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Modelling the effects of rehabilitation and changed agricultural practices in a saline-affected rural catchment

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USE OF THESIS

MODELLING THE EFFECTS
OF REHABILITATION AND
CHANGED AGRICULTURAL PRACTICES
IN A SALINE-AFFECTED RURAL CATCHMENT

MARTIN HELLER.

A Thesis Submitted in Partial Fulfilment of the
Requirements for the Award of

Bachelor of Science (Honours) (Environmental Management)
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Edith Cowan University.

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ABSTRACT

The Bremer river catchment, on the South-coast of Western Australia, is typical of most river catchments in this region in that it has been seriously affected by sedimentation, salinisation and eutrophication brought on by the gradual dominance of agricultural land management practices. Vegetated rehabilitation and changed agricultural land management practices (ie minimum / zero tillage) have now been widely adopted throughout the catchment in response to these degradation issues.

This study examined the potential impact minimum / zero tillage, vegetated rehabilitation and remnant vegetation could have on both a farm and catchment wide scale. A Geographical Information System was developed to identify spatial variability evident throughout the catchment. Three zones were developed by the system to account for spatial variability. Field studies were undertaken to sample the surface runoff flow from areas under the Remnant Vegetation, Vegetated Rehabilitation and Minimum / Zero Tillage land management practice in each of the three zones. Runoff was sampled using a modified Gerlach trough. Runoff sampling was synchronised with the occurrence of the first rainfall / runoff event of the year. Phosphorus, sediment and salt concentrations were the main parameters analysed in the runoff samples collected. Following statistical analysis, the results for these parameters were extrapolated to a load per hectare figure.

Further analysis of the catchment GIS was undertaken to determine the area of each zone and areas under each land practice in each zone. Two series of modelling scenarios, using the extrapolated load data, were used to determine the immediate and long term restorative effects increasing areas of vegetated rehabilitation could have on both a zone and catchment basis.

This study concluded that minimum / zero tillage in the catchment, in combination with further wide-spread adoption of vegetated rehabilitation will have the capacity to reduce catchment degradation caused by eutrophication and sedimentation. Its extensive implementation can address these two forms of degradation by decreasing runoff concentrations of phosphorus and sediment. Salinity problems in the catchment will be indirectly effected through resulting changes to the groundwater table. Additional changes to current land management practices are also necessary for instance fertility testing and fertiliser application-on-need should be incorporated into the minimum / zero tillage land management practice if they haven't been already.

DECLARATION

I certify that his thesis does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any situation of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signature

Date 8.11.96

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CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 General Introduction

Rivers have often been referred to as the integrators of activities in the catchment with the watershed being a meaningful physical boundary (Martin & Lockie, 1993). The impact of activities in any one area within this defined region can have a serious impact on the entire catchment and river (Erskine, 1994). As such the health of the river is a direct reflection of the health of the entire catchment (Cullen & Lake, 1995).

Naturally vegetated catchments generally maintain aquatic health. As land is subsequently cleared for agricultural pursuits, the transportation of nutrients and sediments increases, via such mechanisms as surface and subsurface flow, thereby reducing aquatic values (Cullen & Lake, 1995). The severity of this reduction generally depends on the extent of clearing in the catchment (Cullen & Lake, 1995).

Over the past 200 years, land and stream degradation, primarily on a catchment-wide scale, has become a significant environmental problem throughout most of Australia (Erskine, 1994). Most of this degradation can be associated with the development of arable land and associated land management practices and the subsequent alterations to the biophysical environment created by these practices.

Agricultural practices have replaced native vegetation with introduced or exotic perennial crops and pastures, involved the extensive use of heavy machinery, repeated cultivation, increased reliance on synthetic chemicals and has involved the introduction of, and overgrazing by, introduced animals (Conacher & Conacher, 1995). The biophysical alterations created by agriculture include the interception and redirection of water, the translocation of soil materials (by wind, overland flow, through flow, ground-water, mass movement and leaching), loss of soil structure, the formation of subsoil hardpans, the development of soil toxicities, changed nutrient cycling, and the activities of soil biota (Conacher & Conacher, 1995).

Agriculture has been identified as the major non-point-source polluter of Australia's water ways (Australian Water Resources Council, 1983; Weaver & Prout, 1993; Cullen & Lake, 1995). The agricultural effluents of primary concern are nutrient additives of nitrogen (N) and phosphorus (P). Once transported from agricultural lands to aquatic systems they are known to accelerate the biological productivity of aquatic systems leading to eutrophication and associated degradation of riverine and estuarine health (as documented by Vollenweider, 1980 and Weaver & Prout 1993).

Both nitrogen and phosphorus are essential additives due to the infertility of Australian soils and thus costly fertilisers are seen as essential to sustain current agricultural methods (Moody & Chapman, 1994). Their release and migration off arable land is thus often seen as an economic loss.

The successful management of agricultural non-point-source pollution requires a comprehension of the pollutant transport mechanisms from the land to the riverine system. These mechanisms are complex with hydrological, topographic, chemical type, soil type and land-use factors all significant in determining the impacts of the pollution and the means by which to control or reduce their effects (Morse, Eatherall and Jenkins, 1994) .

The complexity of spatial factors has lead to the creation of a number of Geographical Information Systems (GIS) models to address the issue of agricultural non-point source pollution. Most of the models (De Roo, 1993; Klaghofer & Birnbaum, 1993) have tested quantitative measurements of pollution, runoff and/ or erosion from various land management activities. The models have been used to evaluate alternative strategies for improved land management and have been applied on varying scales from small farms to entire catchments (De Roo, 1993). Unfortunately in the past this has involved the costly acquisition of detailed data (De Roo, 1993). The inherent cost factor has often reduced the ability to apply the GIS modelling technique on a more widespread basis. This has often meant that small rural communities have been unable to use this approach to attain the necessary information on the catchment-wide impact of various land management practices.

The GIS model could provide practical solutions to handle the detailed spatial variability that exists within catchments (Klaghofer & Birnbaum, 1993) and quantify the impact of existing land management practices, and alternative management practices on a catchment scale. This could then be used to identify and highlight the restorative potential of alternative management practices. The GIS catchment model could then aid small rural communities during future land management decisions.

1.2 Significance of the Study.

This study focused on the Bremer river catchment on the South Coast Western Australia, as detailed in Figure 1.1. The Bremer River is ephemeral, running every five to six years. The river system consists of the Wellstead Estuary, the Bremer River, Devils Creek and associated tributaries (see Figure 1.2). It lies within the boundaries of the Fitzgerald Biosphere reserve buffer zone and is therefore recognised as an internationaly significant area of land-use cooperation.

Typical of most estuaries on the south coast of Western Australia, the Wellstead Estuary is potentially eutrophic if not already eutrophic (Hodgkin and Clark, 1987) and continually shallowing. This has been primarily associated with the accumulation of effluent (ie nutrients and sediments) released by agricultural land management practices, during episodic flooding of the river, that are transported via the Bremer River from the catchment. Another major concern is the increased saline in-flow from the catchment.

1.2.1 The Bremer River and Catchment

The Bremer River is approximately 70 kilometres in length with approximately 80% (Regional Assessment Panel et al, 1996) of the 716 km^2 (Hodgkin and Clark, 1987) catchment cleared for agricultural purposes. The catchment has a typically Mediterranean climate with a mean annual rainfall of 450 mm in the upper catchment increasing to 600 mm at the coast (Hodgkin and Clark, 1987). Rainfall is mainly during winter but summer tropical storms may cause excessive rainfall in a short period of time (Hodgkin and Clark, 1987). Geologically the catchment can be divided into two main regions. The upper catchment consists of the Archaean Yilgarn Block, being duplex sand-plain soils with some lateritic gravel overlying dense mottled clays (Hodgkin and Clark, 1987). (In this area the drainage is clearly defined but less pronounced than the lower catchment). The lower reaches consist of the Pallinup Siltstone (Tertiary marine sediments of the Plantagenet Group) with mainly fine textured sediments and clays composing the common soil types of this area (Hodgkin and Clark, 1987). Low unconsolidated coastal dunes border the mouth of the estuary to the north with a headland of Archaean rock to the south (Hodgkin and Clark, 1987).

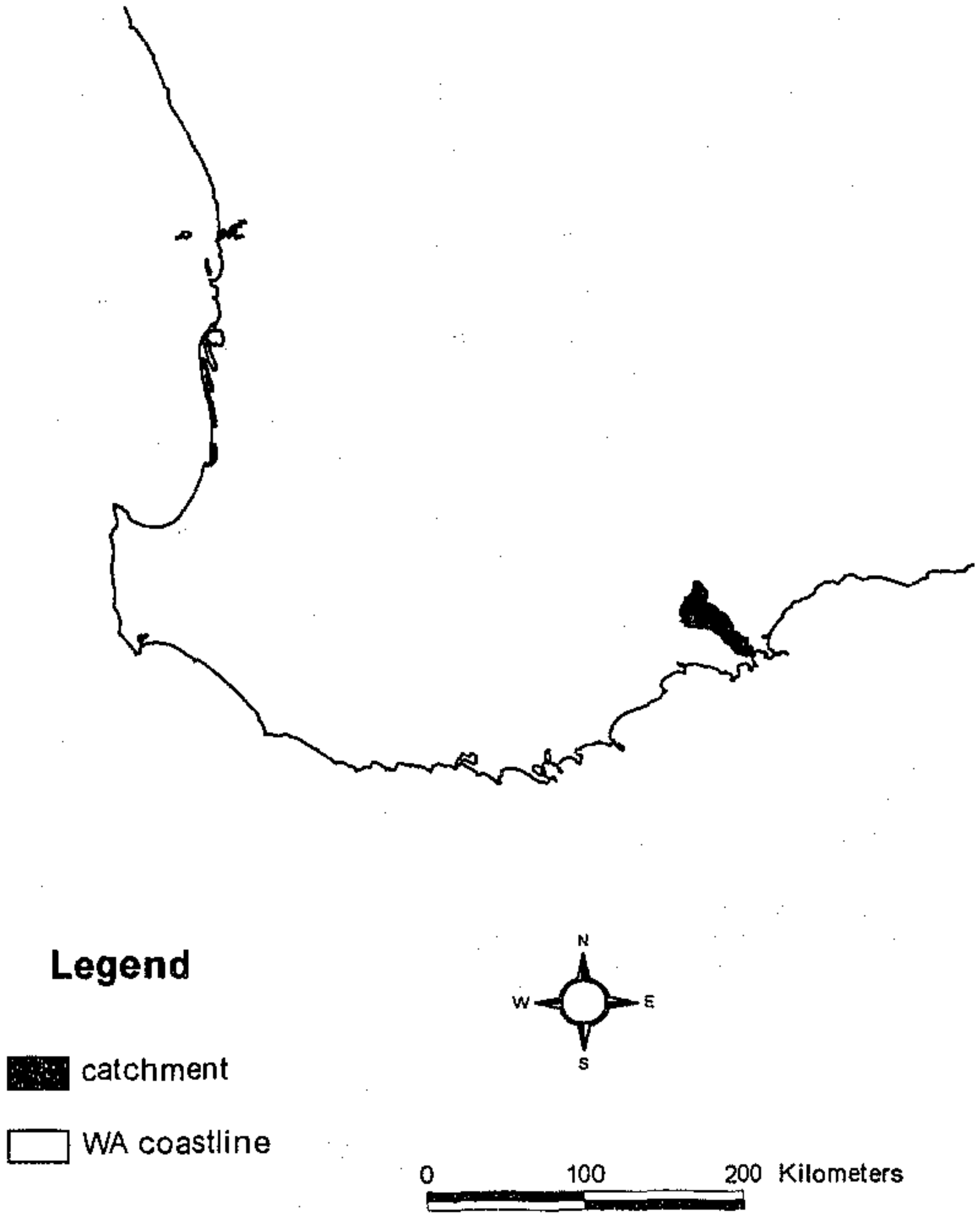

FIGURE 1.1 The location of the Bremer River catchment on the south-coast of Western Australia.

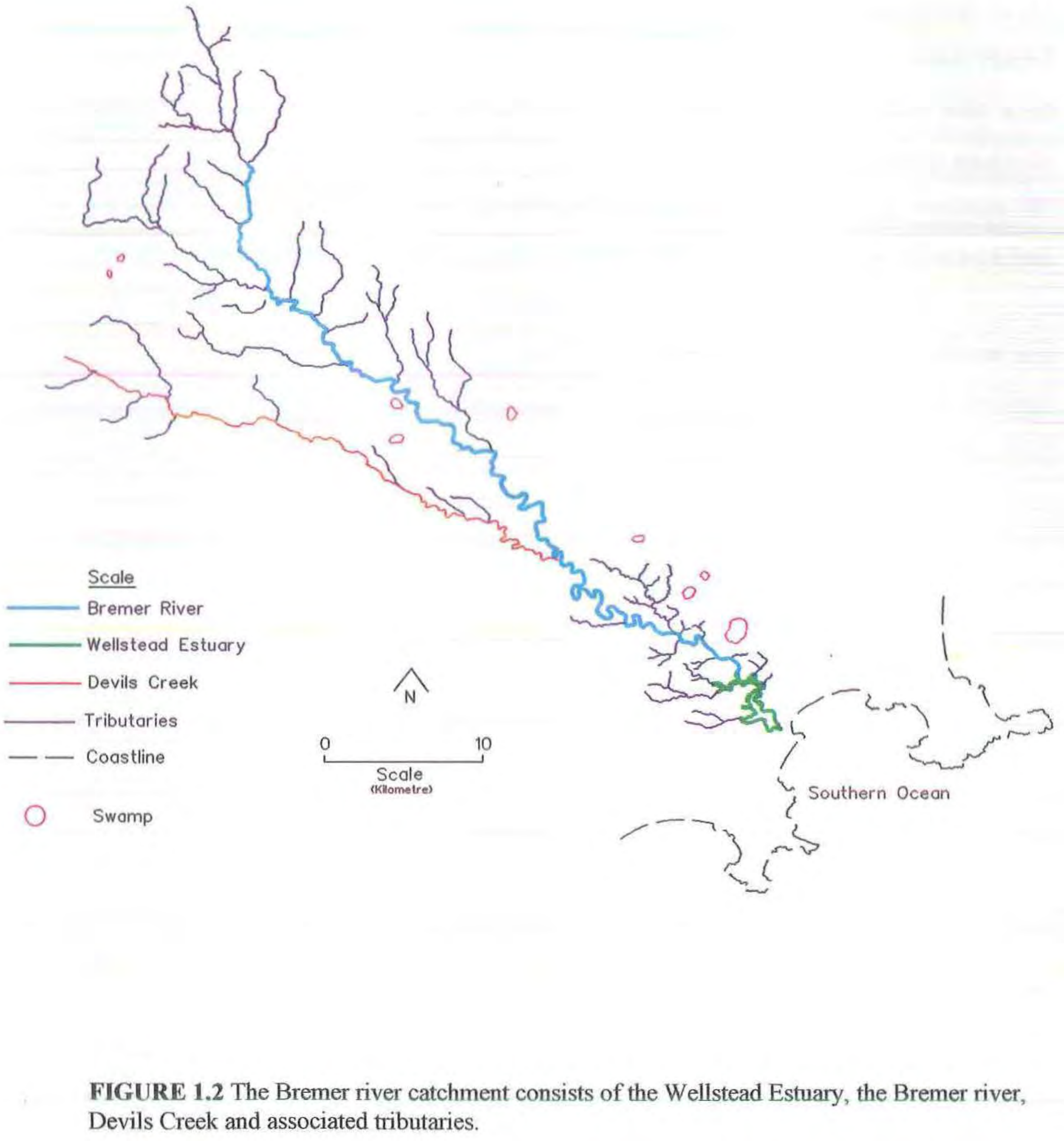

FIGURE 1.2 The Bremer river catchment consists of the Wellstead Estuary, the Bremer river, Devils Creek and associated tributaries.

1.2.2 Land management practices.

A total of 57 farms with an average size of 1167 hectares are located within, or partially within, the Bremer River Catchment. The area was opened up in the late 1950s to agriculture under a combination of war service settlement and conditional purchase land arrangements (T. Overhue, Agriculture Western Australia, pers. comm.).

Three main crops are grown within the Bremer River Catchment. To the far north wheat is grown while barley is the main crop in the south. Canola occurs to the extreme south (R. Morris, Agriculture Western Australia, pers. comm.) where rainfall can sustain the crop. Sheep are grazed throughout most of the catchment with some cattle grazing to the extreme south. Cultivation techniques today are primarily minimum or zero tillage with only a few farmers practicing conventional tillage methods (R. Williams, pers. comm.). Tillage technique changes have been adopted as a form of land rehabilitation and are seen as a step towards agricultural sustainability.

Secondary salinity, caused by rising water tables, water quality degradation and wind erosion are the environmental degradation issues of major concern amongst landowners within the catchment (T.Overhue, Agriculture Western Australia, pers. comm.). Attempts at reducing the impact of these degradive impacts have been addressed via several attempts at land rehabilitation. Rehabilitation has mainly taken the form of revegetation and attempts at alternative forms of farming (eg alley farming). The success of rehabilitation in reducing the various components of catchment degradation is at this stage unknown mainly due to the lack of knowledge on the effects of the practice on the catchment.

1.3 Objective of the Study.

The purpose of this study was to model the effects of rehabilitation and changed land management practice within the Bremer River Catchment. A Geographical Information Systems approach integrated existing information on the catchment and new information, attained via analysis of the GIS database, to obtain catchment-wide statistics for the purpose of modelling.

Field studies were undertaken to quantify the impact of the three common land management practices (ie. minimum / zero tillage, vegetation rehabilitation and remnant vegetation) on the catchment. This was achieved by sampling aspects of the water quality from surface flow of these various practices. The data collected were extrapolated to define the potential catchment wide impact of each practice.

Using information obtained from the GIS database, modelling of the extrapolated data was undertaken to predict the status of the catchment under current land management practices and different scenarios for future land management practices.

1.4 The Research Approach

A catchment, for the purposes of this study, is best defined as ".... a naturally occurring ecosystem with definable boundaries based on surface and/ or ground-water systems. All environmental processes are linked. Water and its movement is the prime vehicle linking the environmental processes - the ecology of the estuary, river and land are interconnected" (Wallis and Robinson, 1992. p. 15). In this sense any holistic study of a catchment must account for all the physical variations and cultural impacts apparent within the confines of the catchment.

Surface runoff and the on and off site effects of erosion, sedimentation, nutrient and chemical transport are all effected by the spatial variability of soils, topography, land cover and land use, climate, and several human-induced changes and management practices. Surface runoff is therefore often at the core of non-point source water quality concerns (Vieux, 1993). Accurate assessment and modelling of these processes must allow for the inherent variability of the catchment (Vieux, 1993). To enable an accurate assessment and modelling of non-point source pollution simplifications of spatial variation are required. One way to do this involves a "lumped parameters approach" (Engel, Srinivasan and Rewerts, 1993. p. 231) which uses " ....an averaging technique to approximate characteristics of each parameter" (Engel, et al. 1993. p.231). In demonstration of this technique Huggins (cited in Engel, et al 1993. p .231) claims that a magnitude of error stemming from such approximations was bound to be introduced due to the fact that the calculation could not account for all spatial variations (parameters) within the catchment boundary. This study has attempted to narrow down the effects of spatial variation via a new approach, the Zone approach. This approach involved the identification of zones of similarity via the analysis and interpretations of a series of physical catchment attributes using a Geographical Information System (GIS). Simplification of whole systems inevitably involves a degree of error but this was reduced by dividing the catchment into a number of distinct, separable zones. The GIS was seen as a convenient and well structured database for handling the large quantities of spatial data needed to allow analysis and identification of relationships and interactions within the catchment.

1.4.1 Aquatic study vs runoff study.

Cullen and Lake (1995, p. 115) claim that "...the quality of water in a river is an ideal performance indicator for the health of a catchment." Poor river water quality (ie high nutrient levels, high rates of sedimentation) can indicate poor land management in the catchment whereas good river water quality may represent the opposite. Unfortunately many river systems on the south-coast of Western Australia are either seasonal, flowing during winter when most rainfall occurs, or ephemeral, flowing only when rainfall is above average. Thus the impact of land uses on river health may be extreme; representing an accumulation of the effects of land use activities over many years.

As identified by Hodgkin and Clark (1988, p. 29) the Wellstead Estuary shows a possible decline in health primarily due to the accumulation of non-point source pollution from the catchment following episodic flooding of the river. This study did not attempt to further quantify the health of the actual river or estuary based on biological health or nutrient levels, rather it aimed to identify the land management practices that were the potential non-point sources of their degradation. To achieve this, the study focused on sampling the main transportation mechanism of soluble chemicals and sediment through the catchment between river flow events, namely runoff.

1.4.2 Soil processes and runoff

Chemical, physical and biological soil processes are known to affect water quality. Physical processes, including soil compaction, crusting and accelerated erosion, occur when there is a decline in soil structure with resultant decrease in water infiltration rates and a increase in surface runoff (Lal & Stewart, 1994). Surface runoff and soil erosion enhance both the transport of dissolved chemicals and sediment borne pollutants into natural waters (Lal & Stewart, 1994).

Runoff will only occur when the rate of rainfall exceeds the rate at which water can infiltrate into the soil. After the infiltration capacity is satisfied, water begins to fill surface depressions. As the depressions are filled overland flow of water begins. Water builds up on the surface until it is sufficient to result in runoff in equilibrium with the rate of rainfall (less evaporation, interception and infiltration) (Schwab, Fnagmeier, Elliot & Frevert, 1993). The depth of water building up on the surface is known as surface detention. The runoff flow moves into defined channels where the build up of the water is known as channel detention. The volume of water in both surface and channel detention is returned to runoff as the runoff rate begins to decrease. Surface water is eventually infiltrated or evaporated (Schwab et al, 1993).

Runoff water originates in sub-catchment areas and will reach a defined drainage line by a number of possible means. (The route the water takes is commonly referred to as the source area.) Where infiltration is poor overland flow will be dominant with source areas easier to define (Cullen, 1983). In areas of deep permeable soils subsurface flow may occur. Where some infiltration occurs, a variable source area with combined surface and subsurface flow may occur (Cullen, 1983).

Soil type, condition and source area determination were essential to the extrapolation of runoff water quality results from this study. To address the issue of soil characteristics soil samples were taken from each study area to determine infiltration rates, and general soil type, to account for runoff water source areas.

1.4.3 Nutrient movement in runoff

Research (Ahuja & Lehman, 1983; Ahuja, 1985; Sharpley, 1985) indicates that soluble and particulate chemicals may be transferred from the soil to runoff from a depth as great as 2.0 cm. However Ahuja (1985, p. 48) states that the degree of mixing between soil and rainwater and the chemical transfer decreases exponentially with depth. Impervious soils, with poor infiltration are known to have higher chemical transfer to runoff rates (Ahuja & Lehman, 1983).

Most soil and nutrient movement from non-point sources occurs during very brief storm periods (Rayment & Poplawski, 1992). During such events, a sub-catchment may contribute nearly all of its annual nutrient loads to streams. Such events are commonly the first runoff event of the rainfall season. Any attempt at quantifying the nutrient load into streams and creeks from diffuse agricultural sources must involve sampling runoff during the first high rainfall event. This study has achieved this by sampling the first two runoff events of the year by sampling in a remote manner with the placement of runoff samplers prior to the first rainfall / runoff event. This allowed for the sampling of runoff during the first major rainfall / runoff event of the season and thus assumed maximum concentrations in both nutrient and particulate matter. A second sampling round qualified the peak concentrations of the first and allowed for an insight into subsequent nutrient loading to streams from sub-catchments during subsequent rainfall events of the same rainfall season.

1.4.4 Runoff water quality

The principal pollutants in runoff have been identified (Lal & Stewart, 1994) as including sediments, nitrates, phosphates, dissolved organic carbon, and major pesticides. (This study was limited to the analysis of the phosphorus and sediment concentrations in the runoff water sampled.)

Both soluble and particulate forms of Phosphorus (P) can be transported in runoff. Particulate phosphorus encompasses all solid forms including organic matter eroded during runoff, and P sorbed by soil particles. Because P is relatively immobile in soil, most P lost from agricultural lands primarily is adsorbed to eroded soil transported by runoff (Schuman, Spomer & Piest, 1973; Sharpley & Halvorson, 1994). Transformation in concentrations of P in runoff water is a common occurrence. The amount that reaches a water body is always considerably less than the edge-of-field losses (Sharpley & Halvorson, 1994). These transformations are accentuated by the transport of sediment in runoff water, and the ability of the sediment to both sorb and desorb P. Consequently, the extent of this loss must be considered in assessing the impact of P transported in runoff as a function of agricultural management (Sharpley & Halvorson, 1994). Past studies have measured only soluble P and total P in runoff. Sharpley and Halvorson (1994, p. 35) state that the "...estimation of biologically available P transport in runoff is needed to estimate more accurately the impact of agricultural land management practices on aquatic systems."

Amounts of P transported in runoff from uncultivated or pristine land is considered the background loading, which cannot be reduced (Sharpley & Halvorson, 1994). Because the runoff from these areas carries little sediment they are usually dominated by the soluble form of P. Phosphorus in natural waters in Australia are usually at levels of a few hundredths or tenths of a μg/L (Manahan, 1990).

