stake. What implications does this have for future initiatives that are locally initiated by one party (e.g. Local Government)?

- How important are private benefits in enabling a contribution to the public good? Individual partners in the HRIC have tangible and specific business oriented objectives for being involved, for which they can see an early return on investment that in its own right justifies their involvement. As a consequence, they felt able to be thoroughly committed to the notion that the HRIC provides a greater public code, educational and capacity building role. Does this mean that initiatives more specifically targeted at these public rather than private benefits are less likely to succeed?

While many regional planning activities promote a consultation process, few have been successful in mitigating the decision-making process completely to community stakeholder groups. The HRIC is an example in which community groups have control and ownership of resource information and related decision-making. This initiative is an exceptional example of community based decision-making, and exemplifies an emerging trend for self determination and community empowerment in undertaking the planning process. The most distinctive features of the HRIC are its capacity building function for stakeholders and the enthusiasm and willingness to learn on the part of the participants. Both are derived from a healthy balance between individual (agency) interests and community spirit. Commitment to joint projects was directly related to a sense of ownership and involvement in the decision-making process. It is reasonable to assume that this level of interest maybe more difficult to instigate and sustain in more complex regional communities. The HRIC model will not be applicable across all circumstances, with the level of community involvement that can be attained is likely to remain across a spectrum of possibilities from community consultation to community initiated ventures.

6. PROJECT TECHNOLOGY

The research reported has been instrumental in the development of NRMtools, a distributed decision support toolkit. NRMtools is an integrated software package that comprises client-end software implemented in LPA WinProlog with some additional html-based and Java-based components. Development included the development of sockets and http functionality in Prolog. The server–end software is controlled through a cgi layer written in C which co-ordinates the application of a range of discrete software tools written in Prolog and C or created through the customisation of commercial software packages such as ArcView (through Avenue), ArcView Internet Map Server and Excel.

7. RECOMMENDATIONS FOR FUTURE ACTIONS

A number of research opportunities have emerged as a consequence of our experiences in the Herbert River catchment during the life of this Project. So as to focus potential future actions, these opportunities can be classified into three broad classes, namely:

Technical

- While this Project was able to utilise satisfactorily the AGNPS model, there remains a clear need to develop an advanced capacity to model the distribution of sediments, nutrients and water on a tropical floodplain where over-bank events dominate.
- This study and others (eg in the Johnstone catchment) have developed an excellent understanding of physical and chemical processes in tropical river systems, however we did not investigate the impact of land use changes on aquatic biology or ecology. Although LWRRDC funded R&D is being undertaken in this area, more R&D is required in riverine ecology and toxicology if the real impact of land use change is to be assessed;
- R&D is presently being undertaken to investigate the benefits of riparian vegetation as a buffer to nutrients and sediments in the tropics. However, the significant biophysical variability of tropical regions means that additional R&D will have to occur if landholders are to fully realise the benefits of improved riparian management.
- The results of this study have in general been well communicated to stakeholders at a local and regional level. However, there remains significant doubt in a number of other

fora as to the sugar industry's environmental record in terms of water quality. Hence, the industry needs to more actively promote the results of Projects like this and the recently completed work in the Johnstone Rivers to non traditional audiences.

Institutional

- This study has clearly demonstrated that the upper and middle sections of the Herbert River catchment contribute the bulk of sediment and nutrient discharged into the marine environment. While much of the middle catchment is National Park and in pristine condition (hence its contribution to the sediment load is "natural"), land degradation in the upper catchment is having a major impact on sediment loads exported from the catchment. While technical solutions to this problem present some opportunities for amelioration, we argue that real change in the upper catchment is only likely to be achieved through institutional reform, structural adjustment and the introduction of incentives for landholders in the region.

- This study has shown that water quality in the lower Herbert catchment (ie the cane growing region) is at present satisfactory. However, an ongoing monitoring and evaluation effort is required if the sugar industry is to continue to demonstrate environmental compliance and duty of care. This will require a significant institutional commitment from the industry and its partners in local and state government in the future.

- The NRMtools approach has a broad applicability to other natural resource management activities in the sugar industry and beyond. The Project team is attempting to operationalise NRMtools in other cane growing catchments (eg Moreton Mill Area), but full realisation of its potential across the industry will require additional funding support.

Capacity Building

The success of the HRIC provides a unique example of how the capacity of a small rural community to undertake improved natural resource management can be improved dramatically through the injection of funding to support employment of quality technical staff at a local level. The HRIC model also provides an example of a highly innovative and novel approach to technology transfer, extension and education. While the HRIC model may not be applicable in all cane growing regions, we encourage SRDC to take a leadership role by assisting the industry to explore the applicability of collaborative models such as the HRIC in other cane growing regions.

8.   LIST OF PUBLICATIONS

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9.   ACKNOWLEDGEMENTS