In attempting to assess the impact of agricultural management on P loss in runoff, little if any information is available on the background losses of P from a given location before cultivation (Sharpley & Halvorson, 1994). Consequently, quantifying any P loss following cultivation is also difficult. Problems are primarily associated with the expensive and labour intensive techniques of water quality monitoring studies, which are mostly site-specific and impossible to replicate due to the fact that they seldom attempt to account for the spatial and temporal variations in edaphic, climatic and topographic conditions. A review of past studies (Schuman, et al, 1973; Omernik cited in Sharpley & Halvorson, 1994) enables generalisations about the effect of agricultural practices on P transport in runoff. These studies have shown that P loss in runoff increases as the proportion of the catchment under native vegetation declines and areas under agricultural land management practices increase. Ryden, Syers and Harris (cited in Sharpley & Halvorson, 1994 p. 41) claims that "....the loss of P from forested land tends to be similar to that found in sub-surface or base flow from agricultural land." Naturally vegetated areas are considered to conserve P, with P input in rainfall usually exceeding outputs in stream flow (Sharpley & Halvorson, 1994). Considering these factors , vegetated areas are often utilised as riparian or buffer strips around drainage areas to reduce the level of P inputs from agricultural areas. Value then lies in both the retention of native vegetation and the strategic placement of rehabilitated vegetation in catchments.

This study has compared the three main land uses of the Bremer River catchment in an endeavour to come to a comprehension of the degree and manner of pollutant concentrations running off these land use areas. Both particulate and soluble phosphorus were studied for in the runoff water samples. Sediment (and its components), as acknowledged by the past studies, a potential transport mechanism for phosphorus in some areas, was also analysed for in the runoff water samples taken. Defining spatial variation within the catchment, using a GIS, creating homogenous zones of physical similarity, attempted to address the factors which had limited past studies. This allowed for the extrapolation of results to provide a potential catchment wide impact from the current land use practices. Modelling of these extrapolated figures, using a number of land management practice ratios, provided an indication into the possible changes in pollutant loss in the catchment. By the comparison of land use areas and the extrapolation of results on a catchment wide basis, this study has attempted to highlight the potential effectiveness of rehabilitation throughout the catchment.

1.5 Objectives

A number of research objectives have been generated from the approach taken from this study. These objectives are :

1. To determine the degree of impact from each land management practice.

2. To determine if variation between the same management practices occurs between different zones.

3. To determine if other factors have an effect on the impact from each zone.

4. To determine the potential effectiveness of rehabilitated vegetation in the catchment.

5. To determine the degree to which non-point source pollution could be potentially reduced by increasing the area of rehabilitation within the catchment.

CHAPTER 2

METHODS

2.1 Developing the Bremer River catchment GIS

The initial search for data, with particular reference to the catchment, uncovered information defining both the physical and cultural features of the catchment. Most of the information uncovered was in hard copy format and located following extensive searches of available literature, the Internet, and sources within government agencies. The initial interpretation and analysis of the information provided an indication of both variation and relationship between the physical and cultural features of the catchment. Unfortunately, in a hard copy form, these could only really be guessed due to the inability to match and combine the hard copies of the information.

For this reason a GIS for the catchment was considered. The GIS would allow further analysis of the physical and cultural attributes of the catchment to uncover relationships and interactions between the attributes and aid in defining further research potentials. The GIS would also allow further manipulation of the data combining a number of data coverages (a GIS data file containing geographic information on one or more, physical or cultural attribute/s covering a defined geographic region).

Finally the GIS was considered as the only means by which information gained through field research could be successfully extrapolated on a catchment-wide basis.

2.1.1 Composing the GIS

The composition of the Bremer River GIS involved extensive research into the form (file format and compatibility with existing GIS programmes) and availability of data. This initially involved consultation with a number of state and federal government agencies. It was well known that GIS data coverages were usually expensive and their usage restricted to pre-specified purposes. The consultation was successful with the agencies providing access to a large number of data coverages with flexible licensing arrangements and only minimal costs. Securing the data enhanced the potential scope of the project and aided in maintaining low costs. Three main agencies provided the information; Department of Land Administration (DOLA), Agriculture Western Australia (AWA), and Water and Rivers Commission. Table 2.1 details the Geographical Information Systems data coverages obtained from the various government agencies, the file format initially obtained and acknowledges licensing agreements made for access to the GIS data coverages.

Table 2.1

The GIS data coverages and file formats obtained from various government. Acknowledgment is made to those agencies that provided GIS files under licensing agreements.

	ENVIRONMENTAL ASPECT	FILE FORMAT	SOURCE / AGENCY
BIOTIC	Remnant Vegetation mid 1992	Microstation	AWA *
SUBSTRATE	Soils	Microstation	AWA - Albany
	Geology	Microstation	WRC - Perth
	Topography	Microstation	DOLA - Perth *
	Drainage	Microstation	WRC - Perth
	Catchment Boundary	Microstation	WRC - Perth
	Coastline features	Microstation	WRC - Perth
LAND USE	Roads and Tracks	Microstation	WRC - Perth
	National Park Boundary	Microstation	WRC - Perth

KEY

AWA	Agriculture Western Australia
WRC	Water and Rivers Commission
DOLA	Department of Land Administration
*	Provided under licensing agreement

2.1.2 Choice of Spatial Information Systems

Two Spatial Information systems were used for the purposes of this study, Microstation (v95, Bentley systems) and ArcView (2.1a, Environmental Systems Research Institute [ESRI]). Microstation and ArcView were both used because most of the data coverages obtained were in Microstation format, but Microstation was limited both in its ability to analyse and to provide statistical information on individual digital data coverages. Microstation offered easy editing and manipulation of the data coverages and the export of data coverages to other Geographical Information Systems.

ArcView offered a statistical tool which could be used to easily determine areas of locations within the catchment, provided clear and accurate images for analysis and finally provided a series of layout tools suitable for the final presentation of images.

Importing of all Microstation data files and coverages had to occur via ArcInfo 7 (ESRI) due to direct compatibility problems between Microstation and ArcView.

2.1.3 Defining the catchment

Upon obtaining the GIS data coverages from the source agencies initial inspection of the files indicated that most were on the broad geographic scale covering Western Australia's south coast. To overcome this problem the data coverages had to be customised solely to the Bremer Catchment area.

The topographic information obtained from the Department of Land Administration (DOLA) was analysed and a catchment boundary was defined from it. The process initially involved the manipulation of the 24 individual topographic data coverages in Microstation to form a mosaic (a new data coverage). Once created the mosaic was further manipulated highlighting 5 metre contour intervals. Using Microstation an on-screen analysis and determination of the catchment boundary was undertaken. This procedure involved making judgements on the height of the contours and spot heights, and the increase and decrease of these values. As a guide the catchment boundary obtained from the Water and Rivers Commission was placed on top of the topographic mosaic data coverage. A line was digitised, on-screen, between the increasing and decreasing values. The accuracy of this method was considered to be extremely good due to 1 metre spot heights and 5 metre contour interval features of this new coverage. The final step was to export the newly created catchment boundary data coverage into ArcView for the accurate determination of the catchment area.

Past studies on the Bremer River system had indicated that the catchment size was either 695 km^2 (Hodgkin and Clark, 1987) or 716 km^2 (Hodgkin and Clark 1988). Although the methods used to derive these figures were not indicated, the authors concluded that estimates made were approximate due to the poorly defined drainage channels of the catchment. Using the analysis tools in ArcView the catchment area was determined as being 728 km^2.

The data coverages obtained from the government agencies were then edited to the catchment boundary in Microstation and exported to ArcView. This procedure completed the Bremer River Catchment GIS.

2.1.4 Defining the Zones

The study established three zones which were distinguishable from each other according to a variety of different physical attributes. This approach would narrow down the spatial variability that was evident in the catchment and provide spatial continuity in each zone (Kemp, 1993).

The three zones were defined by analysing the soils, geology and topographical data coverages for spatial variation and associations using the features of both Microstation and ArcView, and from associated descriptive literature (Northcote, Bettenay, Churchward and McArthur, 1967; Northcote, Hubble, Isbell, Thompson and Bettenay, 1975; Thom and Chin, 1984). In many cases the descriptive literature (Northcote et al, 1967; Thom and Chin, 1984) were complimentary to the data coverages in the GIS. The created catchment boundary was used as a frame and placed over the top of the soil, geology and topography coverages in Microstation. Guiding lines were separately digitised to identify points of variation. The geology data coverage was then placed on top of the soils data coverage and comparisons made between the two. Finally the topography data coverage was placed on top of the other two data coverages with final comparisons made between all three data coverages. Borders were digitised between the three zones forming a new data coverage, the zone data coverage which was then exported to ArcView.

Table 2.3 details each environmental attribute and their characteristics in each zone. Clear distinctions between zones are apparent in all environmental attributes. Figures 2.1 and 2.2 present individual environmental attributes, (from Table 2.3), and Figure 2.3 shows the new zone coverage indicating the three spatially distinct zones. Additional NON-GIS related information is presented in Table 2.4. This information enhances the individual characteristics of each zone. Relationships between environmental attributes in each zone are apparent and the zones are distinguishable from each other.

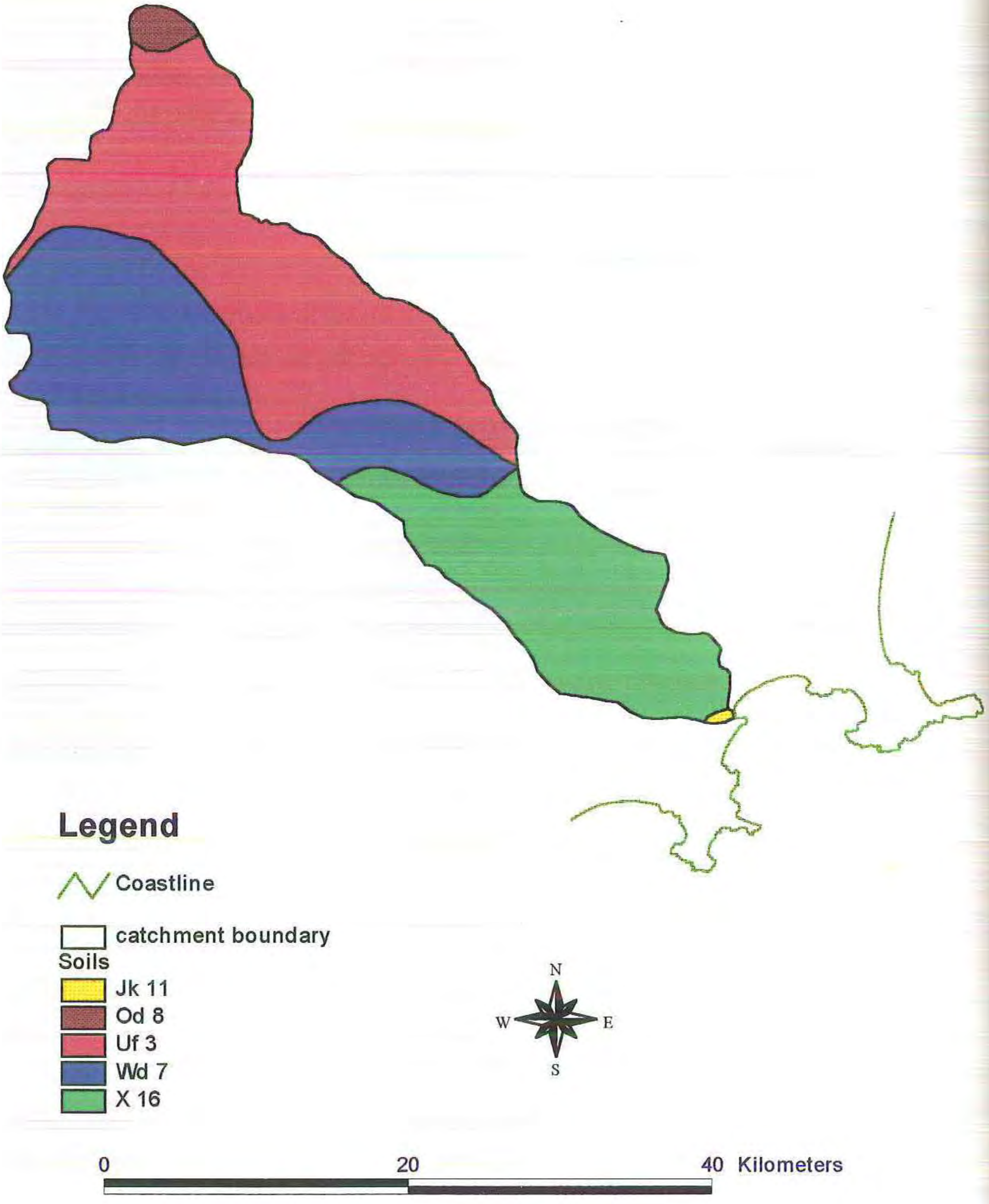

FIGURE 2.1 The major soil groups of the Bremer river catchment.
(Source Northcote et al. 1967)

Jk 11	Shallow sandy soils with some Granitic Massifs
Od 8	Hard alkaline red soils with some gnessic rock outcrops.
Uf 3	Solodized Solonetz and Solodic Soils
Wd 7	Sandy acidic yellow mottled soils containing ironstone gravel.
X 16	Sandy neutral yellow mottled soils with leach sands.

(Source Northcote et al, 1967)

FIGURE 2.1 Legend

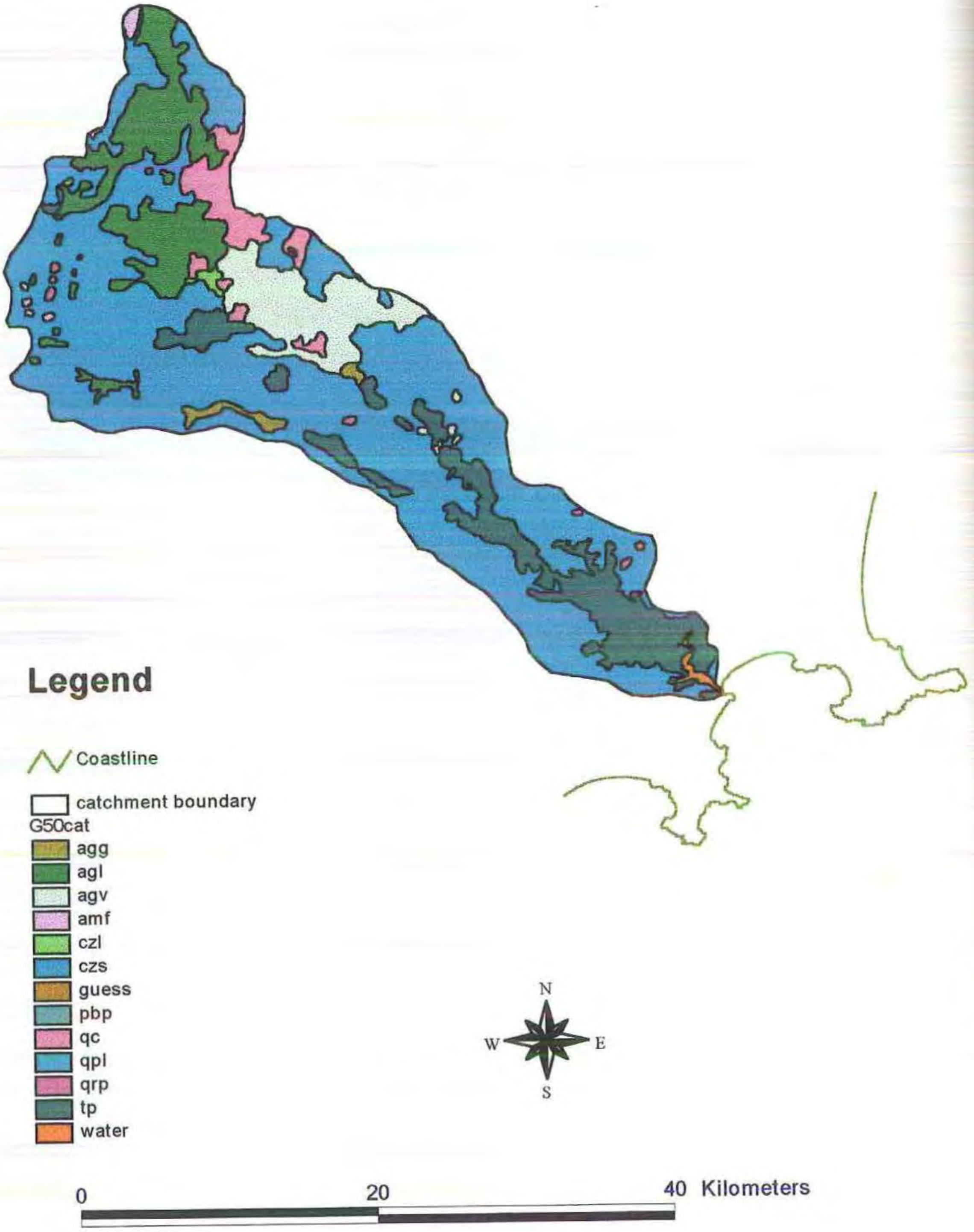

FIGURE 2.2 The major geological groups of the Bremer river catchment.
(Source :Thom and Chin, 1984)

Symbol	Description	Epoch
agg	Adamellite amd granodiorite - foliated, granoblastic texture and sparse garnet.	Archaean
agl	Granite and adamellite - medium to coarse grained, with abundant large phenocrysts	Archaean
agv	Adamellite - medium to coarse grained, with abundant large phenocrysts	Archaean
amf	Metamorphosed agmatite	Archaean
czl	Duricrust and weathered rock - includes laterite, lateritic gravel, silcrete and kaolinized rock.	Cainozoic - Tertiary
czs	Sandplain - yellow to white sand and clay.	Cainozoic - Tertiary
pbp	Gneiss - mainly granitic augen gneiss	Proterozoic
qc	Colluvium and minor alluvium	Cainozoic - Quaternary
qpl	Calcareous shelly sandstone and grit, equivalent Tamala Limestone.	Cainozoic - Quaternary
qrp	Clay and sil deposits in brackish claypans and swamps	Cainozoic - Quaternary
tp	Plantagenet Group : yellow to grey siltstone, silty sandstone and spongolite of the Pallinup Siltstone	Cainozoic - Tertiary
water	Wellstead Estuary.	

(Source : Thom & Chin, 1984)

FIGURE 2.1 Legend

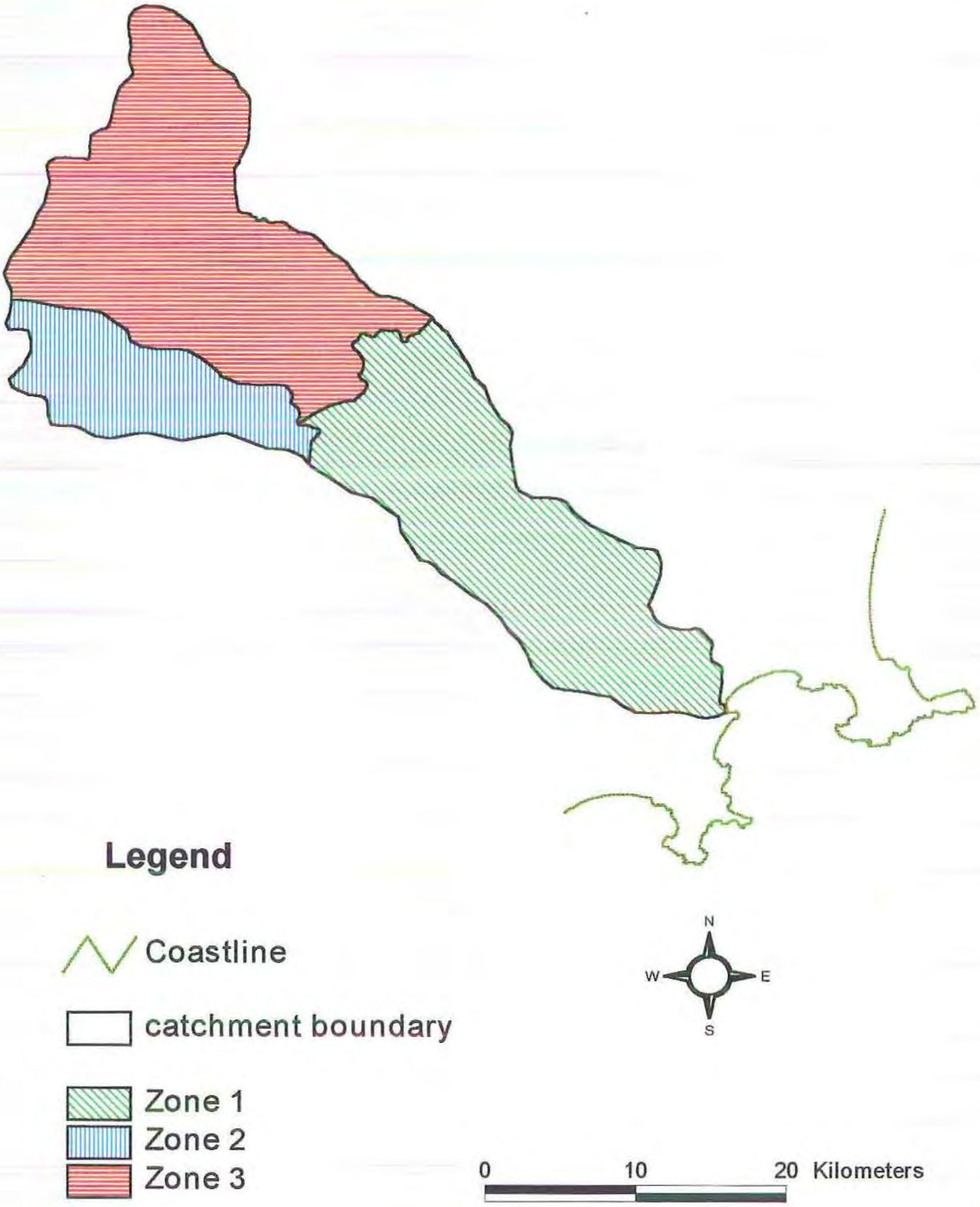

FIGURE 2.3 The three defined zones of the Bremer river catchment.

Table 2.2

THE THREE ZONES OF THE BREMER RIVER : The defining Environmental Attributes of each zone. The defining Environmental Attributes were summarised from GIS data coverages and associated descriptive literature.

Environmental Attribute	ZONE 1 Lower Bremer	ZONE 2 Devils Creek	ZONE 3 Upper Bremer
Geology	CAINOZOIC *(a)* Tertiary Marine Limestone BEDROCK *(a)*: Pallinup Siltstone	ARCHAEAN *(a)* Granitic Rocks. BEDROCK *(a)*: Yilgarn Block	ARCHAEAN *(a)* Granitic Rocks. BEDROCK *(a)*: Yilgarn Block
Soils	General Description *(b)* : Humic soils Soil Type *(c)* X 16 - chief soils sandy neutral yellow mottled soils with leached sands.	General Description *(b)* : Yellow podsolic soils Soil Type *(c)* Wd 7 - : chief soils on the plains are sandy acidic yellow mottled soils containing ironstone, laterite or gravel.	General Description *(b)* : Solodized solonetz and solodic soils. Soil Type *(c)* Uf3 - : chief soils are hard neutral yellow mottled soils containing ironstone gravels in their surface horizons on the flat to gently undulating ridge crests.
Topography	*(c)* Plains with many flats.	*(c)* Flat to gently undulating plain or plateau at low elevation with few flats.	*(c)* Dissected plateau at low elevation having an undulating to rolling ridge and slope relief with some steep bluffs adjacent to drainage-ways ; some swamps

SOURCES
(a) = Geological Survey of Western Australia, 1984; *(b)* = Northcote, et al 1975;
(c) = Northcote et al, 1967;

Table 2.3

THE THREE ZONES OF THE BREMER RIVER : The defining Environmental Attributes of each zone. The defining Environmental Attributes were summarised from additional descriptive literature.

ENVIRONMENTAL ATTRIBUTE	ZONE 1 Lower Bremer	ZONE 2 Devils Creek	ZONE 3 Upper Bremer
RAINFALL : (Average annual)	437 mm *(a)*	444 mm *(b)*	410 mm *(c)*
LAND SYSTEMS *(d)* (general area)	JO = Jona Conack	LG = Lower Gairdner	UG = Upper Gairdner
AVERAGE DEPTH TO BEDROCK *(e)*	28.50 m	16.50 m	8.69 m
AVERAGE DEPTH TO GROUND-WATER TABLE *(e)*	11.7 m	5.71 m	2.41 m
AVERAGE CONDUCTIVITY OF GROUNDWATER *(e)*	3216 mS/m	2847 mS/m	1624 mS/m
AVERAGE TOTAL SALT STORAGE *(e)*	not available	1983 tonnes per hectare	973 tonnes per hectare
GENERAL SALINITY RISK RATING *(f)*	Low Salinity hazard rating	High Salinity hazard rating.	Medium salinity hazard rating.

SOURCE *(a)* R. Williams Meechi Road Gairdner, Rainfall records 1982 - 1995. *(b)* Gairdner Grazing Company, Devils Creek Road, Gairdner, Rainfall records 1959 - 1995. *(c)* Jerramungup weather station, Jerramungup. Rainfall records 1895 - 1995. *(d)* Agriculture Western Australia. *(e)* Martin, 1992. *(f)* Ferdowsian, McFarlane and Ryder, 1994.

2.1.5 The statistics extracted from the GIS

A number of statistical calculations were undertaken using the catchment boundary data coverage and zone data coverage and the query tool in ArcView. These figures are indicated in Table 2.4.

Table 2.4

The results from the ArcView statistical analysis of the zone and catchment boundary data coverages. Figures indicate the area estimates for each zone and the catchment.

CHARACTERISTIC	DATA COVERAGE USED	MEASUREMENT
Total area Zone 1	Zone data coverage	28,677 hectares
Total area Zone 2	Zone data coverage	10,994 hectares
Total area Zone 3	Zone data coverage	33,152 hectares
Total area of Catchment	Catchment boundary data coverage	72,824 hectares

2.1.6 Errors in data conversions

Despite the growing role of data standards, the major issue of incompatibility arises when sharing data coverages from various government organisations and when transferring the data between GIS systems (Evans, 1994). The quality and accuracy of the data obtained from various government agencies is assumed to be of the highest level. The issue of incompatibility therefore is faced when transferring data between GIS systems. The problem lies in the syntactic organisation of the data coverages in one GIS and the semantic interpretation of the data between GIS systems (Evans, 1994). Some loss or discrepancies, of information, when converting between GIS systems does occur, not from a lack of co-ordination "...but from legitimate differences in the information requirements" (Evans, 1994, p. 206) of the individual GIS systems.

Often this loss of information goes unnoticed and may cause error in the future use of the data coverage in other geographical information systems. In the case of the 1992 remnant vegetation data coverage some information was lost between the conversion from Microstation file format (dgn) to the Arc/View file format. This was only apparent when viewing the on-screen image of the coverage on each system. To correct this problem two procedures were considered. These were to either re-digitise the coverage in Arc/Info or to introduce an error factor. To re-digitise lost information in Arc/Info would have been a timely and possibly erroneous process. Errors may have occurred due to the fact that it was extremely difficult to quantify the degree of information lost. The introduction of an error factor was not supported by any literature source. Unfortunately this study has been unable to find a solution to rectify this problem. This matter has been highlighted to indicate a potential source of error in using the statistical figures from the 1992 remnant vegetation data coverage for future modelling extrapolation.

2.1.7 Defining Remnant Vegetation area

Using Arc/View the 1992 remnant vegetation data coverage was placed upon the zone data coverage, then using the query tool of this program the total area in each zone under remnant vegetation was determined. The zone data coverage was replaced by the catchment boundary data coverage to determine the total area of remnant vegetation in the catchment. The results of these calculations appear in Table 2.5.

Table 2.5 also indicates the area of remaining land (other land uses) in each zone, and catchment. This information was obtained for the extrapolation and modelling of field research data on a catchment wide basis.

Table 2.5

The total areas of remnant vegetation and remaining land (other land uses). Percentage figures have been used to give an indication of the relationship between remnant vegetation and the other land uses.

	Total area of Remnant Vegetation (ha.)	% of Zone	Total area of remaining land. (other land uses)	% of Zone.	Total Area. (ha.)
Zone 1	12839	44.8 %	15838	55.2 %	28,677
Zone 2	1452	13.2 %	9542	86.8 %	10,994
Zone 3	3700	11.2 %	29452	88.8 %	33,152
Catchment	17991	24.7 %	54833	75.3%	72,824

2.2 LAND USE AREAS

For the purposes of this study the following common land management practices were studied :

1. Minimum / Zero Tillage.
2. Vegetated Rehabilitation.
3. Native Remnant Vegetation (Remnant Vegetation).

2.2.1 Remnant Vegetation

Remnant Vegetation was defined by this study as being an area of land, larger than 1 hectare in size, with a dominance of native vegetation, in the under, mid and upper storeys, with the total exclusion of stock from these areas for at least 4 years.

Remnant Vegetation was considered a land use practice due to the fact that a land management decision had resulted in its existence. Most remnants (greater than 1 hectare in size) on agricultural land within the catchment are the result of either the presence of poison bush (*Gastrolobium spp.*) within the remnant, proximity to drainage lines (riparian strips) or known saline areas (areas of ground-water discharge). Selecting areas of Remnant Vegetation in the catchment was difficult. The criteria for the selection of these areas were :

a. All areas selected had to be fenced off from stock (stock exclusion) so that the chosen area would represent a natural area of native vegetation .

b. The past history of disturbance in the area had to be identified.

c. The remnants selected had to be representative of other remnants in their respective zone with similar slope and soil type.

d. Remnant areas chosen had to be similar, in terms of soil type and slope, to the other land management practice sampling areas, in their respective zone, to allow for comparisons between areas.

2.2.2 Vegetated Rehabilitation

An area of Vegetated Rehabilitation was defined by this study as being an area of land, previously under, or effected by, agricultural production which had been extensively rehabilitated by the planting of various forms of perennial, deep rooted, flora endemic or exotic to Australia to either counter-act or prevent land degradation problems (ie. salinisation of the soil, wind erosion and water erosion).

The land management practice of Vegetated Rehabilitation is clearly apparent throughout most of the catchment. Unfortunately, for the purposes of this study, its forms are wide and varied. Agro-forestry, shelter belts, replanted low lying areas and replanted drainage lines, are but some forms of vegetated rehabilitation in the catchment. At present, apart from agro-forestry, rehabilitated areas are taken out of agricultural production, and therefore incur short-term negative cost to the land owner in initial capital outlay but may be considered to boost land production as they reduce or reverse land degradation.

Selecting areas of Vegetated Rehabilitation with similar land management characteristics was difficult. It was recognised that in order to compare runoff results between rehabilitated vegetation in all three zones, the areas selected should have used the same vegetated rehabilitation practice (ie all three areas Agro-forestry), be all the similar age, and a similar size. Vegetated Rehabilitation is more of a site specific type practice in the Bremer catchment with no wide-spread conformity, in technique, between farm locations.

The selection criteria for the category of Vegetated Rehabilitation was therefore restricted to areas of similar soil type and slope to the other land management practices in the zone to ensure appropriate comparisons.

2.2.3 Minimum / Zero Tillage.

Minimum / zero tillage can be defined as the cultivation for weed control and/or preparation of a seed bed, whilst maximising stubble cover of the soil, and minimising soil disturbance (Carter, 1994). In the catchment individual paddocks on farm locations are commonly rotated on a 3 : 2 year production rotation (ie. 3 year pasture : 2 years crop). Fertilisers are applied during the years of cropping, with canola, lupins and barley the most common crop. The two most commonly adopted land cultivation practices in the catchment are either minimum or zero tillage, with both being seen as a form of conservation tillage. Most tillage occurs between 7 to 21 days of the break of season (first winter rain greater than 10 mm).

Fertiliser quantity, type and methods of application vary greatly throughout the catchment. Most farms are under different fertiliser regimes, with some soil testing prior to application. Fertiliser application varies greatly between land owners and within farms.

As the period of sampling coincided with the break of the season, the cultivation of a number of paddocks restricted access to these areas. As the tilling of the paddock would result in wide-spread soil disturbance, detrimental to runoff scars and soil stability, paddocks that had just recently (ie. in 1995) been cropped, therefore in their first year of pasture, were chosen as potentially suitable as sampling areas.

The criteria for the selection of Minimum / Zero Tillage sampling areas also included :

a. Identifying the past fertiliser application history.

b. The areas selected had to be representative of other minimum / zero tillage areas in their respective zone with similar slope and soil type.

c. The areas chosen had to be similar, in soil type and slope, to the other land management practice areas, in their respective zone, to allow for comparisons.

d. The potential absence of livestock during the sampling period, minimising soil disturbance and potential interference with runoff water quality and runoff collector set up.

2.3 The Sampling Areas

Although a total of 57 land owners have land, partially or totally, within the catchment the best manner in which to set up a manageable sampling regime was to choose one land location / owner in each zone and to locate sampling areas and replicate sites within these locations.

By selecting a single farm location in each zone site specific information was easily obtained, rainfall records and updates were easier to obtain and calculate, and distances travelled were kept to budget.

2.3.1 Slope measurements and locations of sampling areas

Upon selection all sampling sites were thoroughly surveyed to ensure that they represented areas typical of the zone. Slope measurements (in degrees), using a clinometer, and general GPS locations, using a Magellan GPS (Global Position System), were measured. Table 2.6 below indicates the measured slope and GPS location for each of the sampling areas.

Table 2.6

The slope and GPS location for each of the sampling areas selected.

Zone	Land use sampling area.	Slope measurement	GPS Location.
1	Remnant Vegetation	14 °	50 H 0700727 UTM 6209926
1	Vegetated Rehabilitation	9 °	50H 0700884 UTM 6211026
1	Minimum / Zero Tillage	7 °	50H 0699672 UTM 6209816
2	Remnant Vegetation	12 °	50 H 0690211 UTM 6210161
2	Vegetated Rehabilitation	8 °	50H 0691903 UTM 6209235
2	Minimum / Zero Tillage	5 ° - 8 °	50H 0687219 UTM 6229442
3	Remnant Vegetation	7 °	50H 0686669 UTM 6228099
3	Vegetated Rehabilitation	7 °	50H 0687351 UTM 6228330
3	Minimum / Zero Tillage	6°	50 H 0687219 UTM 6229442

2.4. Sampling Areas Zone 1 : Lower Bremer

Kent Location 1874, 626 hectares in area, has been farmed by Mr Ross Williams since the early 1970's.

Figure 2.4 indicates the location of the sampling sites on Location 1874 in relation to the catchment, zones and other sampling sites and Figure 2.5 shows Location 1874 and the three sampling areas on this property.

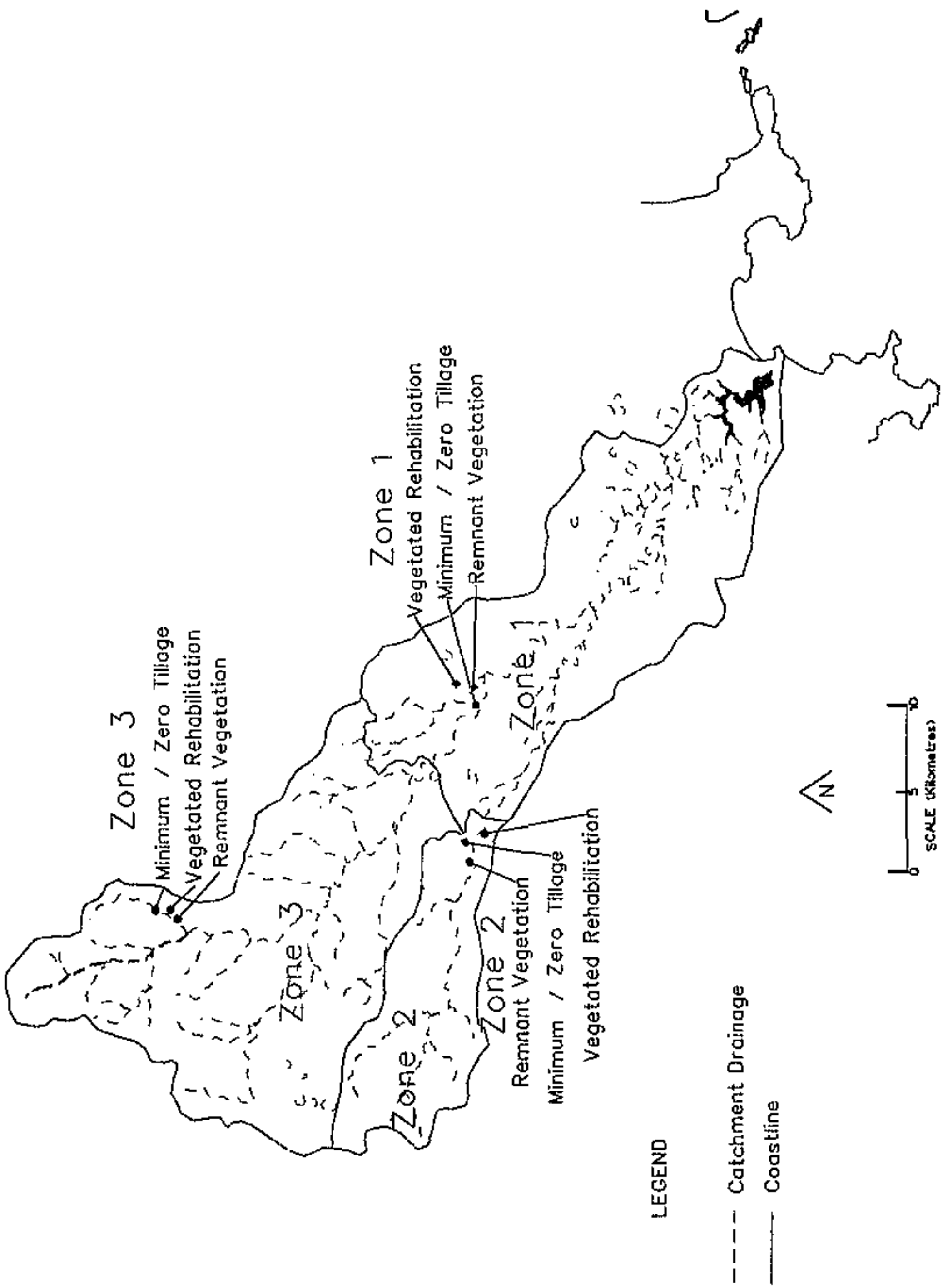

FIGURE 2.4 The location of all runoff sampling sites, in each zone, in the Bremer River catchment.

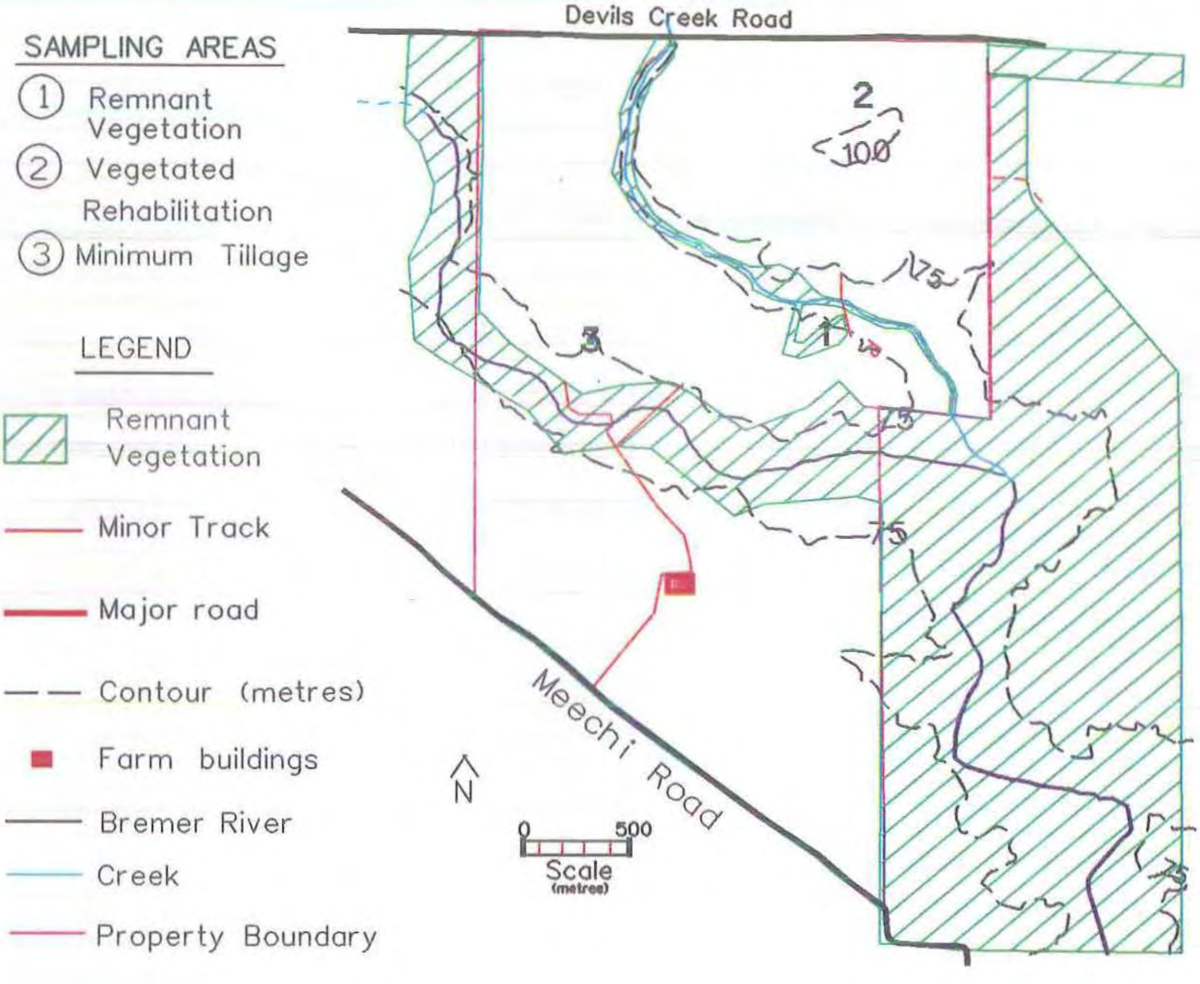

FIGURE 2.5 The location of the runoff sampling sites on Location 1874

2.4.1 Remnant Vegetation.

The size of the Remnant Vegetation area chosen on location 1874 was approximately 5 hectares. The remnant was approximately 1.8 kilometres north of the main farm buildings.

The remnant extended from the top of a slope to mid slope. The area immediately below this had been cleared. The remnant had not been cleared due to presence of poison bush (*Gastrolobium* spp.) Runoff scars, at 2 - 5 centimetres depth, were clearly apparent in the remnant. Replicates were set up on these individual runoff scars approximately 27 metres apart.

2.4.2 Vegetated Rehabilitation

The Vegetated Rehabilitation area chosen on location 1874 was a 58 metre wide buffer strip on a paddock. The buffer strip was approximately 3.2 kilometres north of the main farm buildings.

The remainder of the paddock was under Minimum / Zero Tillage land use. The buffer strip had been sparsely vegetated with Tuart (*Eucalyptus gomphocephala*) and Pistachio (*Pistacia sp.*) trees in 1992 / 93. A contour drain ran along the buffer strip. The drain was approximately 32 metres from the edge of the up slope section of the buffer strip and was approximately 5 metres wide. Runoff scars were apparent leading down into the drain from the up slope section of the buffer strip. Replicates were set up on these individual runoff scars approximately 9 metres apart.

Several sites were inspected prior to the selection of this area. This site was larger than other potential sites and although the potential for interference from the up slope paddock was considered, the width of the buffer strip was anticipated to reduce this potential.

2.4.3 Minimum / Zero Tillage

The Minimum / Zero Tillage area chosen on location 1874 was a major paddock approximately 1.4 kilometres north-west of the main farm buildings.

The paddock extended to the north for approximately 800 metres and was an average of 300 metres wide (in a general east west direction). The paddock was under a 3 year pasture (for sheep grazing) 2 year grain crop (barley) production cycle, with 1996 being the start of the pasture phase. Table 2.7 indicates the fertiliser application regime of the paddock during the last 4 years. Fertiliser was only applied when the paddock was cropped. During this period of time the land owner applied the minimum tillage technique.

Table 2.7

The fertiliser application regime for the minimum tillage paddock on location 1874, zone 1, chosen for runoff sampling.

Year / Month	Fertiliser Name	Amount applied (kg/ha)	Phosphorus component (kg/ha) ●	Nitrogen component (kg/ha) ●
1996	n/a	-	-	-
1995 May / June	Agras	100	7.6	17.5
1995 February	Plain Super	100	9.1	nil
1994 May / June	Plain Super	100	9.1	nil
1993	n/a	-	-	-

● (Source : Rural Traders RTC Fertiliser, N.D.)

N/A None applied

The paddock drained down to the south towards the Bremer River where the landowner had constructed a dam for the collection of runoff water. The dam had a number of apparent runoff scars, 5-11 cm in depth, leading from the paddock. These were considered suitable for runoff collection.

Replicates were set up on these individual runoff scars approximately 7 metres apart ensuring that each runoff scar originated from a different source area. Sheep tracks were apparent around the dam but were approximately 10 metres away from the closest replicate.

2.5 Sampling Areas : Zone 2 Devils Creek

Kent Location 1488, 1366 hectares in area, has been farmed by Mr Keith Jones since 1959. Mr Jones is one of the original farmers of the Bremer River catchment.

Figure 2.1 indicates the location of the sampling sites on Location 1488 in relation to the catchment, zones and other sampling sites. Figure 2.5 shows Location 1488 and the three sampling areas on this property.

2.5.1 Remnant Vegetation.

The Remnant Vegetation site chosen on Location 1488 was part of a riparian strip of native vegetation bordering onto Devils Creek, as indicated in Figure 2.6. The remnant was approximately 900 metres south of the main farm buildings. The remnant was known to the farmer to be extremely salty, with the water table close to the surface. It was for this reason that the remnant had not been cleared. The remnant had, in the past, been grazed by sheep but had been fully fenced for approximately 5 years. Vegetation in the remnant was rather sparsely distributed, with several salt tolerant plant species (eg Chenopodiaceae sp.) present. Runoff scars were clearly apparent throughout the remnant ranging in depth from a few centimetres to half a metre. Replicates were set up on these individual runoff scars approximately 10 - 15 metres apart.

2.5.2 Vegetated Rehabilitation

The Vegetated Rehabilitation area chosen on Location 1488 was an area of relatively undisturbed soil down-slope from an agro-forestry plot. The site was approximately 1.2 kilometres south-east of the main farm buildings. The agro-forestry (alley farming) plot consisted of an eight tree, 14 metre wide *Pinus pinaster* alley. The pine trees were approximately eight years old and were well established. They formed part of an extensive agroforestry plot on the farm. Several runoff scars were apparent leading out of the plot on a 45 degree angle towards a contour drain. The land between the agro-forestry plot and the contour drain had not

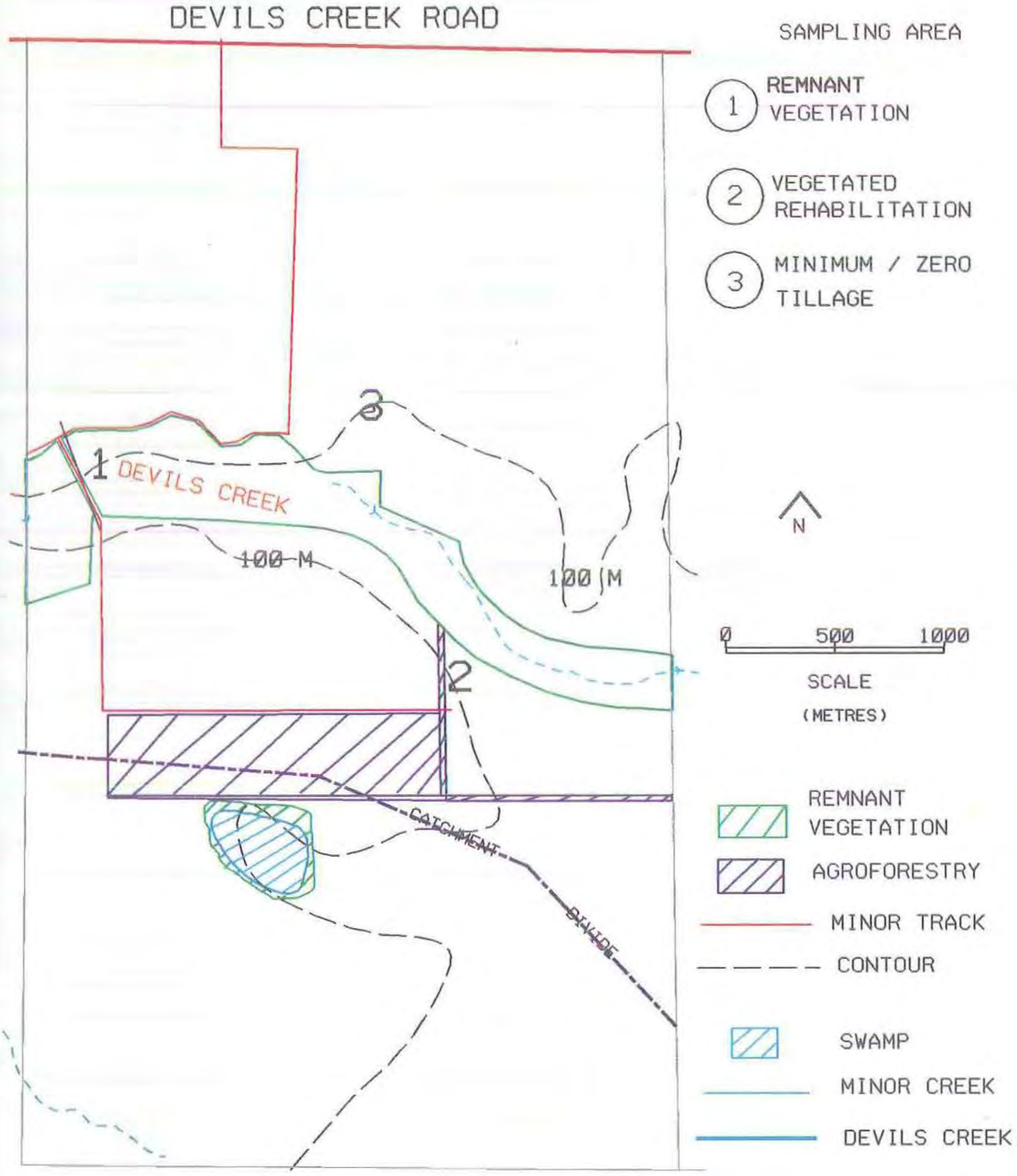

FIGURE 2.6 The location of the runoff sampling sites on location 1488

been cultivated due to its close proximity to the drain and was considered as a relatively undisturbed area of cleared land. Replicates were set up on individual runoff scars approximately 5 metres apart.

2.5.3 Minimum / Zero Tillage

The Minimum / Zero Tillage site chosen on Location 1488 was a major paddock of approximately 20 hectares in area. The paddock was under a 3 year pasture (sheep grazing) 2 year grain crop (lupins or canola) production cycle, with 1996 being the start of the pasture phase. The paddock was relatively undisturbed from any recent stock movement and the crop stubble from the previous year's crop was evident throughout the area. Table 2.8 indicates the fertiliser application regime of the paddock during the last 4 years. Fertiliser was only applied when the paddock was cropped. During this period of time the land owner applied the zero tillage technique to the area.

Table 2.8

The fertiliser application regime for the zero tillage paddock on Location 1488, zone 2, chosen for runoff sampling.

Year	Fertiliser Name	Amount applied (kg/ha)	Phosphorus component (kg/ha) ❶	Nitrogen component (kg/ha) ❶
1996	n/a	-	-	-
1995	Agras no. 1	125	9.5	21.8
	Urea	70	-	32.2
1994	Superphosphate	200	18.2	
	Agras No. 1	45	3.42	7.9
	Urea	100		46
1993	n/a	-	-	-

❶ (Source : Rural Traders RTC Fertiliser, N.D.)

N/A None applied

The paddock sloped gently, in a V shape, down to a pronounced runoff scar (creek) leading into a Stock Dam . Several runoff scars leading towards the pronounced runoff scar were clearly apparent.

Replicates were set up on these individual runoff scars approximately 8 metres apart.

2.6 Sampling Areas Zone 3 : Upper Bremer

Kent Location 1393 and 1396 (1303 and 1395 hectares in size respectively) have been farmed by Mr George Houston since the early 1960s. He is one of the original farmers of the Bremer River Catchment but has now passed on the management of the farm to his son Ross. The farm is managed off site, as Ross lives on a property near Needilup approximately 30 kilometres from the farm. Extensive revegetation of drainage lines has occurred on location 1393 as a result of extensive water logging and potential salinisation problems.

Figure 2.1 indicates the location of the sampling sites on Location 1393 and 1396 in relation to the catchment, zones and other sampling sites. Figure 2.6 shows location 1393 and the three sampling areas on this property.

2.6.1 Remnant Vegetation .

The size of the Remnant Vegetation area chosen on Location 1396 was approximately 20 hectares. As indicated in Figure 2.6, the remnant is approximately 1.5 kilometres from Maringarup road.

The remnant sloped from east to west. The nearest drainage line was at the bottom of the slope. The remnant had not been cleared due to the presence of poison bush (Gastrolobium sp.) and had been fenced off from stock for at least 10 years. A few defined drainage lines were apparent throughout the remnant and leading to these were runoff scars. Replicates were set up on these individual runoff scars approximately 15 metres apart.

2.6.2 Vegetated Rehabilitation

The Vegetated Rehabilitation area chosen on location 1393 was an area of recently (ie 1993) rehabilitated land with sparse plantings of tree seedlings. The site was approximately 710 metres north east of the remnant vegetation area.

The rehabilitated area formed part of an up-slope drainage line. Deep ripping of the soil for the planting of trees was clearly evident. The area was vegetated with sparsely distributed trees and clumps of reeds and sedges. Paddock fences bordering the area had been moved away from the area by approximately 10 metres. The area was

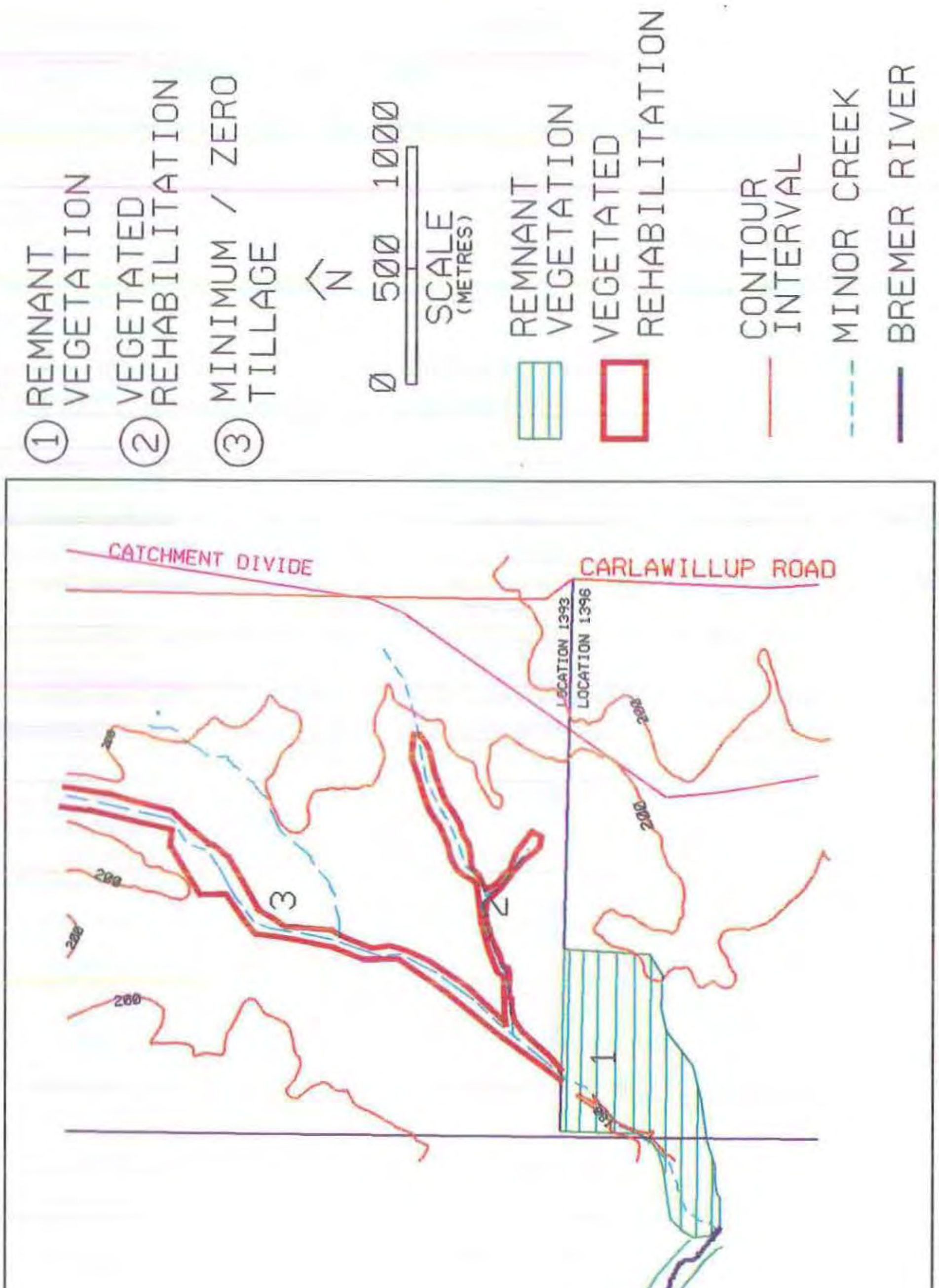

FIGURE 2.7 The location of runoff sampling sites on location 1393 and 1396

fenced off from stock. The exposed ripped soil had a number of runoff scars. Replicates were set up approximately 5 metres apart.

2.6.3 Minimum / Zero Tillage

Several sites were initially viewed as potential areas for runoff collection but had to be abandoned due to the excessive compaction and dryness of the soil which made the set up of each replicate impossible due to the impenetrability of the soil. The site finally chosen was a major paddock greater than 50 hectares in area. The paddock was 1.53 kilometres north east of the Remnant Vegetation land use area.

The paddock was under a 3 year pasture (for sheep grazing), 2 year grain crop (canola) production cycle, with 1996 being the start of the pasture phase. The paddock was relatively undisturbed from any recent stock movement and the crop stubble from the previous years crop was clearly evident throughout the area. Table 2.9 indicates the fertiliser application regime of the paddock during the last 4 years. Fertiliser was only applied when the paddock was cropped. During this period of time the land owner applied the minimum tillage technique to the area.

Table 2.9

The fertiliser application regime for the zero tillage paddock on location 1393, Zone 3, chosen for runoff sampling.

Year / Month	Fertiliser Name	Amount applied (kg/ha)	Phosphorus component (kg/ha) ❶	Nitrogen component (kg/ha) ❶
1996	n/a	-	-	-
1995 / May	Agrich	100	11.4	12
	Urea	50		23
1994 / May	Agrich	100	11.4	12
	Urea	50		23
1993	n/a	-	-	-

❶ (Source : Rural Traders RTC Fertiliser, N.D.)

N/A None applied

The major paddock was divided into three minor paddocks. The minor paddock chosen was approximately 30 hectares in size. The highest point of the paddock was approximately 500 metres away from the chosen sampling area. Several minor (1-2 cm) runoff scars were apparent through the dense stubble. Replicates were set up on these individual runoff scars approximately 12 metres apart.

2.7 Calculation of Source Areas

Runoff scars were all full investigated and replicate placement was made only on runoff scars originating from individual source areas. This procedure ensured that only one source area was sampled per replicate. Runoff scars were fully investigated upon selection. Runoff scars, for the purposes of this study, can be described as areas of soil eroded by water, from minor sheet eroded areas through to larger gully (to a depth of 20 cm).

The calculation of the source area (an area of the paddock from which surface runoff was accumulated and flowed towards a runoff collector) was determined for each replicate by on-site surveying during the initial set up of the runoff collectors.

The calculation process involved determining the length of the runoff scars on which the replicate had been placed using a tape measure. With the aid of a clinometer, and general visual estimation, the area of the land sloping towards the runoff scar, with soil visible movement scars (ie. sheet and rill erosion) indicating this direction, were determined. Using a 100 metre tape measure and guiding post perimeter measurements of this area were then made.

Measurements were then double checked by the researcher and field assistant. Source areas were later calculated using standard geometrical area calculations as described in Maxwell (1957).

As no past methods for the calculation of source area was uncovered during the course of the study, the technique used was considered suitable for the purposes of this study.

Attention must be made to the fact that the source area calculations were made for the extrapolation of the data from the first runoff event only. They were determined assuming that only surface runoff occurred during this event when the, assumed, poor infiltration rates of the soil would have resulted in mainly surface runoff flow (Cullen, 1983). The calculation of source areas of subsequent runoff events were considered impossible to calculate due to the fact once the soils had been moistened both surface and sub-surface flow occurs (Cullen, 1983) effectively expanding the source area.

Results of the calculations appear in Appendix 7.1 showing the source areas calculated for each individual replicate, in each land use area and zone. Figures are recorded to two decimal places.

2.8 Soil Analysis

Soil samples were collected for two main reasons: to provide a general indication of the type, and attributes of, soil from the nine sampling areas, and to make comparisons of the soil from each sampling site before and after the first rainfall event to reveal any changes in the soil chemistry.

2.8.1 Soil sample collection

Soil samples were taken from each sampling area , 9 soil samples in total, at the time of the initial set up of the runoff collectors (soil sampling round one) and during the collection of the first runoff sample (soil sampling round two).

A representative 1 kg soil sample was taken from the top 10 cm (0-10 cm) (Rayment and Higginson, 1992) of the soil profile within the source area of a randomly chosen replicate of each land use area in each zone. In most instances a 2.5 metre long crowbar was used to take the first soil sample, an indication of the initial dryness of the soil. The second round of soil samples were taken using a trowel. Soil samples were placed in large clean plastic bags and sealed.

2.8.2 General soil descriptions

The following attributes were analysed for in the soil samples taken during soil sampling round one :

1. Particle size analysis (using methods described in Black, 1965).
2. Organic matter content (using methods described in Black, 1965).

3. Brief profile descriptions based on field observations and particle size analysis.

In addition, water repellence using methods described in McDonald, Isbell, Speight, Walker and Hopkins (1990) was analysed in both sampling rounds.

Data obtained from the results of a recent soil survey (Overhue, 1995 a,b,c), within close (2 kilometre radial distance) proximity of the sampling areas, were used for comparison to results obtained and previous descriptions. This survey included results on particle size, soil conductivity, soil pH and organic matter content.

2.8.3 Soil change : before and after rainfall event

To give an indication of the changes in soil chemistry following the first runoff event of the year, two soil attributes, pH and conductivity, known to change on a temporal basis (McDonald et al, 1990), were measured from the soil samples. Results could indicate changes in soil chemistry brought on by rainfall and the potential for loss of salt and hydrogen ions to runoff water.

Methods used were :

1. Soil pH using method 4A1 pH of 1:5 soil / water suspension (Rayment and Higginson, 1992)]
2. Soil conductivity using method 3A1 EC of 1:5 soil / water suspension valid at 25°C (Rayment and Higginson, 1992)

As it was not possible to ensure totally homogenous soil samples, replicates were considered necessary for these tests. Five replicates were considered sufficient to give a true representation of each soil attribute.

2.9 Runoff Collectors for Runoff Sampling.

2.9.1 The use of Runoff Plots

Runoff plots in general should only be used for two main reasons. Firstly when the data collected will be used in a comparative study and secondly when the data obtained will be used to construct or to validate a model or equation to predict runoff characteristics or soil loss (Hudson, 1993). These factors corresponded with the main research questions of the project and therefore runoff plots were considered ideally suited for the study. Bounded plots have boundaries (eg. walls, fences or partitions) which limit an area from which runoff and soil are being collected (Hudson, 1993) but in some instances it is considered appropriate to use unbounded plots. Unbounded plots, with no boundaries to limit an area from which runoff and soil are being collected, are usually considered cost effective but have the potential to cause errors when calculating source areas. Another issue concerned the fact that without any boundaries to direct or limit runoff into the trough, the amount of runoff collected will entirely depend upon the occurrence of minor depressions or rills (Hudson, 1993). To address this issue Hudson (1993, p. 33) suggests " ...a larger number of replicates as appropriate to overcome variations which may arise." For the purposes of this study unbounded plots, with replications, were considered cost effective in meeting the objectives of the study.

2.9.2 Runoff Collector Trough

The most appropriate runoff collector initially considered was an automatic sampler (Hudson, 1993) but at an estimated $4000 cost per unit this was beyond the budget of this study.

Four issues were taken into consideration when designing the size and capacity of the sampling system. Firstly the collector system needed to be able to handle the maximum probable rate of flow and secondly store the maximum probable quantity of runoff. Thirdly it needed to preserve the sample for a period of more than one day (but less than three days) due to the fact that the location was 550 km from Perth. Finally it needed to act as a passive sampler that could be set prior to the rainfall/ runoff event awaiting suitable climatic conditions.

A United Nations co-developed method which addresses the above issues is the Gerlach Trough (Hudson, 1993). This is a passive sampling technique which consists of a small collection gutter which is dug into the soil surface and connected to a small collecting container on the downstream side. It is considered inexpensive, in relation to other sampling methods, and uncomplicated in construction and sampling. Low costs result in the ability to set more replicates which can overcome any potential problems which may be encountered and adds power to later statistical testing of results.

Although the basic concept of this sampling technique was adopted for this study, significant alterations were made to adapt the collector to the uses intended. Figure 2.8

details the modified Gerlach trough (runoff collector) used in this study based on its low cost (as indicated in Table 2.10), uncomplicated construction, and its repeatability.

Table 2.10

The components and cost of the modified Gerlach trough.

ITEM	COST ($)
3 Wooden Stakes	2.25
2 Metres fencing wire	2.00
10 litre Polyethylene bucket	0.90
Polyethylene dustpan (trough)	1.95
Polyethylene tubing (2 cm diameter)	0.80
1 Litre Polyethylene Bottle	1.10
40 cm x 40 cm Poly-film plastic sheet	0.50
Wire tie	0.20
1 metre masking tape	0.40
Flagging tape 50 cm	0.20
TOTAL COST PER REPLICATE	10.30

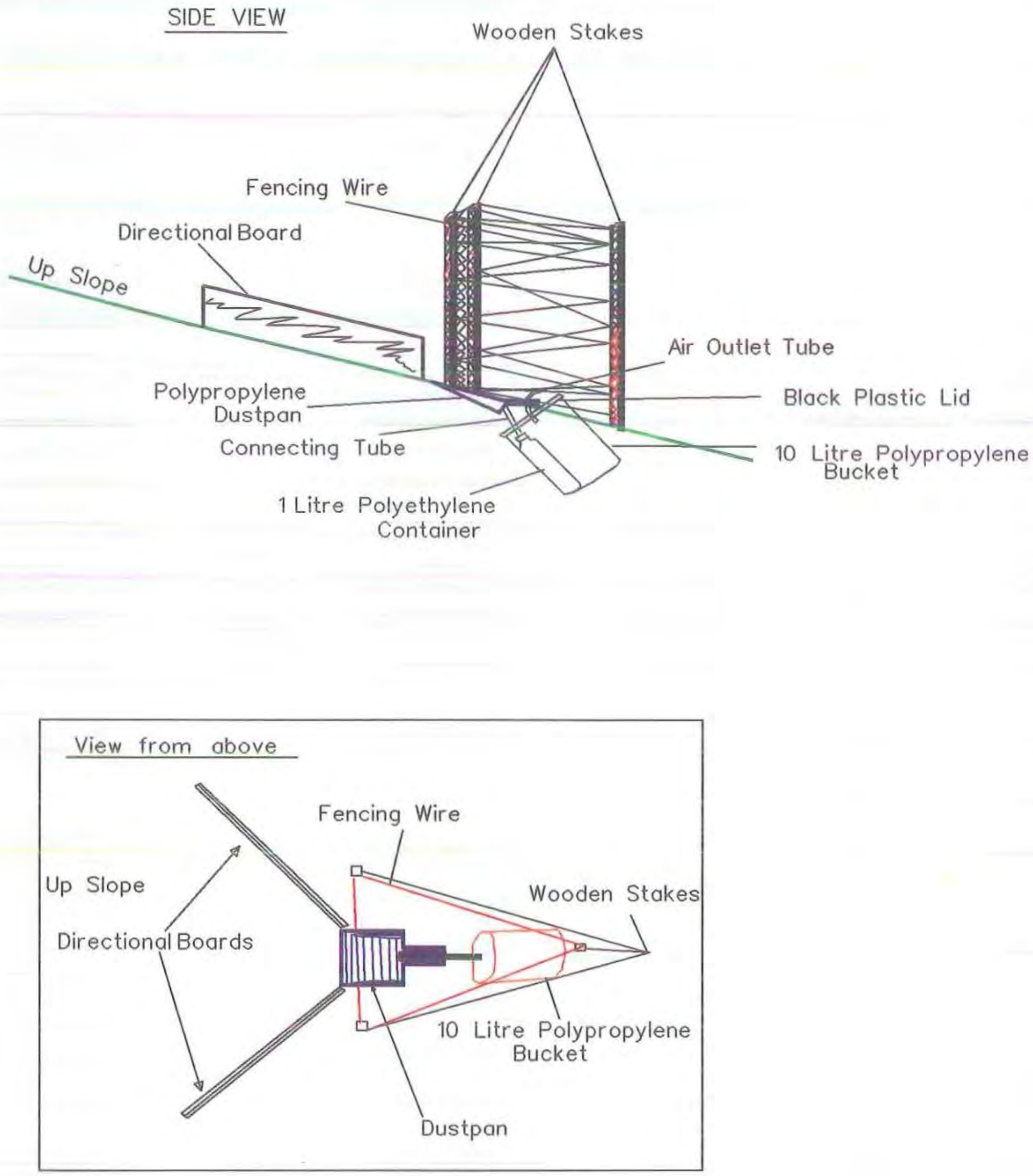

FIGURE 2.8 The modified Gerlach Trough used to sample runoff.

2.9.3 A description of the runoff collector and on-site construction

As mentioned in Section 2.7, a site was chosen where a past runoff scar was apparent. At the site a 10 litre polypropylene plastic bucket (sub-sampler) with a 1 litre decontaminated polyethylene container secured inside was dug into the ground, down slope from the runoff scar and from where the collector trough was placed. The 10 litre bucket acted as a sub-sampler and collected any runoff exceeding the one litre capacity of the sampler. The 1 litre container was used as the main sampler because the polyethylene material was known to have minimal nutrient sorption problems (Rayment and Poplawski, 1992). The collection trough was carefully placed into position ensuring that the trough lip was flush with the ground and that the trough was partially dug into the ground to make use of the sloping form of the dustpan. The dustpan was then connected to the 1 litre polyethylene container via a 0.40 metre length of 2 cm diameter tubing. The bucket was covered with a black poly-film sheet (40 cm by 40 cm) and secured with a wire tie and masking tape to avoid any possible dilution from direct rainfall and any other forms of contamination.

To aid in ensuring that a quantity of water was collected two pre-cut 0.90 metre lengths of Hardiplank ® were used as directional boards. The planks were used to direct water towards the sampling trough.

2.9.4 Replicates.

Having considered unbounded plots of sub-catchment size and the runoff collector to be used, the number of replicates required in each of the three areas in each three zones needed to be defined.

Hudson (1993, p. 5) considered that "for a sample to be representative of the whole population it must be large enough to reflect the variation within the population," believing that the minimum number of replicates required to obtain conclusive results is 3. But with the potential for error and the relative low cost of each runoff collector, 5 replicates were considered sufficient to represent possible variations in measurement and errors. Considering 5 replicates in each of the three land uses, in each of the three zones, a total of 45 replicates were set up.

2.9.5 When to set the runoff collectors

A number of land owners (R. Houston, pers. comm.; K. Jones, pers. comm.; R. Williams, pers. comm.) within the catchment were approached and asked when the season typically broke and when seeding usually occurred. The response unanimously was that middle of May (May 15th on average) was considered the break of the season. In order to ensure that this target day was met, addressing the possibility of rainfall / runoff two weeks before or after this date, runoff collectors were constructed prior to this date. Runoff collectors where set-up between the 19 and 23 of April, 1996. Prior to this date between 32.6 mm (in Zone 3) and 48.5 mm (in Zone 2) had fallen throughout the catchment for the year, with no runoff.

2.10 Sampling of Runoff

Two methods were used for taking the physio-chemical measurements and water samples for later nutrient analysis.

For those runoff collectors in which less than a litre was collected sampling was done directly out of the one litre container after the sample was gently, but thoroughly, shaken to homogenise it.

The second method was applied to those runoff collectors in which amounts greater than one litre was collected with the sample overflowing into the ten litre overflow container. Sampling involved emptying the sample from the one litre container into the 10 litre container. Once this was done the sample was thoroughly shaken to homogenise it and considered ready for taking water samples for nutrients and measuring for water physio-chemical measurements.

2.10.1 Volume

Volume was measured in the one litre container via the 50 ml gradations marked on the side of the container. The volume of runoff sample collected in the ten litre container was measured by 100 ml gradations marked on the side of the container. Measurements were made to 50 ml intervals in both containers. Results were recorded on a field sheet and later input into an Excel 4 spreadsheet.

2.10.2 Total Phosphorus

A 250 ml translucent low density polyethylene container was used to store the runoff water samples for the laboratory analysis of total phosphorus. This form of container is known to produce minimal nutrient sorption problems (Rayment and Poplawski, 1992). Possible contamination of the sample from impurities within the container was avoided by rinsing it with excess runoff water before taking the sample. In the instances where this was not possible the bottle was thoroughly rinsed with deionised water. The decontaminated container was first used to take 250 ml of the sample for filtering for use in the analysis of orthophosphate and total suspended solids. Another 250 ml sample was taken from the runoff collector and placed immediately in a freezer (Clesceri et al, 1989). The freezer was provided by a catchment land owner. The sample was then transported back to Perth in an Esky on ice. Once in Perth the sample was placed in a deep freezer before analysis in the Laboratory. Prior to analysis the sample was defrosted in the Laboratory.

Several methods were considered for the analysis of total phosphorus but the Perchloric Digestion Method (Davies, 1992), was adopted due to the availability of the reagents and the Skalar spectrophotometer which utilised them.

2.10.2.1 Perchloric Digestion Method

This method involved the conversion of organic phosphorus into a mineralised form (orthophosphate) using concentrated perchloric acid. This was achieved by digesting 20 ml of the sample with 0.6 ml of Perchloric acid (5.8 M.) on a block digestor. The block digestor was heated following a program described in Davis (1992). The digested solution was made up to the 20 ml with deionised distilled (DDI) water. The resulting orthophosphate was determined using a single solution method (Skalar, n.d.) using the Skalar auto-analyser spectrophotometer.

Two reagents were used for this method; Ammonium Molybdate (solution as per prescribed components [Skalar, n.d.]); Ascorbic acid reagent (solution as per prescribed components [Skalar, n.d.]). A standard curve was made by using a known standard solution of phosphate (Skalar, n.d.) and then taking five known concentrations of this phosphate solution. Samples were well shaken before being put through the auto-analyser. Selected samples were replicated in the same run and between runs in an attempt to identify any possible sources of error in the readings from the auto-analyser. Minimal differences (<50µg/L) were encountered. Due to high levels of total phosphorus in some samples dilution was necessary. Of those samples that needed dilution, replicates were run, again, in an attempt to identify any possible errors in the readings from the auto-analyser. No great variations were recorded (<100µg/ L) and the means between the replicates were used as the final result.

Figures from the Auto analyser run were then converted to parts per billion (µg/ L) using the correlation of the standard curve. In all cases the standard curve returned a correlation greater than r = 0.999. Final results, in mg/L, were then entered into a Excel 4.0 (Microsoft) spread sheet for data analysis.

2.10.3 Orthophosphate

A single, 125 ml, translucent, low density, polyethylene container was used to store the runoff water sample for the analysis of orthophosphate.

A 250 ml sample was taken out of the runoff collector using the container used for the total phosphorus sample. The sample was then poured into a sterilised filter tower. A GFC Whatmann 45µm glass filter paper was used to filter the sample. This was later used for the Total Suspended Sediment procedure. A hand pump and, in some cases, a mains powered electrical pump were used to filter the sample. Approximately 50 ml of the 250 ml filtered water was then used to decontaminate the 125 ml polyethylene before the container was filled with the filtered sample. The filter paper was carefully placed in a marked sealable plastic bag and together with the sample frozen immediately (Clesceri et al, 1989). The sample was then transported back to Perth in an Esky on ice where it was placed in a deep freezer.

The sample was then defrosted in the Laboratory for the purpose of orthophosphate analysis. The single solution method was also adopted for the actual orthophosphate analysis and procedures were identical to those already described for the Total Phosphorus analysis.

2.10.4 Sediments

The analysis of Total Suspended Sediment in the runoff water sample followed the procedure 2540 D. TOTAL SUSPENDED SEDIMENT DRIED AT 103 - 105 C°

(Clesceri et al, 1989). This procedure was chosen to allow the usage of the filter paper for further analysis of the sample to define mineral and organic components of the total suspended sediment.

The procedure involved pre-treatment of the GFC Whatmann 45µm glass filter paper as per Clesceri et al(1989). The pre-treatment of the filter paper was carried out less than 24 hours before leaving Perth in an attempt to conform with the method described in Clesceri et al (1989).

As previously mentioned, the filter papers were used for the filtering of water samples for the Orthophosphate procedure and frozen after use. Once in the laboratory filter papers were carefully defrosted and analysed for total suspended sediment (T.S.S.) following Clesceri et al (1989). Final results, in mg/L, were then entered into a Excel 4.0 spread sheet for data analysis.

2.10.5 Determining Mineral and Organic components of Total Suspended Sediment

The filter papers were then used to determine the fixed and volatile solids of the total suspended sediment following method 2540 E. Fixed and Volatile Solids Ignited at 550 ° C documented by Clesceri et al (1989).

Final results, in mg/L, were then entered into a Excel 4.0 spread sheet for data analysis.

The results of this procedure should only be used as an approximate guide to these two types of solids as there is potential for error in the analytical procedure. The potential error is associated with the potential loss of volatile solids during the initial drying (Clesceri et al, 1989). The organic and mineral components will always add up to the total suspended sediment figure due to the fact that only one component is actually being measured, the loss of the organic component.

2.10.6 Salt, Total Dissolved Solids (T.D.S.)

Conductivity was measured in the field using a Wissenschäftlich-Technische Werkstätten Conductivity electrode probe meter following methods described in Clesceri et al (1989). Measurements were recorded in µS/ cm after the nutrient samples were taken. In the instances where there was insufficient sample, measurement of conductivity took place prior to the removal of the sample for nutrient analysis. In this instance, prior to measuring, the electrode probes were thoroughly cleaned using deionised water. The measurements were recorded on a field sheet for later input into an Excel spreadsheet. Upon input into the spreadsheet conductivity figures were converted to Salt, Total Dissolved Solids (T.D.S.) in mg/L (ppt) by multiplying the conductivity figure by 0.6 following Williams (1966). This conversion was made for later modelling and extrapolation.

2.10.7 pH

pH was measured in the field using a Wissenschäftlich - Technische Werkstätten pH electrode probe meter following methods described in Clesceri et al (1989). The pH meter was calibrated following manufacturer's instructions, prior to leaving Perth and on a daily basis during the period of time in the field. Ease of access and possible alterations to pH by temperature fluctuations and biological activity justified the measurement of pH in the field. pH measurements were recorded on a field sheet and later input into an Excel spread sheet.

2.11 Data Analysis

There were four main components to the statistical analysis. The first, descriptive statistics, presented the overall results, from both sampling rounds, of each variable from each of the areas in each zone. The second, data normality, analysed the normality of the data from the first sampling round and applied the logarithmic conversion of some results to allow further statistical analysis. The third, correlation calculation, analysed the data from the first sampling round to uncover any relationship or associations between variables. Finally, a series of two factor analysis of variance (ANOVA) tests were performed on the data from the first sampling round to identify trends and to allow for a comparison of results from all variables.

The analysis of the results from the first and second sampling round were dealt with separately due to the fact that they were sampled for two different reasons and had varying degrees of sampling success. The results from the first sampling round were anticipated to be conclusive of the first rainfall / runoff, first flush, event of the year and would allow for the comparison of results between the different land use areas and zones. Sampling success was higher during this event and therefore resulted in the ability to statistically test the data for correlations and the two way factorial analysis of variance. The results from the second sampling round were anticipated to be indicative of post-first flush. Sampling success was lower during this event and therefore resulted in a reduced ability to statistically test the data.

2.11.1 Descriptive Statistics

Utilising the statistical analysis tools of Excel 4 (Microsoft) the mean, variance, standard deviation and standard error of the mean were calculated for each sampling round, for each variable in each area, in each zone.

Results for each sampling round were then presented, separately, via graphs which were constructed in Excel 5 (Microsoft) with standard error bars and mean concentration values expressed.

2.11.2 Normality of Data

The data from the first sampling round had to be reviewed for normality to allow for further statistical analysis. The review concerned the future analysis of the data using parametric statistical techniques (ie correlations and ANOVAs) (Fowler and Cohen, 1990). These techniques make comparisons of the mean from two or more samples assuming that the variances of each are similar enough that the differences between them may be ignored. Where this does not occur the data were considered not normal and in need of transformation. Transformation, which is said to stabilise the variance (Fowler and Cohen, 1990), simply converts the selected raw data into a derivative value. A logarithmic transformation was considered necessary in the cases where the variance of the sample was larger than the mean (Fowler and Cohen, 1990) . Appendix 7.2 details the variance figures which indicated the need for conversion.

To allow for comparison between correlations all the data were thus transformed. Excel 4 was used for this procedure.

2.11.3 Correlations

Assuming that the transformation of all the data had conferred normality, Pearson's correlation statistical calculation was used to identify any relationships between source area (ha), total volume of runoff sample (ml), Total Phosphorus (mg/L), Orthophosphate (mg/L), Total Suspended Solids (mg/L), the mineral and organic component of the total suspended solids (mg/L), pH and salt, (Total Dissolved Solids [mg/L]). These correlations were arranged into seven correlation matrices, as indicated in Table 2.11, using Excel 4 (where matrices 2-7 each used a particular subset of the data used for matrix 1).

Table 2.11

The different combinations of the data from the results of runoff event one used to compiled seven correlation matrices.

Matrix Number	Data used to compile the correlation matrix
Matrix 1	all zones.
Matrix 2	zone 1.
Matrix 3	zone 2.
Matrix 4	zone 3.
Matrix 5	All Remnant Vegetation areas.
Matrix 6	All Rehabilitated Vegetation areas.
Matrix 7	All Minimum / Zero tillage areas.

2.11.4 Analysis of variance

A series of two-way factorial analysis of variance (ANOVA) tests were performed to compare the influence of the two factors, land use (Remnant Vegetation and Minimum / Zero Tillage) and zone (Zones 1,2,3), on the seven dependent variables (Total Phosphorus, Orthophosphate, Total Suspended Sediment, the mineral and the organic component, Salt (Total Dissolved Solids) and pH).

Raw data was initially tested for homogeneity, using the F-Max Test (Ott, 1993). Results of this test, confirming previous tests for normality, indicated that there were problems in the variance of various variables. A logarithmic transformation (Fowler and Cohen, 1990) of all data was therefore carried out to allow further comparisons between all tests. SPSS was the statistical program used to calculate the ANOVAs and to conduct the F-max Test. The ANOVA calculation made by SPSS included a consideration for unequal samples sizes.

The analysis of variance was only applied to the areas under Remnant Vegetation and Minimum / Zero Tillage. The exclusion of Rehabilitated vegetation from this calculation was made due to the fact that this particular land use had too many inherent variables (see Section 2.2.2).

CHAPTER 3

RESULTS

3.1 Rainfall and Runoff

The amount of rainfall that was necessary to produce each rainfall / runoff sampling event was initially unknown. Rainfall figures for Bremer Bay and Jerramungup were monitored on a daily basis, in Perth, between April 25th and July 21st, via the Ozweather Internet site compiled by the James Cook University, Queensland. Constant consultation with the landowners in each zone was also made to ensure that the first, and subsequent, rainfall / runoff events did not go unnoticed. Runoff collectors were checked by the landowner in zone one[1] following heavy rain to ensure no water accumulation within the sampler. This was considered necessary to ensure that the water collected was a product of the rainfall / runoff event sampled, and not more than one event.

3.1.1 Rainfall / Runoff Events

Two rainfall / runoff events were sampled during the period of the study. Figure 3.1 shows the amount of rainfall that fell leading up to the first and second rainfall / runoff sampling events. Both sampled rainfall / runoff events are clearly indicated in the figure by relatively large increments.

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[1] Ideally all landowners should have performed this inspection but the landowner in zone one was the only landowner who was suitably instructed to inspect the sampler without compromising the sampler set up.

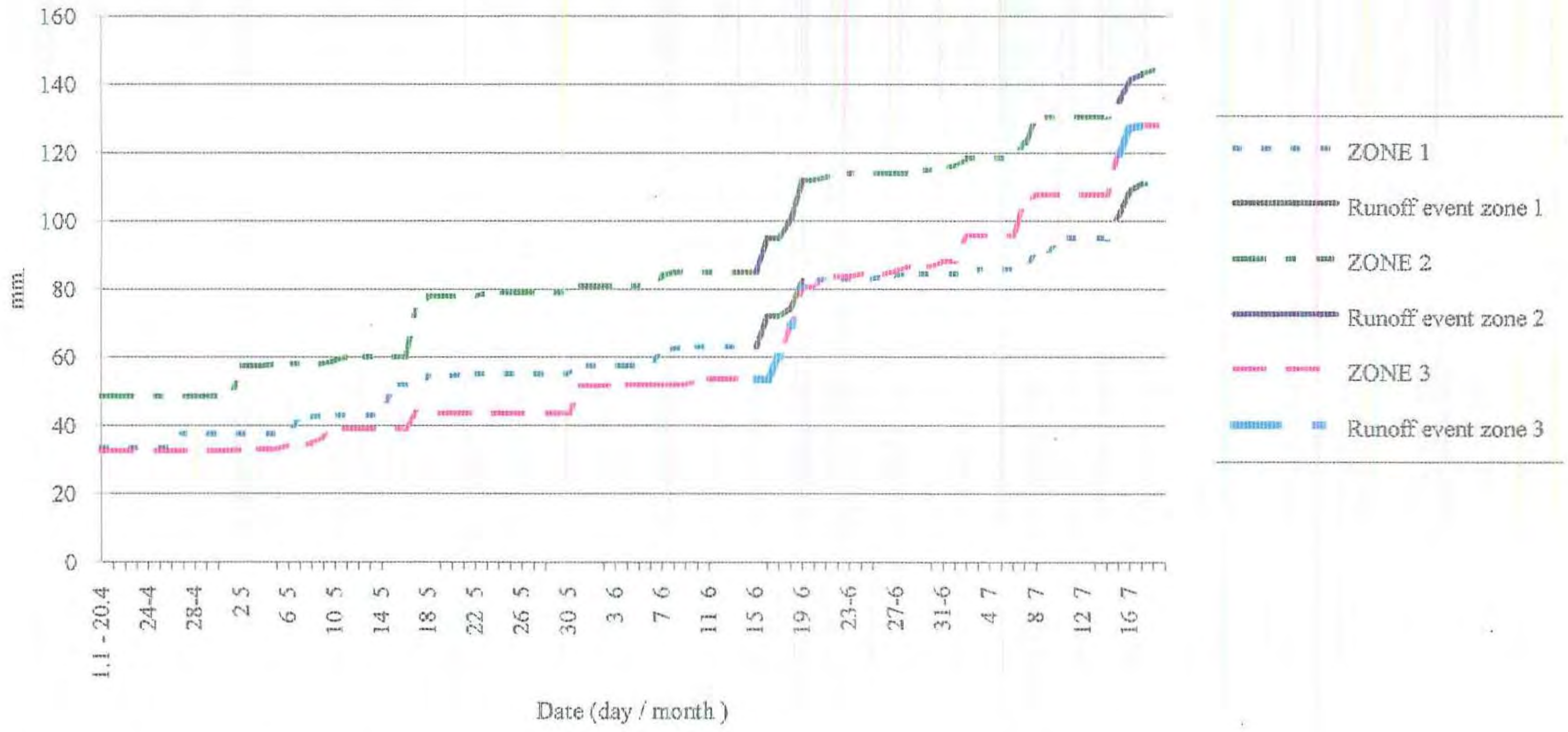

FIGURE 3.1 Line Graph showing the cumulative rainfall from each zone, between April and July 1996, leading up to rainfall events one and two

3.2. Additional environmental information

3.2.1. Low rainfall

Rainfall figures for the study period were well below average. Table 3.1 compares the average April - July monthly rainfall to the 1996 rainfall over this period.

Table 3.1
A comparison between the average and 1996 April - July rainfall figures. Each Zone showed well below average rainfall figures for 1996.

	ZONE 1		ZONE 2		ZONE 3	
	AVERAGE	1996	AVERAGE	1996	AVERAGE	1996
APRIL	16.3	11.5	26.5	12.5	30.8	12.9
MAY	73.1	17	68.5	32.5	49.1	19
JUNE	49	27	54.1	34	49.2	35
JULY	53	32.5	58.5	36.5	51.5	77.4

Note. All measurements in millimetres.

3.2.2. Adverse wind conditions

Additional information not indicated in Figure 3.1 was the prevalence of above average wind speed, intensity and duration experienced throughout most of the sampling period. Figure 3.2 gives an indication of the wind intensity and duration during the month of July. Figure 3.3 indicates the above average wind speeds experienced during the same month when compared to past records.

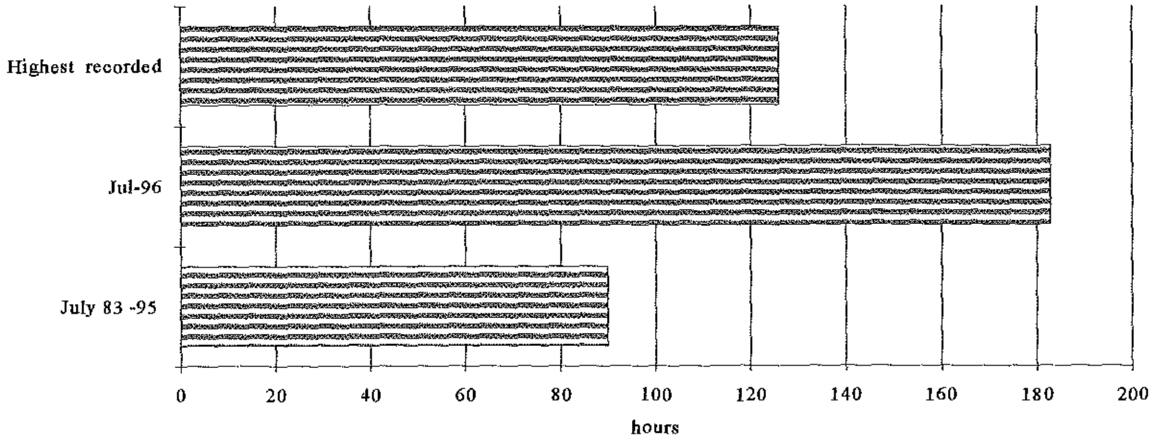

FIGURE 3.2 Bar Graph showing the hours of erosive winds greater than 29 km/hr recorded at the Jerramungup Weather Station.The July average (1983 - 1995), July 1996 results and the previous highest July record are indicated. (SOURCE : Agriculture Western Australia, Jerramungup.)

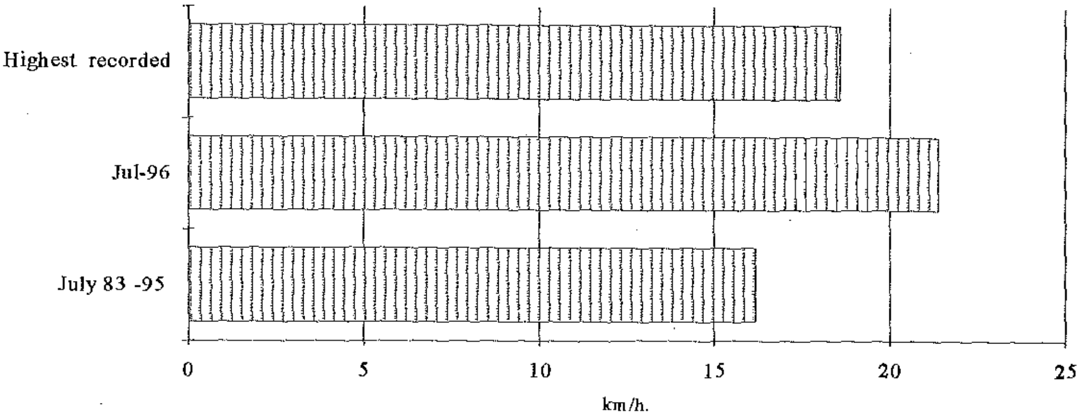

FIGURE 3.3 Bar Graph showing the Average Wind speed for the month of July recorded at the Jerramungup weather station. The July average (1983 - 1995), July 1996 results and the previous highest July record are indicated. (SOURCE : Agriculture Western Australia, Jerramungup.)

3.2.3. Analysis of rainwater

The occurrence of above average wind conditions resulted in excessive top soil mobilisation throughout most of the catchment. The incidence of soil particles in rainwater was considered and addressed by measuring aerial-phosphorus (total phosphorus) and conductivity. Two rain water samples were collected, one each from zone one and two, during the second rainfall / runoff event and later analysed for total phosphorus and conductivity using methods as for runoff samples detailed in section 2.10.2. The results of the analysis of these samples, indicated in Table 3.2, show the presence of total phosphorus. Conductivity concentrations are negligible.

Table 3.2

The results of the analysis of rainwater collected in Zone 1 and Zone 2. Results show low Total Phosphorus concentrations and negligible levels of conductivity.

	ZONE 1	ZONE 2
conductivity	6.2 μS/cm	4.1 μS/cm
aerial phosphorus (total phosphorus)	98 μg/ L	82 μg/ L

3.3 Soils

3.3.1 General soil descriptions

Figure 3.1 indicates the location of the sampling areas in relation to the major soil groups (described by Northcote et al, 1967) of the catchment.

Analysis of the attributes of the soil samples are indicated in Tables 3.3 to 3.5. In Zone 1 soil particle size were described as medium to fine grained, in both the Remnant Vegetation and Vegetated Rehabilitation sampling area, whereas in the Minimum / Zero Tillage sampling area soil particle size were described as medium grained. The Remnant Vegetation area was also dominated by the presence of ironstone throughout its surface and A horizon. In Zone 2 soils with similar particle size occurred throughout the sampled areas. Soils were all described as medium to coarse grained. In Zone 3 soil particle size analysis differed in the Remnant Vegetation sampling area, where the soils were described as coarse to medium grained, to the medium to fine grained soils of the Vegetated Rehabilitation and Minimum / Zero Tillage sampling area.

The results of the soil particle analysis, in general, were comparable to those found in the study by Overhue (1995), but indicated spatial variation in soil groups within individual zones.

The organic matter content of all soil samples were low with results ranging from 1.03% in Zone 3, Remnant Vegetation to 1.88 % in Zone 2, Minimum / Zero Tillage.

In all areas, soils were strongly water repellent before the first runoff event (Soil sampling round one) and non-water repellent following the first rainfall / runoff event (Soil sampling round two).

Table 3.3

The results of the soil sample attribute analysis from all runoff sampling areas in Zone 1.

ZONE 1	PARTICLE SIZE				Org. C. (L.O.I.)	General Description	Water Repellence	
	CS	MS	FS	S/C	%		Before event	After event
Remnant Vegetation	4	32	52	12	1.67	Ironstone / clay	Strongly water repellent	Non water repellent
Vegetated Rehabilitation	9	26	47	18	1.78	Medium to fine sand over clay at 30 cm	Strongly water repellent	Non water repellent
Minimum / Zero Tillage	25	48	25	2	1.19	Medium sand over clay at 10 - 30 cm	Strongly water repellent	Non water repellent
*1	6	33	57	4	1.7			

Key : CS = Coarse Sand; MS= Medium Sand; FS= Fine Sand; S/C= Sand clay; L.O.I.= Loss on ignition.
(*1 = SOURCE : Overhue, T. Soil Survey Sheet, JSI 1151 R. Williams)

Table 3.4

The results of the soil sample attribute analysis from all runoff sampling areas in Zone 2.

ZONE 2	PARTICLE SIZE				Org. C. (L.O.I.)	General Description	Water Repellence	
	CS	MS	FS	S/C	%		Before event	After event
Remnant Vegetation	26	49	16	9	1.51	Medium to Coarse grained sand over clay at 10 - 30 cm	Strongly water repellent	Non water repellent
Vegetated Rehabilitation	24	59	13	4	1.57	Medium to Coarse grained sand over clay at 20 cm	Strongly water repellent	Non water repellent
Minimum / Zero Tillage	28	52	12	8	1.88	Medium grained sand over clay at 10 - 30 cm	Strongly water repellent	Non water repellent
*2	13	41	34	12	1.9			

Key : CS = Coarse Sand; MS= Medium Sand; FS= Fine Sand; S/C= Sand clay; L.O.I.= Loss on ignition.
(*2 = SOURCE : Overhue, T. Soil Survey Sheet , JSI 1144 Cherene 2 G. Hall)

Table 3.5

The results of the soil sample attribute analysis from all runoff sampling areas in Zone 3.

	PARTICLE SIZE				Org. C. (L.O.I.)	General Description	Water Repellence	
ZONE 3	CS	MS	FS	S/C	%		Before event	After event
Remnant Vegetation	32	47	7	4	1.03	Coarse to medium grained sand over clay at 20 cm	Strongly water repellent	Non water repellent
Vegetated Rehabilitation	19	39	28	14	1.40	Medium to fine grained sandy loam over clay at 10 cm	Strongly water repellent	Non water repellent
Minimum / Zero Tillage	5	42	35	18	1.04	Medium to fine grained sandy loam over clay at 10 - 20 cm	Strongly water repellent	Non water repellent
*3	19	38	35	8	1.3			

Key : CS = Coarse Sand; MS= Medium Sand; FS= Fine Sand; S/C= Sand clay; L.O.I.= Loss on ignition.
(*3 = SOURCE : Overhue, T. Soil Survey Sheet, JSI 1139 Couranga K. Thomas.)

3.3.2 Changes in soil pH

The analysis of the soil samples before the first rainfall / runoff event and after the first rainfall event show that soil pH levels both increased and decreased in land use areas. Figure 3.4 indicates this pattern in pH levels. A large increase in soil pH levels in the Remnant Vegetation area, Zone 1, was noted after the first rainfall / runoff event.

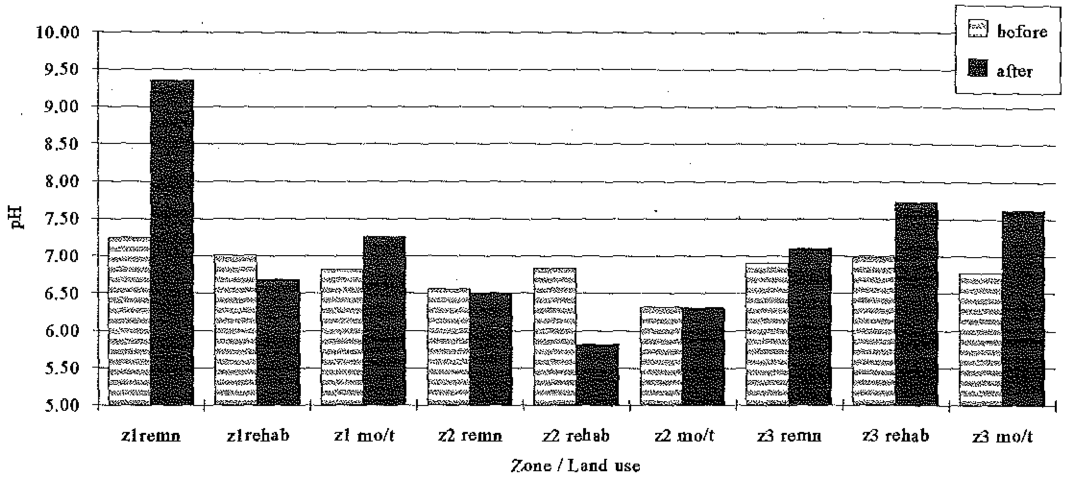

FIGURE 3.4 Column graph showing the results of the Soil pH from all land use areas, taken before the first runoff event and immediately after the first runoff event.
KEY: z1-z3 = Zone 1, Zone 2, Zone 3; remn = Remnant Vegetation; rehab= Vegetated Rehabilitation; mo/t = Minimum / Zero Tillage .

3.3.3 Changes in soil conductivity

The analysis of the soil samples before the first rainfall / runoff event and after the first rainfall event show that soil conductivity decreased in all areas. Figure 3.5 indicates the varying amount of decrease in conductivity throughout the sampled sites. A significant decrease in soil conductivity concentrations in the Remnant Vegetation area, Zone 2 is the most distinguishable change.

The decrease in conductivity can be linked with the loss of salts during the first runoff event. Comparisons between the loss of salts in the soil and the concentrations of salt in the runoff water samples for the first runoff event should be possible.

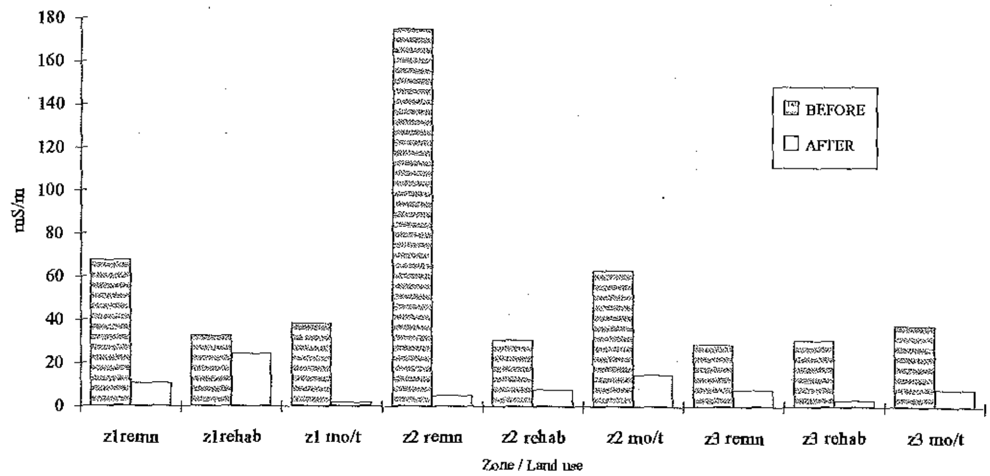

FIGURE 3.5 Column graph showing the mean Soil Conductivity from all land use areas, taken before the first runoff event and immediately after the first runoff event.
KEY: z1-z3 = Zone 1, Zone 2, Zone 3; remn = Remnant Vegetation; rehab= Vegetated Rehabilitation ; mo/t = Minimum / Zero Tillage.

3.4 Runoff Event One

Table 3.6 indicates the spatial variability of the first rainfall / runoff event. During the first event zone two had the largest amount of rainfall with 28mm over 4 days. Zone 1 had the lowest amount of rainfall. The runoff yield calculations, made using methods described in Hudson et al (1993, p 115), indicated that all zones had sufficient rainfall to cause runoff. Zone 2 had the largest amount of calculated runoff whilst zone 1 had the lowest amount of calculated runoff.

Table 3.6

Rainfall occurred over a number of days in June to produce the first rainfall / runoff event, as indicated by runoff yield results .

ZONE	16.6 (mm)	17.6 (mm)	18.6 (mm)	19.6 (mm)	20.6 (mm)	Total (mm)	RUNOFF YIELD
1	9	0	2.5	8	0	19.5 / 4 days	1.52 mm
2	10	0	5.5	11.5	0	28 / 4 days	4.76 mm
3	0	6.6	9	11.3	0	26.9 / 3 days	4.27 mm

3.4.1 Sampling runoff collected

Sampling commenced two days after the last rain day and was carried out over a three day period as indicated in Table 3.7 .

Table 3.7

The sample collection regime for the first rainfall / runoff event occurred over a three day period.

ZONE	Friday 21.6	Saturday 22.6	Sunday 23.6
1	Vegetated Rehabilitation Remnant Vegetation	Minimum / Zero Tillage	
2			Remnant Vegetation Vegetated Rehabilitation Minimum / Zero Tillage
3		Remnant Vegetation Vegetated Rehabilitation Minimum / Zero Tillage	

All runoff sampling areas were successful at collecting runoff (see Table 3.8). Rainfall variability throughout the catchment influenced the success of the individual runoff sampler and the volume of water collected. Figure 3.6 indicates that some runoff samplers did not collect any runoff whilst the largest volume collected was 5100 mls in replicate 4, zone 2 rehablitated vegetation.

Zone 2 which had the most rainfall of the sampled event subsequently had greater sampling success (Table 3.8) and collected, in general, larger volumes of runoff.

Table 3.8

Number of replicates in which water collected was collected in the modified Gerlach trough, enabling sampling of zones and land use areas after rainfall / runoff event one.

	Remnant Vegetation	Vegetated Rehabilitation	Minimum / ZeroTillage.	Total
ZONE 1	3	5	5	13
ZONE 2	4	5	5	14
ZONE 3	3	2	4	9
	10	**12**	**14**	**36**

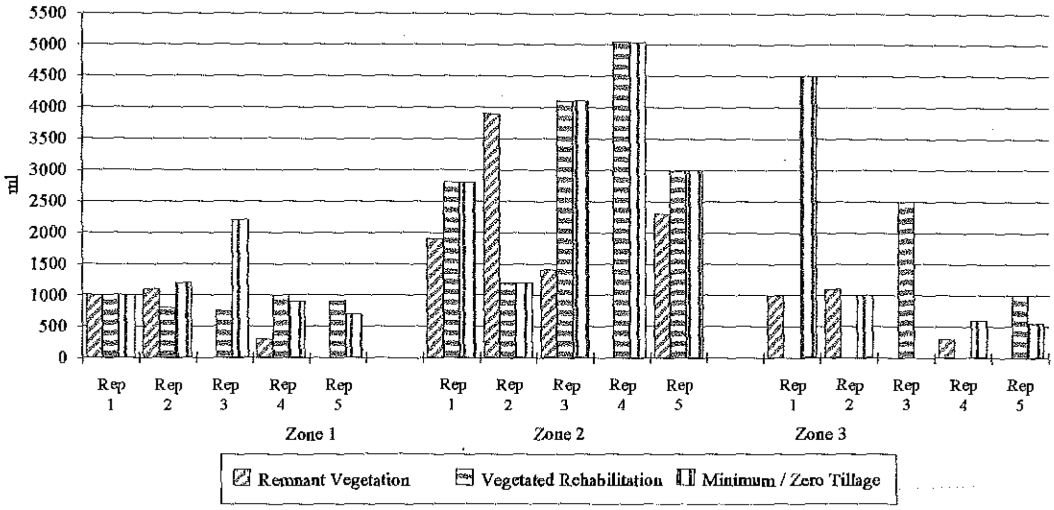

FIGURE 3.6 Column graph showing the runoff volume collected from each replicate, for all zones following runoff event one.
Key : Rep # = Replicate.

3.5 Runoff Event Two

After the collection of runoff samples from runoff event one the runoff collectors were cleaned with a combined Hydrochloric acid and distilled water (DDI) wash. The collection samplers were then set up for the next runoff event. Consultation with the landowners in each zone was again necessary to ensure that the runoff collectors were not accumulating rainfall within the sampler and that the next sample would be from the next runoff event.

Table 3.9 indicates the spatial variability of the second rainfall / runoff event. Zone 2 had the lowest falls. This resulted in no runoff yield in the zone and thus no collection. Zone 1 had similar rainfall to zone 2 but this fell over a three day period and resulted in some runoff yield (Hudson et al, 1993). Zone 3 had the largest amount of rainfall and the highest calculated amount of runoff yield.

Table 3.9

Rainfall occurred over a number of days in July to produce the second rainfall / runoff event. Zone 2 had low rainfall over a four day period resulting in no runoff.

ZONE	15.7 (mm)	16.7 (mm)	17.7 (mm)	18.7 (mm)	19.7 (mm)	TOTAL (mm)	RUNOFF YIELD
1	6.5	7.5	2	0	0	16 / 3 days	0.65 mm
2	0	4.5	6.5	1.5	1.5	14 / 4 days	0.296 mm
3	0	12	7.6	0.8	0	20.4 / 4 days	1.79 mm

3.5.1 Sampling runoff collected

Sampling commenced one day after the last rain day and was carried out over a three day period as indicated in Table 3.10.

Table 3.10

The sample collection regime for the second rainfall / runoff event occurred over a three day period.

Zone	Friday 19 th July 1996	Saturday 20th July 1996	Sunday 21st July 1996
1	Vegetated Rehabilitation Remnant Vegetation	Minimum / Zero Tillage	
2			Minimum / Zero Tillage Remnant Vegetation Vegetated Rehabilitation
3		Minimum / Zero Tillage Vegetated Rehabilitation Remnant Vegetation	

All runoff sampling areas in zone 1 and 3 were successful at collecting runoff (see Table 3.11). As indicated in Figure 3.7, rainfall figures lower than the first rainfall / runoff event resulted in generally lower volumes of runoff being collected. Several runoff collecters in these two zones were unsuccessful whilst the largest volume collected was

6100 mls in replicate 5, Zone 1 remnant vegetation. To note is the large volumes collected in the remnant vegetation areas of zone 1. Other land use areas of this zone had considerably smaller volumes of runoff collected.

Table 3.11

Sampling success of zones and land use areas following rainfall / runoff event two.

	Remnant Vegetation	Vegetated Rehabilitation	Minimum tillage.	Total
ZONE 1	4	3	5	12
ZONE 2	0	0	0	0
ZONE 3	1	1	3	5
TOTAL	**5**	**4**	**8**	**17**

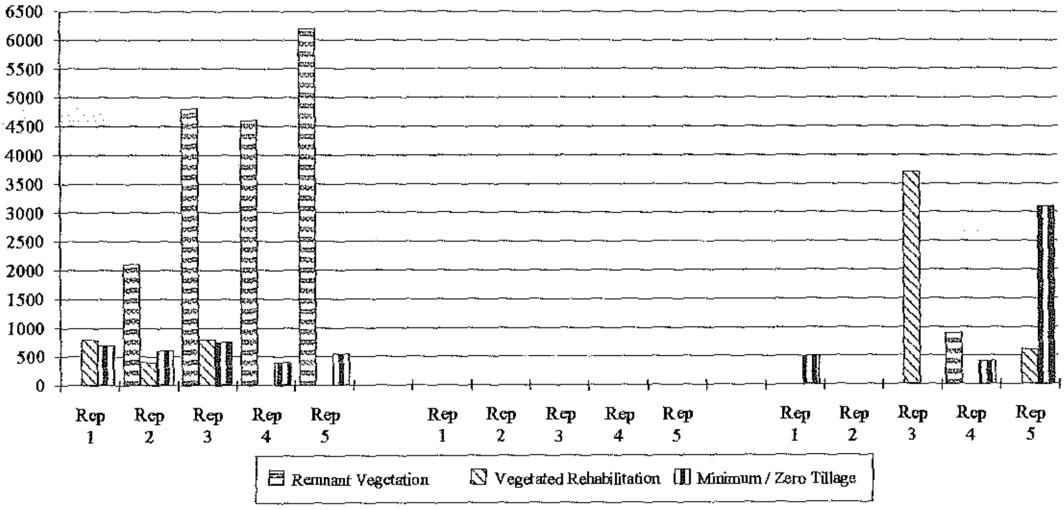

Figure 3.7 Column graph showing the runoff volume collected from each replicate, for all zones following runoff event two. Key : Rep # = Replicate.

3.6 Statistical testing of results

The analysis of the results from the first and second sampling round were dealt with separately due to the fact that they were sampled for two different reasons and had varying degrees of sampling success.

Sampling success was higher during the first event and therefore resulted in the ability to statistically test the data for correlations and analysis of variance. Raw data for all variables measured for in runoff water samples for Runoff Event One appear in Appendix 7.3.

Sampling success was lower during the second event and therefore resulted in a reduced ability to statistically test the data. Raw data for all variables measured for in runoff water samples for Runoff Event Two appear in Appendix 7.4.

3.7 Descriptive Results

3.7.1 Total Phosphorus

The results of Total Phosphorus indicate higher mean concentrations between land use areas in the first runoff event compared to the second runoff event (see Figure 3.8). The highest mean concentrations in runoff event one were in areas of Minimum / Zero Tillage. The lowest mean concentrations of Total Phosphorus occurred in the Remnant Vegetation land use. In concentrations for this runoff event ranged from a low of 0.100 mg/ L in replicate 1, Zone 2, of the Remnant Vegetation land use to a high of 4.762 mg/L in replicate 3, Zone 2, of the Minimum / Zero Tillage land use.

The highest mean concentration in runoff event two were in the Minimum / Zero tillage land use in Zone 1. Total Phosphorus mean concentrations were considerably lower in both Remnant Vegetation and Vegetated Rehabilitation areas of this zone. Total Phosphorus concentrations in Zone 3, although relatively low, were highest in the Minimum / Zero Tillage land use and lowest in the Remnant Vegetation land use. In general figures for runoff event two ranged from a low of 0.049 mg/ L in replicate 2, Zone 1 of the Remnant Vegetation land use to a high of 2.575 mg/L in replicate 4, Zone 1 of the Minimum / Zero Tillage.

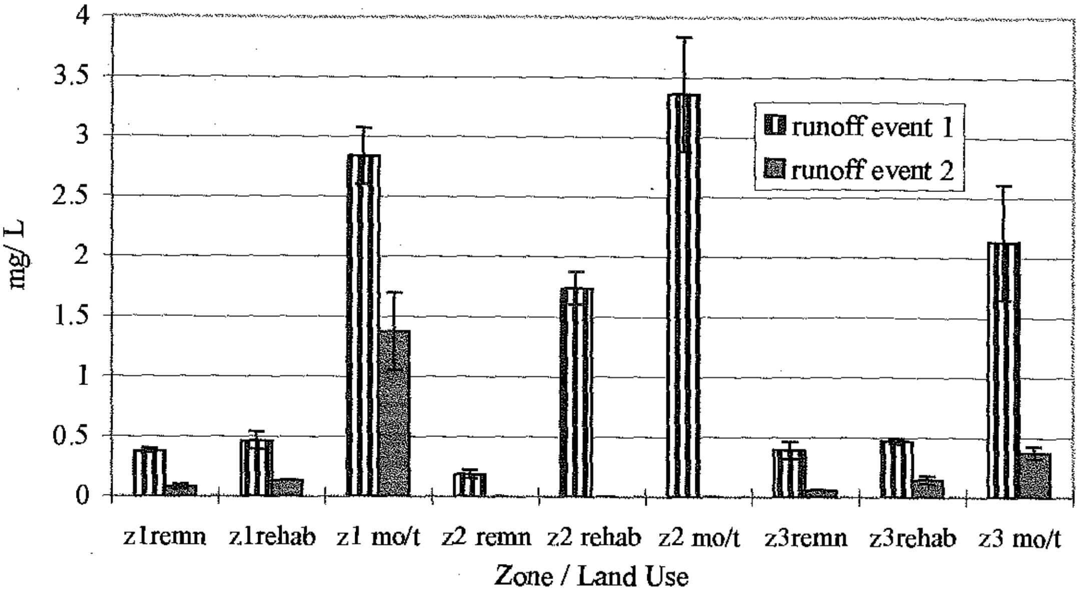

FIGURE 3.8 Column graph showing the mean concentrations and standard error of Total Phosphorus in runoff samples from runoff event one and two. Differences in concentrations are apparent between land use areas.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.1.1 Analysis of variance

The results for the two way factorial analysis of variance test calculated using the Total Phosphorus data from the first runoff event appear in Table 3.12. Results indicate a very highly significant difference between the higher mean concentrations in the Minimum / Zero Tillage land use compared to lower mean concentrations in Remnant Vegetation land use.

Table 3.12

The results for the two way factorial analysis of variance test calculated using remnant vegetation and minimum / zero tillage total phosphorus data from the first runoff event.

Source of Variation	df.	SS.	F	Significance of P
ZONE	2	1.05	1.14	N/S
LAND USE	1	33.98	73.77	###
ZONE by LAND USE	2	2.00	2.17	N/S
RESIDUAL	17	7.83		

KEY
N/S - Not significant
- P <0.001 (very highly significant)

3.7.2 Orthophosphate

Orthophosphate, a component of total phosphorus, also clearly indicates differences in mean concentrations between land use areas in both rainfall / runoff event one and two. The highest mean concentrations for the first runoff event, as indicated in Figure 3.9, occurred in the Minimum / Zero tillage land use areas. The lowest mean concentrations of Orthophosphate occurred in the Remnant Vegetation land use areas. In general figures for the first rainfall / runoff event ranged from a low of 0.016 mg/ L in replicate 2, Zone 2, of the Remnant Vegetation land use to a high of 3.364 mg/L in replicate 3, Zone 2, of the Minimum / Zero Tillage land use.

Orthophosphate mean concentrations in runoff event two were considerably lower than runoff event one. The highest mean concentration of Orthophosphate was in the Minimum / Zero tillage land use in Zone 1. Orthophosphate concentrations were considerably lower in both Remnant Vegetation and Vegetated Rehabilitation areas of this zone. Orthophosphate concentrations in Zone 3 were highest in the Minimum / Zero Tillage land use and the lowest in the Remnant Vegetation land use. In general figures for the second runoff event ranged from a low of 0.018 mg/ L in replicate 4, Zone 1 of the Remnant Vegetation land use to a high of 1.798 mg/L in replicate 4, Zone 1 of the Minimum / Zero Tillage land use.

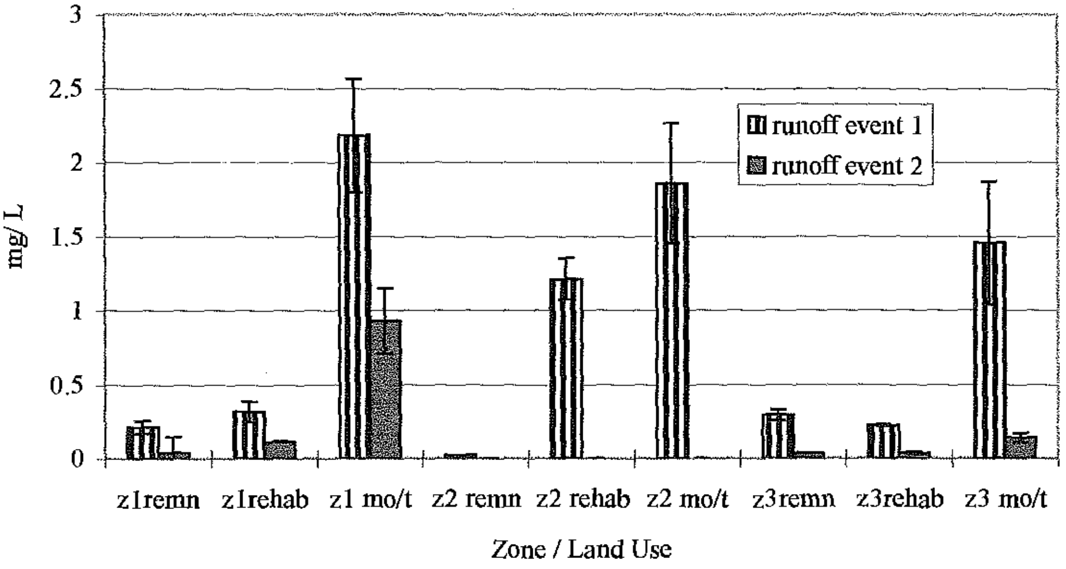

FIGURE 3.9 Column graph showing the mean concentrations and standard error of Orthophosphate in runoff samples from runoff event one and two. To note are the differences in mean concentrations between land use areas.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.2.1 Analysis of variance

The results of the two way factorial analysis of variance test calculated using the Orthophosphate data from the first runoff event appear in Table 3.13. Results indicate a very highly significant difference between the higher mean concentrations in the Minimum/ Zero Tillage land use areas compared to the lower mean concentrations in Remnant Vegetation land use areas.

Table 3.13

The results for the two way factorial analysis of variance test calculated using the remnant vegetated and minimum / zero tillage orthophosphate data from the first runoff event.

Source of Variation	df.	SS.	F	Significance of P
ZONE	2	0.40	0.43	N/S
LAND USE	1	15.22	32.97	###
ZONE by LAND USE	2	0.65	0.70	N/S
RESIDUAL	17	7.85		

KEY
N/S - Not significant
- P < 0.001 (very highly significant)

3.7.3 Total Suspended Sediment

Total Suspended Sediment (T.S.S.) displays a difference in mean concentrations beween the different land use areas in both rainfall / runoff event one and two, as indicated in Figure 3.10.

In rainfall / runoff event one the Vegetated Rehabilitation land use has, in general, the highest mean concentrations although in zone 2 the mean concentration is relatively low. The lowest mean concentrations occur in the remnant vegetation areas. In general figures for the first rainfall / runoff event ranged from a low of 110 mg/ L in replicate 4, Zone 1 of the Remnant Vegetation land use to a high of 1531 mg/ L in replicate 1, Zone 2 of the Minimum / Zero Tillage land use.

In rainfall / runoff event 2 the Vegetated Rehabilitation land use areas has, in general, the highest mean concentrations although in Zone 1 the mean concentration is considerably lower than Zone 3. Mean concentrations in these areas are both higher than the first rainfall / runoff event. The lowest mean concentrations occurred in the Remnant Vegetation areas. In general figures for the second rainfall / runoff event ranged from a low of 136 mg/ L in replicate 3, Zone 1, of the Remnant Vegetation land use to a high of 903 mg/ L in replicate 5, Zone 3, of the Minimum / Zero Tillage land use.

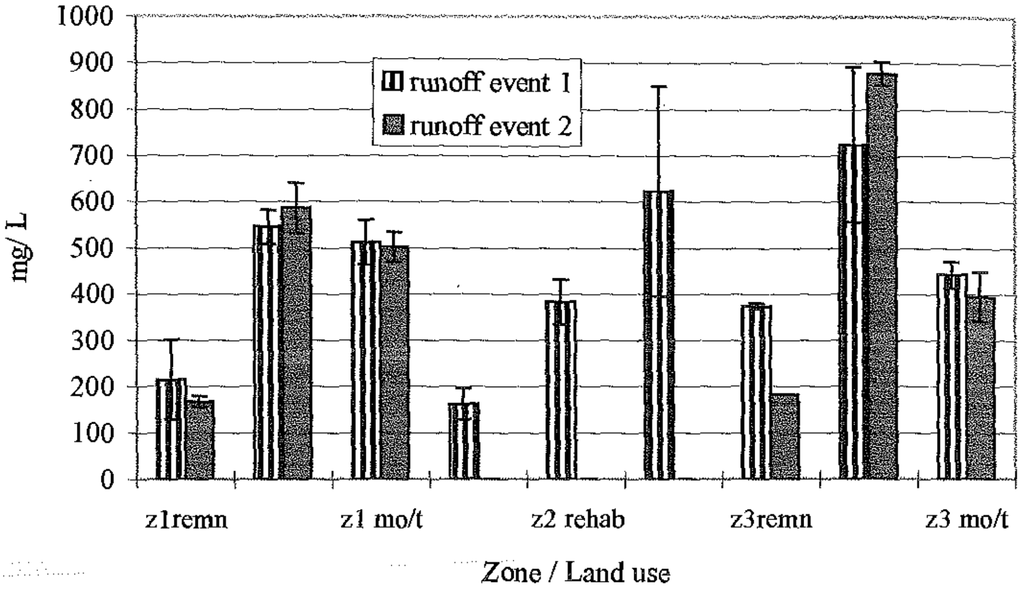

FIGURE 3.10 Column graph showing the mean concentrations and standard error of Total Suspended Sediment in runoff samples from runoff event one and two.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.3.1 Analysis of variance

The results for the two way factorial analysis of variance test calculated using the Total Suspended Sediment data from the first rainfall / runoff event appear in Table 3.14. Results indicate a very highly significant difference between the higher mean concentrations in the Minimum / Zero Tillage land use compared to the lower mean concentrations in the Remnant Vegetation land use.

Table 3.14

The results for the two way factorial analysis of variance test calculated using the remnant vegetation and minimum / zero tillage total suspended sediment data from the first runoff event.

Source of Variation	df.	SS.	MS.	F	Significance of P
ZONE	2	0.45	0.22	1.12	N/S
LAND USE	1	3.85	3.85	19.28	###
ZONE by LAND USE	2	1.39	0.70	3.49	N/S
RESIDUAL	17	3.39			

KEY
N/S - Not significant
- P <0.001 (very highly significant)

3.7.4 Mineral and Organic component of Total Suspended Sediment : Runoff Event One

Figure 3.11 shows the mean concentrations of the Mineral and Organic matter components that make up the Total Suspended Sediment in rainfall / runoff event one. In all instances the mean organic matter content was lower than the mean Mineral content. To note is the generally larger organic matter content in Zone 2.

Concentrations of the organic component of the Total Suspended Sediment ranged from a low of 11 mg/ L in replicate 4, Zone 3, of the Remnant Vegetation land use, to a high of 1113mg/ L in replicate 1, Zone 2, of the Minimum / Zero Tillage land use.

Concentrations of the mineral component of the Total Suspended Sediment ranged from a low of 47 mg/ L in replicate 1, Zone 2 of the Remnant Vegetation land use, to a high of 788 mg/ L in replicate 2, Zone 3 of the Minimum / Zero Tillage land use.

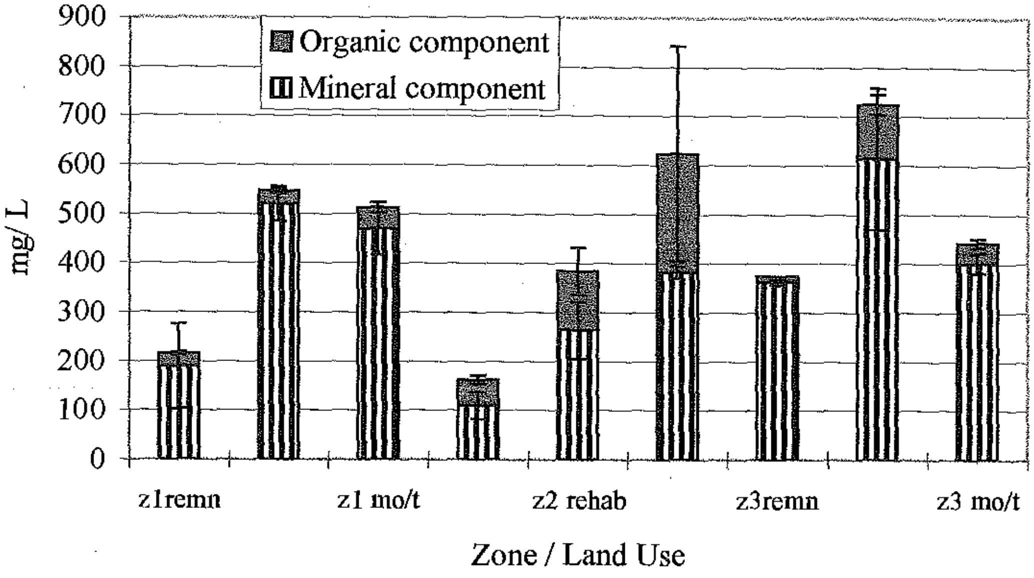

FIGURE 3.11 Column graph showing the mean concentrations and standard errors of the Mineral and the Organic components that make up the Total Suspended Sediment in runoff samples from runoff event one. In all instances the mean organic matter content was lower than the mean Mineral content.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.4.1 Analysis of variance

The results for the two factorial analysis of variance test calculated using the mineral component of total suspended sediment data from the first rainfall / runoff event appear in Table 3.15. Results indicate both a very highly significant difference between the higher mean concentrations in the Minimum / Zero Tillage land use compared to the lower mean concentrations in the Remnant Vegetation land use and a significant difference between mean concentrations in all zones.

Table 3.15
Results of the two way factorial analysis of variance test calculated using the remnant vegetation and minimum / zero tillage mineral component of total suspended sediment data from the first runoff event.

Source of Variation	df.	SS.	F	Significance of P
ZONE	2	1.63	5.17	#
LAND USE	1	4.07	25.74	###
ZONE by LAND USE	2	1.60	5.05	N/S
RESIDUAL	17	2.69		

KEY
N/S - Not significant
- P < 0.05 (significant)
- P <0.001 (very highly significant

The results for the two factorial analysis of variance test calculated using the organic component of total suspended sediment data from the first rainfall / runoff event appear in Table 3.16. Results indicate no significant difference in results between land uses and zones.

Table 3.16

Results of the two way factorial analysis of variance test calculated using the remnant vegetation and minimum / zero tillage organic component of total suspended sediment data from the first runoff event.

Source of Variation	df.	SS.	F	Significance of P
ZONE	2	1.93	0.96	N/S
LAND USE	1	0.58	0.58	N/S
ZONE by LAND USE	2	1.51	0.75	N/S
RESIDUAL	17.17	17		

KEY
N/S - Not significant

3.7.5 Mineral and Organic component of Total Suspended Sediment : Runoff Event Two

Figure 3.12 shows the mean concentration of the Mineral and Organic matter components that make up the Total Suspended Sediment from runoff event two. Similar to runoff event one, in all instances the mean organic matter content was considerably lower than the mean Mineral content. Ratios of the Mineral and Organic components of Total Suspended Sediment in rainfall / runoff event two remain similar to those of rainfall / runoff event one.

Concentrations of the Organic component of the Total Suspended Sediment ranged from a low of 23 mg/ L in replicate 3, Zone 1 of the Remnant Vegetation land use to a high of 183 mg/ L in replicate 5, Zone 3 of the Minimum / Zero Tillage land use.

Concentrations of the Mineral component of the Total Suspended Sediment ranged from a low of 105 mg/ L in replicate 3, Zone 1 of the Remnant Vegetation land use to a high of 720 mg/ L in replicate 2, Zone 3 of the Vegetated Rehabilitation land use.

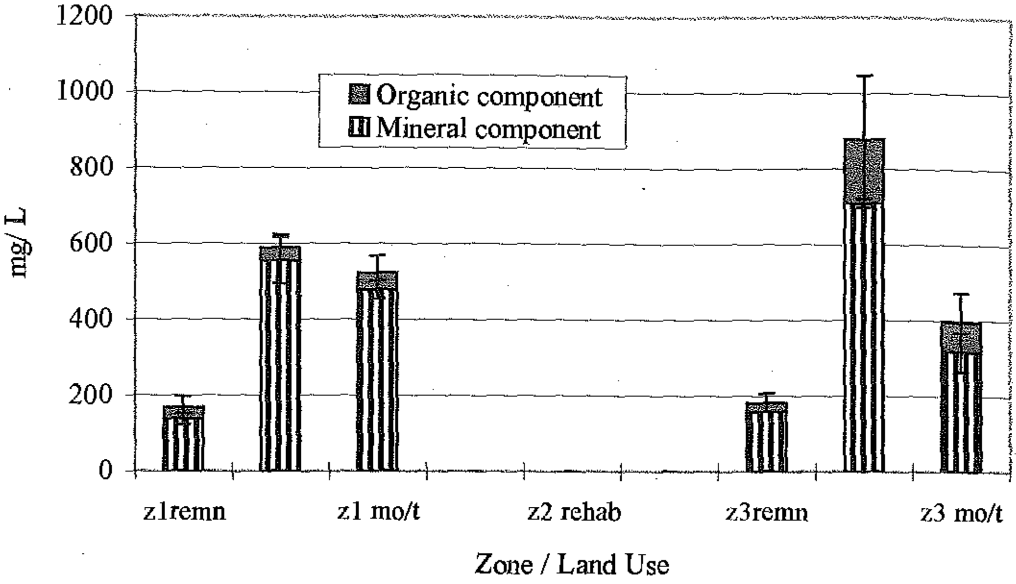

FIGURE 3.12 Column graph showing the mean concentrations and standard errors of the Mineral and the Organic components that make up the Total Suspended Sediment in runoff samples from the runoff event two.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.6 Salt (Total Dissolved Solids)

The results of Total Dissolved Solids appear to have no particular pattern or distinct high or low concentrations in a particular land use areas in both runoff event one and two (see Figure 3.13).

In rainfall / runoff event one the highest mean concentrations occurred in zone 2 remnant vegetation. Total Dissolved Salts figures ranged from a low of 26 mg/ L in Zone 3, replicate 1 of the Remnant Vegetation land use, to a high of 1602 mg/ L in Zone 2, replicate 5, of the Remnant Vegetation land use.

In rainfall / runoff event two mean concentrations in zone one are, generally, greater than those in zone 3. In general figures for Total Dissolved Solids range from a low of 46 mg/ L in Zone 3, replicate 5, of the Minimum / Zero Tillage land use to a high of 234 mg/ L in Zone 1, replicate 2, of the Vegetated Rehabilitation land use.

The inconsistency of any real pattern raises an issue in regards to the effects of salt in runoff as a contributor to the apparent salinisation problems in the catchment.

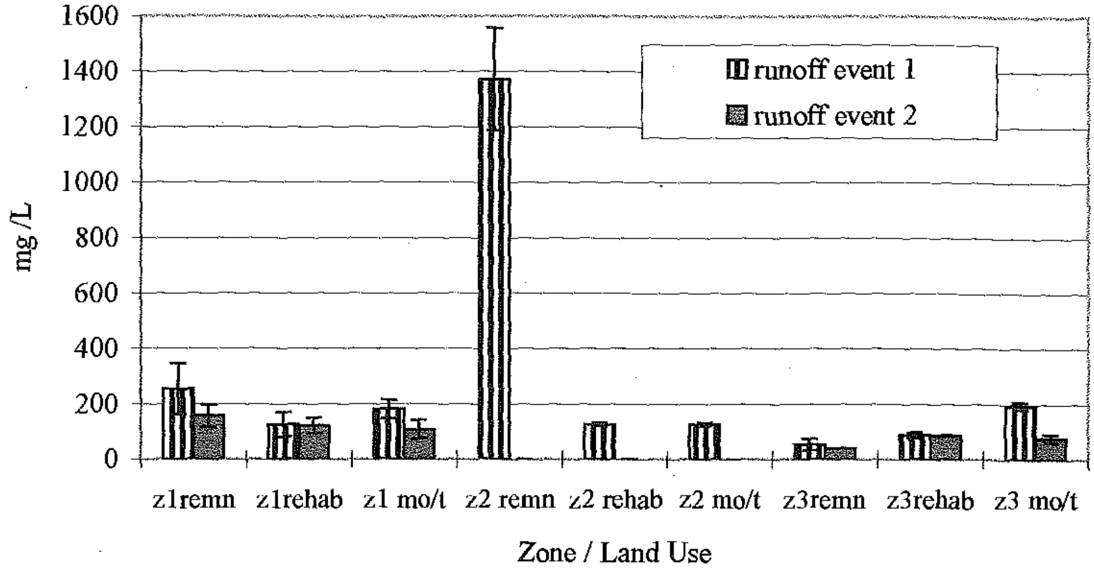

FIGURE 3.13 Column graph showing the mean concentrations and standard errors of the Salt (T.D.S) in runoff samples from runoff event one and two.
(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

3.7.6.1 Analysis of variance

The results for the two factorial analysis of variance test calculated using Salt (TDS) data from the first rainfall / runoff event appear in Table 3.17. Results indicate both a very highly significant difference between the mean concentrations each in land use and a very highly significant difference between mean concentrations in the land uses in each zone. The mean concentrations which stand out most dominantly and that are perceived to have heavily influenced the results of the calculation are results from the Remnant Vegetation area in Zone 2.

Table 3.17
The results for the two way factorial analysis of variance test calculated using the Remnant Vegetation and Minimum / Zero Tillage land use Salt (Total Dissolved Solids) data from the first runoff event.

Source of Variation	df.	SS.	MS.	F	Significance of P
ZONE	2	8.27	4.13	15.55	###
LAND USE	1	0.62	0.62	2.31	N/S
ZONE by LAND USE	2	14.16	7.08	26.62	###
RESIDUAL	17	4.52			

KEY
N/S - Not significant
- P <0.001 (very highly significant)

3.7.7 pH

No distinct patterns in mean pH levels in both rainfall / runoff event one and two are apparent to distinguish between land use areas (see Figure 3.14). In rainfall / runoff event one a distinct difference in the combined pH level of all land uses areas in zone 2 compared to all land use areas in zone 1 and 3 is apparent. This has resulted in a significant difference between zones in the two way factorial analysis of variance calculations, as indicated in Table 3.18, using the pH data of the first runoff event.

pH mean levels in rainfall / runoff event one ranged from 5.9 in zone 2, replicate 5, of the minimum / zero tillage land use to 7.5 Zone 1, replicate 8.4, of the remnant vegetation land use area in zone 1.

pH levels in the rainfall / runoff event two ranged from 6.6 in the Minimum / Zero Tillage land use in zone 3 (replicate 5) to 7.5 in the Remnant Vegetation land use area in zone 1 (replicate 2)

Given these results pH could possibly be dependent upon the type of soil or geology in each zone rather than a particular land management practice.

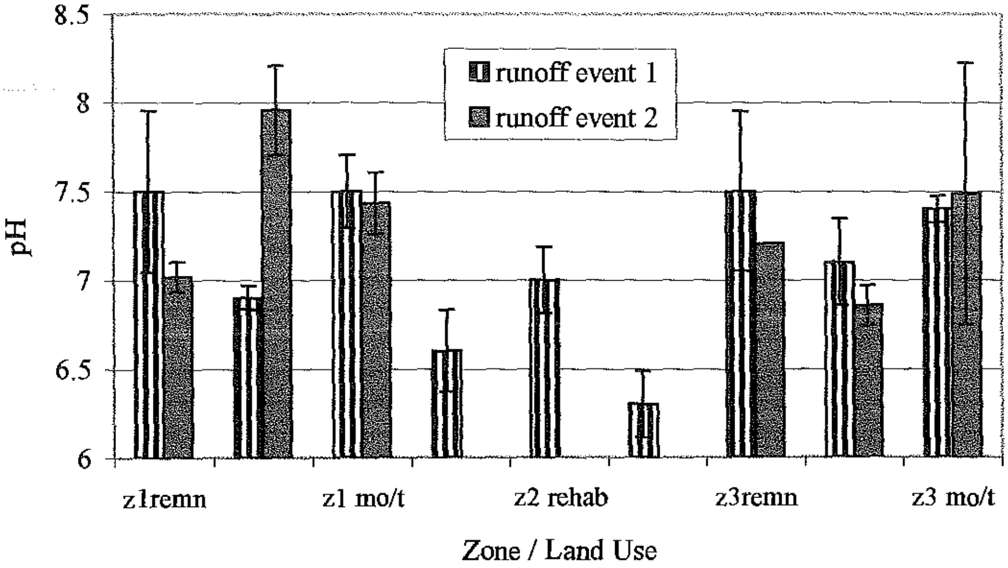

FIGURE 3.14 Column graph showing the mean and standard error of pH levels in runoff sample from runoff event one and two.

(Key : z1-z3 = Zones 1,2,3 ; remn = Remnant Vegetation land use; rehab = Vegetated Rehabilitation land use; mo/t = Minimum / Zero Tillage land use.)

Table 3.18

The results for the two way factorial analysis of variance test calculated using the Remnant Vegetation and Minimum / Zero Tillage pH data from the first runoff event.

Source of Variation	df.	SS.	F	Significance of P
ZONE	2	2.69	4.56	#
LAND USE	1	0.07	0.24	N/S
ZONE by LAND USE	2	0.31	0.52	N/S
RESIDUAL	17	5.01		

KEY
N/S - Not significant
- P < 0.05 (significant)

3.8 Correlation Matrices

Tables 3.19 to 3.24 are the Correlation Matrices which have been calculated by Excel 4 to uncover relationships and associations in the study data. Study data have been reviewed for normality and the logarithmic transformation of all data has now conferred normality. The Correlations are taken to be significant if the r value exceeds the critical value at a probability of 0.05 ($p < 0.05$). Significant correlations are shown in bold.

Table 3.19

Matrix 1 : Correlation matrix using the data from all zones. Figures in bold indicate significant correlations. (n = 36 df = 35 critical r value = 0.325)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	0.204	1							
TP	0.194	**0.346**	1						
PO4	0.086	0.315	**0.917**	1					
TSS	-0.291	-0.199	-0.263	-0.226	1				
Mineral	-0.292	-0.200	-0.264	-0.226	**0.992**	1			
Organic	-0.207	-0.181	-0.204	-0.220	**0.932**	**0.931**	1		
Salinity	0.230	**0.569**	-0.081	-0.071	**-0.404**	**-0.404**	**-0.395**	1	
pH	**-0.467**	-0.089	0.166	0.230	0.239	0.240	0.144	-0.186	1

Table 3.20

Matrix 2 : Correlation matrix using the data from zone 1. Figures in bold indicate significant correlations. (n = 13 df = 12 critical r value = 0.532)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	0.356	1							
TP	0.279	**0.682**	1						
PO4	0.158	**0.711**	**0.970**	1					
TSS	**0.624**	0.326	0.279	0.204	1				
Mineral	**0.653**	0.330	0.249	0.180	**0.996**	1			
Organic	-0.235	0.170	0.475	0.474	-0.239	-0.299	1		
Salinity	0.363	0.124	0.204	0.182	-0.068	-0.043	0.202	1	
pH	-0.129	0.070	0.312	0.206	-0.403	-0.435	0.192	-0.206	1

Table 3.21

Matrix 3 : Correlation matrix using the data from zone 2. Figures in bold indicate significant correlations. (n = 14 df = 13 critical r value = 0.514)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	-0.293	1							
TP	0.113	-0.211	1						
PO4	0.218	-0.267	**0.880**	1					
TSS	0.307	**-0.553**	**0.774**	**0.583**	1				
Mineral	0.430	-0.749	**0.692**	**0.602**	**0.863**	1			
Organic	-0.042	0.002	0.112	-0.117	0.445	-0.0108	1		
Salinity	-0.216	**0.643**	**-0.629**	**-0.584**	**-0.666**	**-0.7155**	-0.0916	1	
pH	-0.022	0.258	**0.524**	**0.639**	0.159	0.0737	-0.1390	0.0757	1

Table 3.22

Matrix 4 : Correlation matrix using the data from zone 3. Figures in bold indicate significant correlations. (n = 9 df= 8 critical r value = 0.632)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	-0.256	1							
TP	-0.210	**0.825**	1						
PO4	-0.311	**0.817**	**0.981**	1					
TSS	-0.358	-0.200	-0.571	-0.489	1				
Mineral	-0.359	-0.200	-0.570	-0.489	**0.998**	1			
Organic	-0.304	-0.285	**-0.645**	-0.563	**0.983**	**0.983**	**1**		
Salinity	0.077	0.569	**0.747**	**0.658**	**-0.778**	**-0.777**	**-0.868**	1	
pH	-0.373	0.286	0.054	0.053	0.256	0.257	0.143	0.221	1

Table 3.23

Matrix 5 : Correlation matrix using the data from all Remnant Vegetation areas. Figures in bold indicate significant correlations. (n= 10 df = 9 critical r value = 0.602)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	0.585	1							
TP	**-0.763**	-0.484	1						
PO4	**-0.703**	**-0.708**	**0.842**	1					
TSS	-0.389	-0.350	0.475	**0.689**	1				
Mineral	-0.390	-0.351	0.476	**0.691**	**0.967**	1			
Organic	-0.323	-0.333	0.378	**0.626**	**0.989**	**0.988**	1		
Salinity	**0.687**	**0.708**	**-0.632**	**-0.799**	**-0.777**	**-0.777**	**-0.783**	1	
pH	**-0.909**	-0.509	**0.708**	**0.624**	0.353	0.354	0.309	-1	1

Table 3.24

Matrix 6 : Correlation matrix using the data from all Rehabilitated Vegetation areas. Figures in bold indicate significant correlations. (n = 12 df = 11 critical r value = 0.553)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	0.189	1							
TP	**0.677**	0.536	1						
PO4	**0.587**	**0.583**	**0.868**	1					
TSS	-0.490	**-0.761**	**-0.611**	**-0.782**	1				
Mineral	-0.435	**-0.713**	**-0.775**	**-0.832**	**0.889**	1			
Organic	0.280	-0.054	**0.554**	0.289	-0.027	-0.406	1		
Salinity	0.218	0.262	0.336	0.269	-0.164	-0.172	0.118	1	
pH	-0.531	-0.334	**-0.710**	-0.473	0.076	0.174	-0.269	-0.343	1

Table 3.25

Matrix 7 : Correlation matrix using the data from all Minimum / Zero tillage areas. Figures in bold indicate significant correlations. (n = 14 df = 13 critical r value = 0.514)

	Volume mls.	Source Area (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salt (TDS) mg/L	pH
Volume	1								
Source	-0.265	1							
TP	-0.034	0.444	1						
PO4	-0.278	0.378	**0.738**	1					
TSS	0.282	0.034	0.332	-0.138	1				
Mineral	0.025	-0.430	-0.261	-0.338	0.430	1			
Organic	0.028	0.153	0.198	-0.099	**0.824**	0.079	1		
Salinity	-0.189	0.400	0.222	0.413	-0.048	0.077	-0.085	1	
pH	-0.072	0.114	0.106	0.295	0.102	**0.564**	-0.177	**0.526**	1

3. 9 Correlation Results

The results of the correlation matrices indicate a number of significant relationships and associations. Correlations which support an assumed relationship or association (significant relationships which occur in most matrices) will be discussed. In the instances where contradictory correlations occur they will be dealt with in depth to explain their occurrence and reason for the apparent contradiction. Finally a closer look at Remnant Vegetation areas will be made to highlight the interactions in natural areas.

3. 9. 1 Source Area : Relationships and Associations

There was a significant positive correlation between source area and Total Phosphorus in matrices 1 (all areas), 2 (all data zone 1), 4 (all data zone 3), 6 (all Rehabilitated Vegetation land use areas). This demonstrates that in the areas where a positive correlation does exist, total phosphorus must be evenly available throughout the source area to increase in concentration with the increase in source area.

The fact that a contradictory significantly negative correlation occurs in matrix 3 (all data Zone 2) will be further discussed in part 3.9.3. A negative correlation between Source Area and Total Phosphorus occurs in matrix 5, all remnant vegetation areas. This will be further discussed in section 3.9.4.

As expected there is a positive correlation between total phosphorus and orthophosphate in all matrices. This can be attributed to the fact orthophosphate is a soluble and available component of total phosphorus. Therefore it can be dissolved when in contact with water and transported to areas down slope. Positive correlations between orthophosphate and source area, occur in matrices 2, 4, and 6, indicating that again, like total phosphorus, the larger the source area the higher the Orthophosphate concentrations in runoff.

Other soluble chemicals should also increase in concentration as source area increases for the same reason as total phosphorus and orthophosphate. This is the case Salt (Total Dissolved Solids). TDS also shares a significant positive correlation with source area in matrices 1, 3, and 5. Matrices 2, 4, 6, and 7, although not significant, have postive correlations between TDS and source area.

3. 9. 2 Total Suspended Sediments

As expected Total Suspended Sediment is significantly positively correlated with the mineral component in all matrices except 7. It is also in a significant positive correlation with its organic component in matrices 1, 4, 5, and 7.

3. 9.3 Inconsistent Correlation

Figure 3.15 indicates the outliers (remnant vegetation data) which appear to have resulted in a negative (-0.211) correlation between Total Phosphorus and Source Area in the Zone 2 matrix. Upon removing these figures from the correlation calculation the result is a significant positive correlation (r =0.7365, n = 10, df = 9, p<0.05) between Rehabilitated Vegetation and Minimum / Zero Tillage land use areas. Considering this change, the fact that no correlation exists for all land use areas in zone 2 appears to have been caused by the large source areas but small total phosphorus concentrations found in the remnant vegetation area.

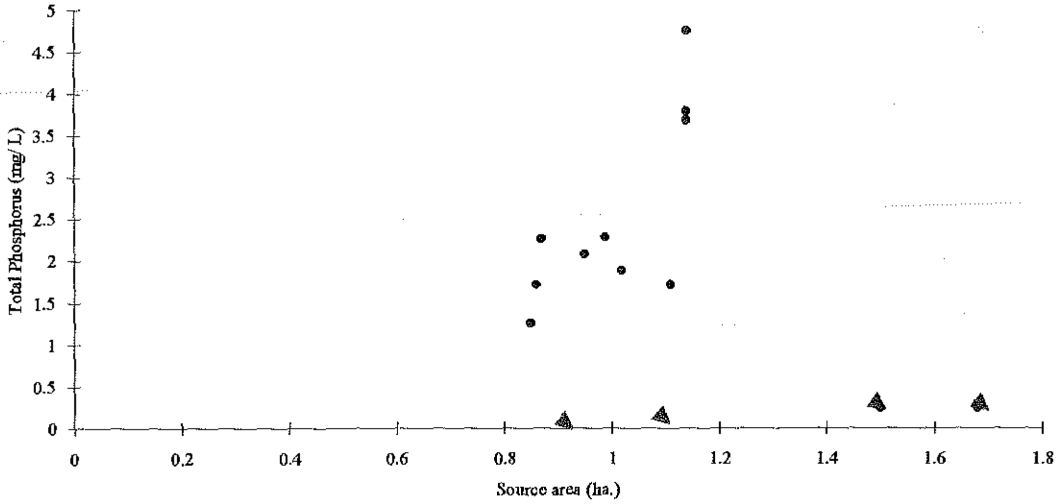

FIGURE 3.15 Scatter plot showing all Total Phosphorus and Source area data from zone 2. Outliers which appear to have affected the correlation calculation are indicated.
(Key: Δ = Zone 2 remnant vegetation data • = Zone 2 other data)

3.9.4 Remnant Vegetation (Matrix 5)

A number of significant correlations, as indicated in Matrix 5 occurred in Remnant Vegetation land use areas. Unlike the other two areas, Remnant Vegetation areas have not been cleared and incur minimal human disturbance. Due to this, the correlations apparent in this area justify further explanation in an attempt to highlight the relationships and associations that exist, between the variables, in natural areas.

A significant negative correlation between Orthophosphate and Source Area, in contradiction to the relationship discussed in section 3.9.1, indicates that a larger source area in Remnant Vegetation areas did not result in higher concentrations of orthophosphate. A significant negative correlation between volume and total phosphorus and volume and orthophosphate and a positive (but not significant) correlation between volume and source area provides further evidence that although a larger source area may have resulted in a larger amount of runoff being collected, the phosphorus concentration in that water did not increase.

A number of possible factors can account for these relationships. Orthophosphate may have been bound to a number of surface features found throughout the entire remnant vegetation source area (eg. detritus and vegetation) and thus not dissolved and transported in the surface runoff. These features may act as barriers to movement and cause either the loss or exclusion of Orthophosphate in the runoff. Also, unlike other areas where phosphorus is actively applied to the soil (and the correlation between orthophosphate and source area exists), Total Phosphorus and its components are only negligibly present in remnant vegetation areas.

A series of positive correlations which exist between Orthophosphate and Total Suspended Sediments, and Orthophosphate and the Mineral and Organic component of Total Suspended Sediments may indicate that Orthophosphate was transported in runoff through contact or adhesion to sediment particles (mineral and organic).

CHAPTER 4

EXTRAPOLATION AND MODELLING

4.1 Conversion from Concentration to Loads

The development of an extensive GIS, and the development of three homogenous zones provided the necessary areal statistics to model the results of the runoff water quality from the first, and most successful in terms of sampling, rainfall / runoff event, for the three land uses in the catchment.

In review of the results from the first runoff event only the results of total phosphorus, total suspended sediment and salt (total dissolved solids) were considered for modelling purposes. The other parameters measured were considered to be either related, therefore with similar trends, to one of the above parameters (ie the relationships between total phosphorus and orthophosphate, and total suspended sediment and its mineral and organic component) or showing no real pattern or quantifiable trend (ie the results of pH). Using the results of the three selected parameters, the calculation of the source area (in ha) and the volume of water collected (in L), the individual replicate results were extrapolated to a milligram per hectare figure, effectively changing the figure from a concentration to a load per hectare. The formulae used in this calculation appears in Table 4.1. An example is used to indicate the procedure used to extrapolate the data.

Table 4.1

The formulae used for the conversion of concentrations to loads from sampling round one from mg/ L to mg/ ha. A hypothetical example is used to indicate the technique used.

Concentration mg/ L	x runoff volume (litre) collected	÷ source area (hectare) calculated =	Load mg/ ha
eg. 0.357 mg/ L	x 1.100 litres	÷ 0.73 ha	= 0.537 mg/ ha.

Mean and Standard Error were calculated from these load figures. Mean results, as indicated in Table 4.2, show similar patterns as the results, described in Section 3.5.

Table 4.2

Loads of Total Phosphorus, Total Suspended Sediment and Salt (TDS) from rainfall / runoff event one. (Figures are Mean ± Standard Error).

Zone	Land Use	T.P. mg/ha	T.S.S. mg/ha	Salt (T.D.S.) mg/ha
1	Remnant Vegetation	0.406 (± 0.109)	278 (± 157.244)	340 (± 153.840)
1	Vegetated Rehabilitation	0.525 (± 0.111)	598 (± 69.811)	136 (± 47.945)
1	Minimum / Zero Tillage	3.349 (± 0.559)	700 (± 238.455)	219 (± 52.617)
2	Remnant Vegetation	0.341 (± 0.104)	340 (± 96.566)	2614 (± 685.138)
2	Vegetated Rehabilitation	5.806 (± 1.184)	1338 (± 379.198)	441 (± 100.405)
2	Minimum / Zero Tillage	9.934 (± 2.184)	2016 (± 576.354)	457 (± 174.236)
3	Remnant Vegetation	0.389 (± 0.156)	402 (± 147.441)	45 (± 12.883)
3	Vegetated Rehabilitation	1.904 (± 0.841)	2538 (± 290.409)	370 (± 179.905)
3	Minimum / Zero Tillage	2.498 (± 1.171)	670 (± 389.101)	309 (± 192.42)

Key T.P. = Total Phosphorus; T.S.S. = Total Suspended Sediment; T.D.S. = Total Dissolved Solids) Sample sizes are indicted in Appendix 7.3, the results of the rainfall / runoff first sampling round.

4.2 Modelling of loads loads on a zone and catchment wide basis

4.2.1 Why model?

The modelling of loads on a zone and catchment wide basis was undertaken to provide scenarios which could predict how increasing areas of vegetated rehabilitation could change total loads. Two types of scenarios were considered, to identify both immediate and long term changes.

It was hoped that the scenarios could give a more comprehensive understanding on the restorative potential of rehabilitation and provide predictive information to the catchment community on some of the benefits of increasing efforts of farm based rehabilitation.

This predictive information could be used by the catchment community in future catchment management decisions identifying parameters which may need careful management in both the entire catchment and / or individual zones.

4.2.2 The modelling of loads on a zone and catchment wide basis.

Mean load values were extrapolated on a catchment wide basis using areal figures obtained from the Bremer River GIS. As indicated in Table 4.3 the catchment can be divided into two main categories, Total Area of Remnant Vegetation and Total Area of all other land uses.

Table 4.3

The total areas of Remnant Vegetation and other land uses in the Bremer River Catchment.

	Total area of Remnant Vegetation (ha)	Total area of other land uses (ha)	Total Area. (ha)
Zone 1	12839	15838	28,677
Zone 2	1452	9542	10,994
Zone 3	3700	29452	33,152
Catchment	17991	54833	72,824

For the purposes of modelling, the proportion of land devoted to other land uses (ie "Total area of other land uses", as indicated in Table 4.3) was inferred to be the proportion of the catchment in which a number of different land use scenarios (areas of land devoted to a combination of land uses) could be created to model the load data.

Areas in the catchment under the Remnant Vegetation land management practice were considered to be fixed within the catchment.

Two series of five land use scenarios were considered for the modelling of the results on a catchment basis. Both were used to highlight the restorative potential of rehabilitated land .

The first series (Scenario Series One), as indicated in Table 4.4, used five scenarios which altered the relative amounts Minimum / Zero and Vegetated Rehabilitation land use in each zone. The load figures were multiplied by the various proportions (in hectares) of each land use to derive the potential impact from each land use under the scenarios for each zone. The extrapolated figures were then combined to estimate the potential impact from each zone and combined again to estimate the potential impact on the catchment following the first rainfall / runoff event. The modelling of the converted figures under the first series of scenarios can only be applied to the catchment under the following assumptions :

1. That the nature of the catchment's Minimum / Zero Tillage and Vegetated Rehabilitation land management practices in the future are the same as those sampled and that the only changes are the percentage occurrence of each practice in the catchment.
2. That the fertiliser application regimes in each area of the Minimum / Zero Tillage land management practice sampled were representative of the common amount applied for each respective zone and that this regime remains fixed over an extended period of time.
3. That the physical condition of a greater proportion of the Remnant Vegetation areas in the catchment remains similar to those sampled by this study.
4. The proportionate area of Remnant Vegetation remain the same as the areas assumed by this model.
5. That present and future rehabilitated areas cease to be fertilised after initial preparation.
6. That each hectare of Minimum / Zero Tillage, Vegetated Rehabilitation and Remnant Vegetation in each zone had the same mean concentrations of salt, total phosphorus and total suspend sediment, as those recorded by this study, after the first flush of the year.

Contravening any of these assumptions will adversely effect the accuracy of modelling under the first series of scenarios.

The second series (Temporal Modelling Scenarios) used the same proportionate land use areas as Scenario Series One (Table 4.4) but the extrapolated results of

Vegetated Rehabilitation were replaced by the extrapolated results of Remnant Vegetation. The modelling of the converted figures under the second series made a number of assumptions which warranted this change. These assumptions were :

1. On a temporal scale (ie 10 - 15 years) the concentrations of total phosphorus and sediment measured by this study in runoff water from areas of Rehabilitated Vegetation will continue to decrease in concentration as soils of these areas become more consolidated and artificially high levels of nutrients in these soils become exhausted following weathering.

2. On a temporal scale runoff water quality from Rehabilitated Vegetation areas will begin to approximate concentrations and loads similar to those found in Remnant Vegetation areas.

3. That those assumptions stated for the first series of scenarios are still valid.

Contravening any of these assumptions will adversely effect the accuracy of modelling under the second series of scenarios.

The modelling of perceived temporal changes in runoff water quality from vegetated rehabilitation was undertaken to envisage the potential longer term effects this land use may have on reducing the degradive effect of poor runoff water quality in the catchment. Exchanging the results of Vegetated Rehabilitation with Remnant Vegetation was therefore an attempt to model the temporal changes to runoff water quality that were predicted to occur (according to Assumption 2 above).

Table 4.4

Scenarios of the land use proportions for the modelling of the extrapolated field data obtained from the first rainfall / runoff event.

SCENARIO	Proportion of Remaining Land	Zone 1	Zone 2	Zone 3	Catchment
Existing	5 % Vegetated Rehabilitation	791	477	1473	2741
	95 % Minimum / Zero Tillage	15047	9066	27979	52092
Scenario 1	10 % Vegetated Rehabilitation	1584	954	2945	5483
	90 % Minimum / Zero Tillage	14255	8588	26507	49350
Scenario 2	20 % Vegetated Rehabilitation	3168	1908	5890	10966
	80 % Minimum / Zero Tillage	12671	7634	23562	43867
Scenario 3	30 % Vegetated Rehabilitation	4751	2863	8836	16450
	70 % Minimum / Zero Tillage	11087	6679	20616	38383
Scenario 4	50 % Vegetated Rehabilitation	7919	4771	14726	27416
	50 % Minimum / Zero Tillage	7919	4771	14726	27416

NOTE. All figures in hectares.

4.3 Results

4.3.1 Total Phosphorus

The results of the first and second scenario series using the total phosphorus load data indicated, in both instances, decreasing trends with the second scenario series having the most significant decrease. Figure 4.1 and Figure 4.2. show the relative contribution of each zone and catchment under Scenario Series One and Two respectively.

In both scenario series, zone 2, the smallest zone of the three, had the highest total load, in comparison to zones 1 and 3. Total loads in this zone decreased, from 92.87 g. (in the Existing Scenario) to 75.59 g. (in Scenario 4) under Scenario Series One and from 90.71 g. (in the Existing Scenario) to 49.52 g. (in Scenario 4) under Scenario Series Two.

The total loads calculated for Zone 1, using both scenario series, reflected the large areas of the zone under remnant vegetation. Results are considerably lower than Zone 2 and Zone 3, the largest zone. Total loads in Zone 1 decreased, from 56.01 g. (in the Existing Scenario) to 35.89 g. (in Scenario 4) under Scenario Series One and from 55.92 g. (in the Existing Scenario) to 34.95 g. (in Scenario 4) under Scenario Series Two.

The total loads calculated for Zone 3, using both scenario series, indicated a general decreasing trend. Under Scenario Series One total loads decreased from 73.08 g. (in the Existing Scenario) to 65.21 g. (in Scenario 4). Under Scenario Series Two total loads decreased from 70.85 g. (in the Existing Scenario) to 42.90 g. (in Scenario 4).

On a catchment wide scale although an increase in areas of Vegetated Rehabilitation lead to decreases in total loads, under Scenario Series One, from 222.40 g. to 176.69 g, the changes in the total loads of total phosphorus from these areas on a temporal scale, under Scenario Series Two were more dramatic. Total loads significantly decreased from 217.48 g. to 127.36 g. under this scenario series.

The second scenario series highlights the significant restorative potential of rehabilitation over a more temporal period as artificially high nutrient levels in soils are exhausted.

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.1 Legend

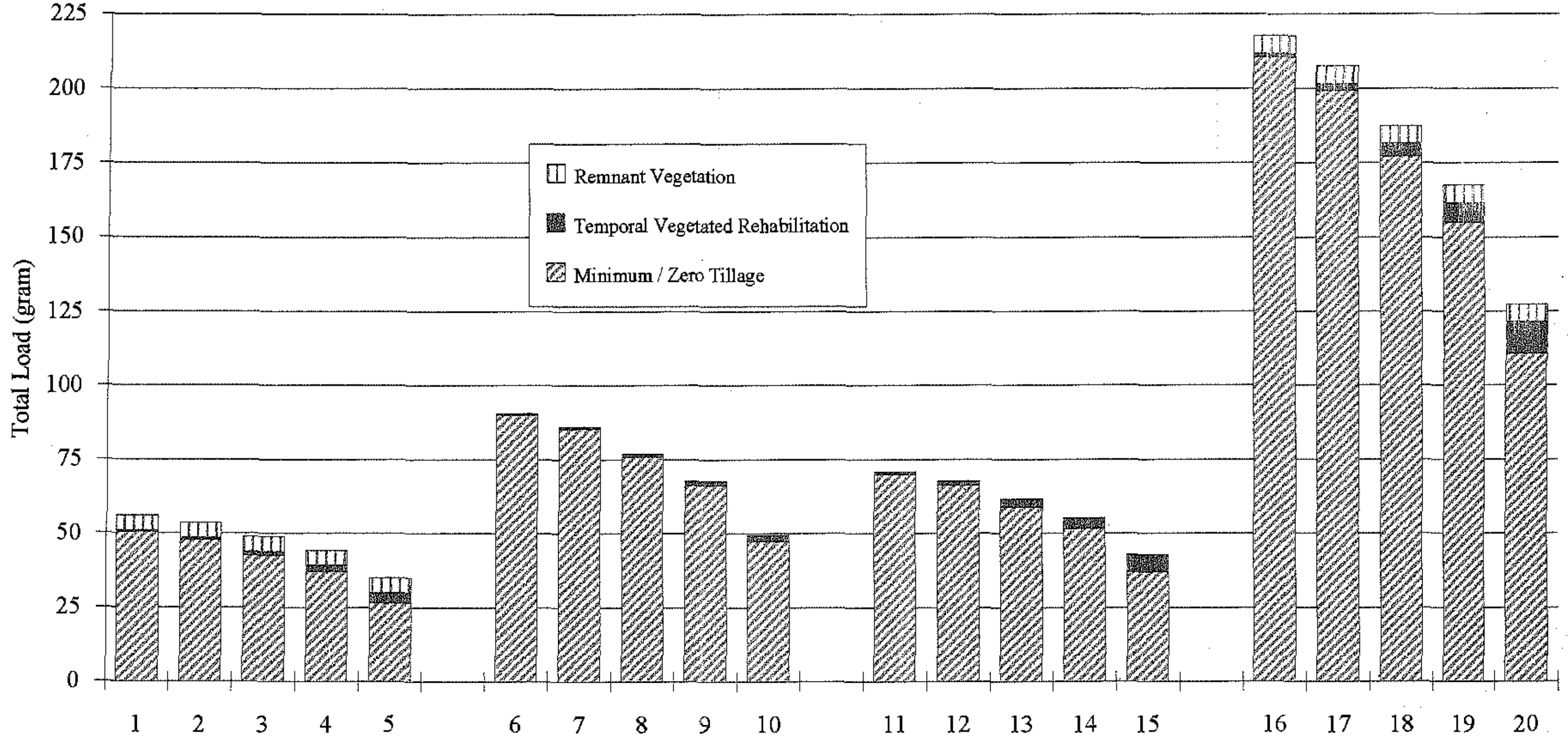

FIGURE 4.2
Histogram showing the results from the Scenario Series Two applied to Zones 1 - 3 and combined to show catchment-wide impact using the Total Phosphorus loads. Columns 1-5 represent 5 scenarios for Zone 1, columns 6-10 represent 5 scenarios for Zone 2, columns 11-15 represent 5 scenarios for Zone 3, and columns 15 - 20 represent 5 scenarios on a catchment wide basis.

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.2 Legend

4.3.2 Salt (Total Dissolved Solids)

The results of the first and second scenario series using the salt (TDS) load data indicated, in general, no change in the Scenario Series One and an increase, in Scenario Series Two. Figure 4.3 and Figure 4.4 show the relative contribution of each zone and catchment under both Scenario Series One and Two respectively.

In Scenario Series One all zones experienced little variation in total loads as the area of Vegetated Rehabilitation increased. Total loads for Zone 1 marginally decreased, from 7.77 kg (in the Existing Scenario) to 7.18 kg. (in Scenario 4) whilst in Zone 3 total loads gradually increased, from 9.35 kg. (in the Existing Scenario) to 10.16 kg. (in Scenario 4). Total loads in Zone 2 remained at a constant level as areas of rehabilitation increased in the zone.

Total loads in Scenario Series Two varied slightly in Zone 1, where total loads increased from 7.93 kg. (in the Existing Scenario) to 8.79 kg. (in Scenario 4), and Zone 3, where total loads decreased from 8.87 kg. to 5.37 kg. Total loads in Zone 2 dramatically increased from 9.18 kg. to 18.44 kg. The series of dramatic increases under Scenario Series Two can be attributed to the saline conditions of the remnant sampled in Zone 2. Modelling results from Zone 2, combined with those from Zone 1 and 3 indicate a significant increase in total load from 25.99 kg. to 32.61 kg.

Overall, the modelling of the salt load data under both Scenario Series One and Scenario Series Two failed to produce a significant decrease in salt loads. This indicated that a more widespread adoption of the Vegetated Rehabilitation land use can have little effect on salt loads in runoff water under these modelling scenarios. This does not mean that Vegetated Rehabilitation does not have a role in reducing the salinity problem of the catchment. The role Vegetated Rehabilitation plays is more associated with reducing the salinity enriched groundwater discharge caused by a rising groundwater table.

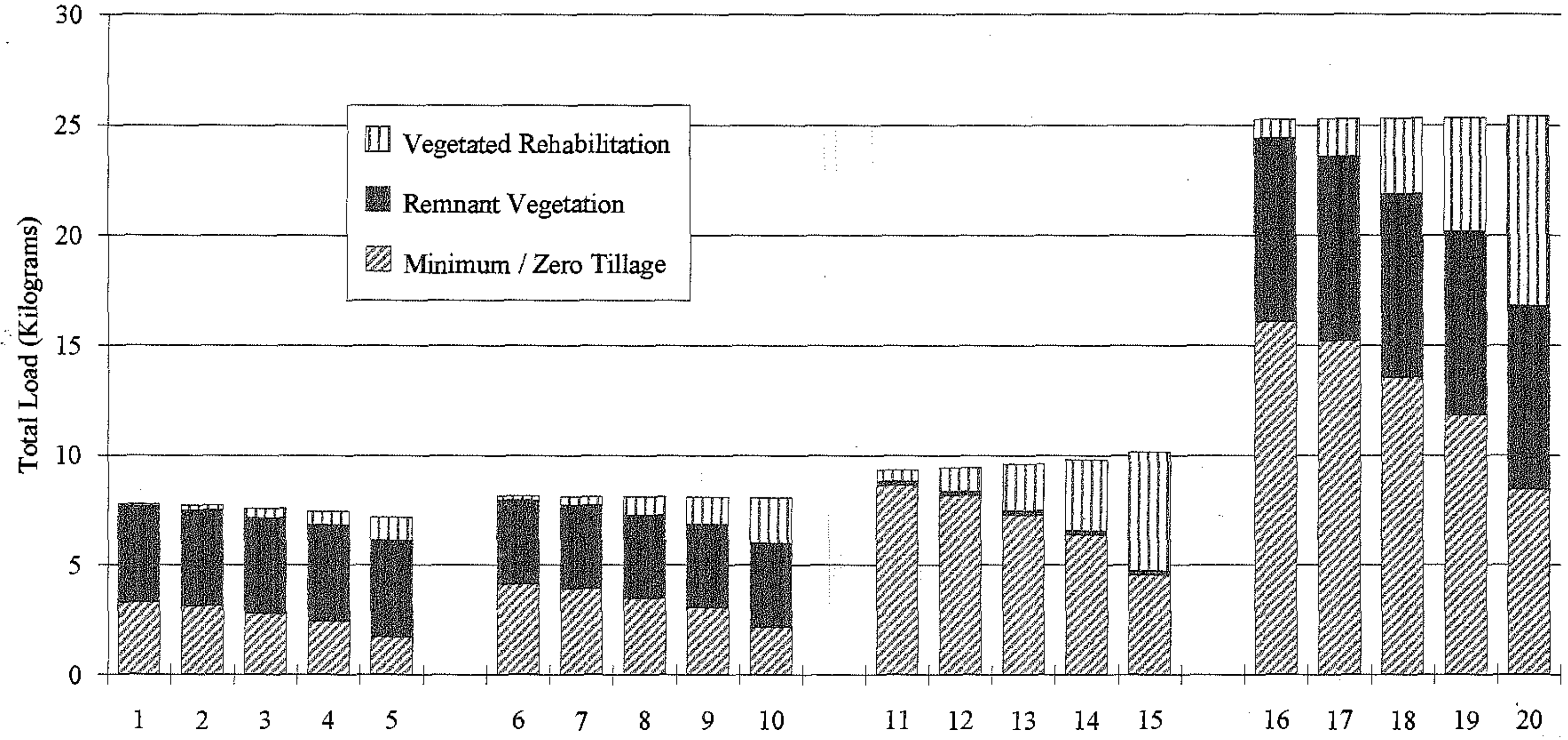

FIGURE 4.3 Histogram showing the results from the Scenario Series One applied to Zones 1 - 3 and combined to show catchment-wide impact using the Salt (Total Dissolved Solids) loads. Columns 1-5 represent 5 scenarios for Zone 1, columns 6-10 represent 5 scenarios for Zone 2, columns 11-15 represent 5 scenarios for Zone 3, and columns 15 - 20 represent 5 scenarios on a catchment wide basis.

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.3 Legend

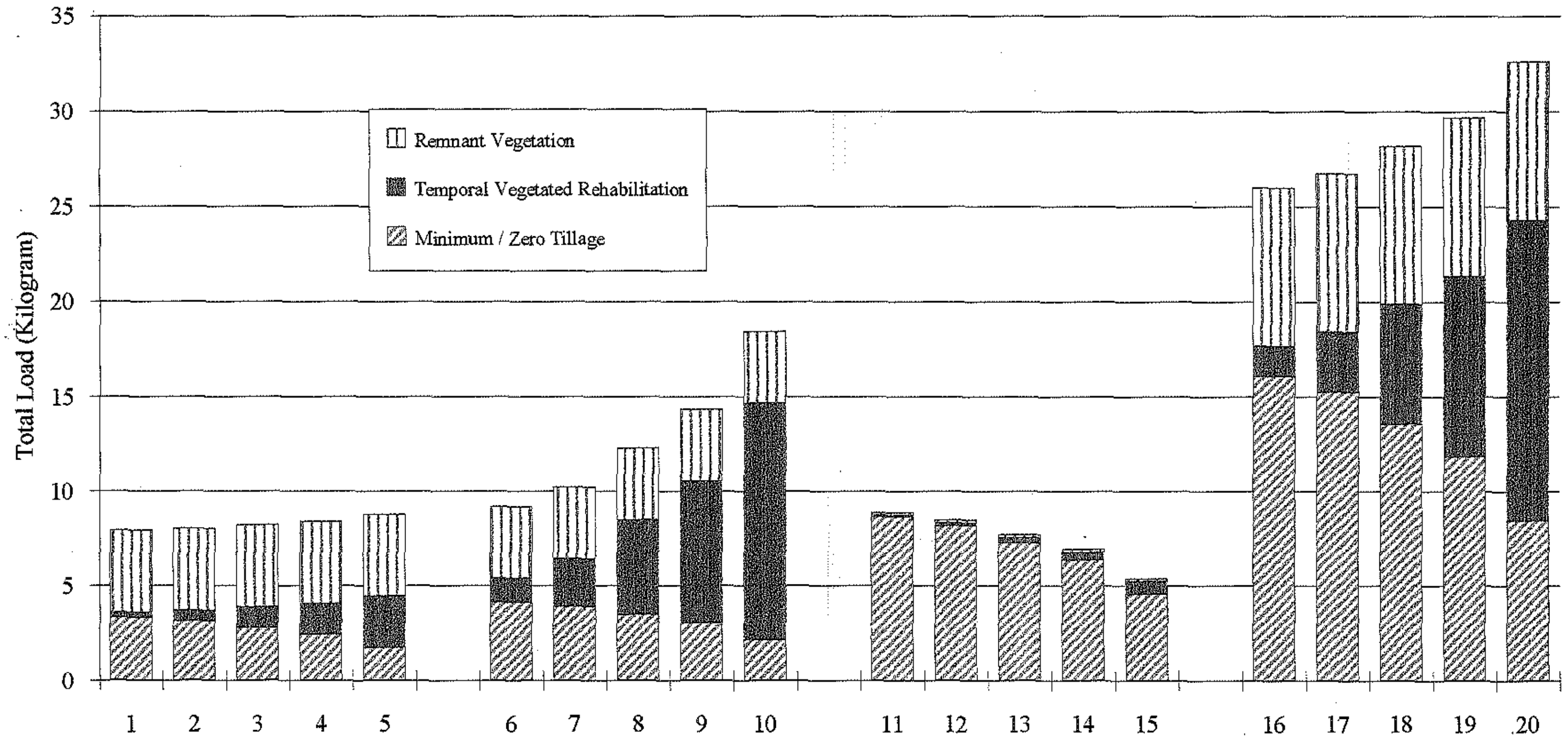

FIGURE 4.4 Histogram showing the results from the Scenario Series Two applied to Zones 1 - 3 and combined to show catchment-wide impact using the Salt (Total Dissolved Solids) loads. Columns 1-5 represent 5 scenarios for Zone 1, columns 6-10 represent 5 scenarios for Zone 2, columns 11-15 represent 5 scenarios for Zone 3, and columns 15 - 20 represent 5 scenarios on a catchment wide basis.

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.4 Legend

4.3.3 Total Suspended Sediment

The results of the first scenario series (Figure 4.5) indicated decreasing loads in zone 1, from 14.57 kg. (in the Existing Scenario) to 13.85 kg. (in Scenario 4), and zone 2, from 19.41 kg. (in the Existing Scenario) to 16.50 kg. (in Scenario 4) but significant increases in zone 3 from 23.99 kg. (in the existing scenario) to 48.74 kg (in Scenario 4).

These results could lead to the conclusion that by increasing areas of rehabilitation sedimentation problems may also increase. Results in zone 3 were severely influenced by the young age of the rehabilitated site, with soil disturbance still evident. Consideration was then given to temporal changes which were perceived to decrease sediment rates, as soils became consolidated. Scenario Series Two was then used to give an indication of possible temporal changes in runoff water quality.

Results from the second series of scenarios (Figure 4.6) gave an indication of the potential temporal decreases in total suspended sediment loads. Sediment loads in all zones decreased with Zone 1 slightly decreasing, from 14.32 kg. (in the Existing Scenario) to 11.32 kg. (in Scenario 4), Zone 2 significantly decreasing, from 18.93 kg. (in the Existing Scenario) to 11.74 kg. (in Scenario 4) and Zone 3 decreasing from 20.85 kg. (in the Existing Scenario) to 17.29 kg (in Scenario 4). On a catchment-wide impact, the total load of total suspended sediment significantly decreased, from 54.10 kg. (in the Existing Scenario) to 40.35 kg. (in Scenario 4).

The results from the two modelling scenarios indicated that initial loads of total suspended sediment from recently rehabilitated areas may increase, in some cases substantially, but on a temporal scale decreases in loads should occur.

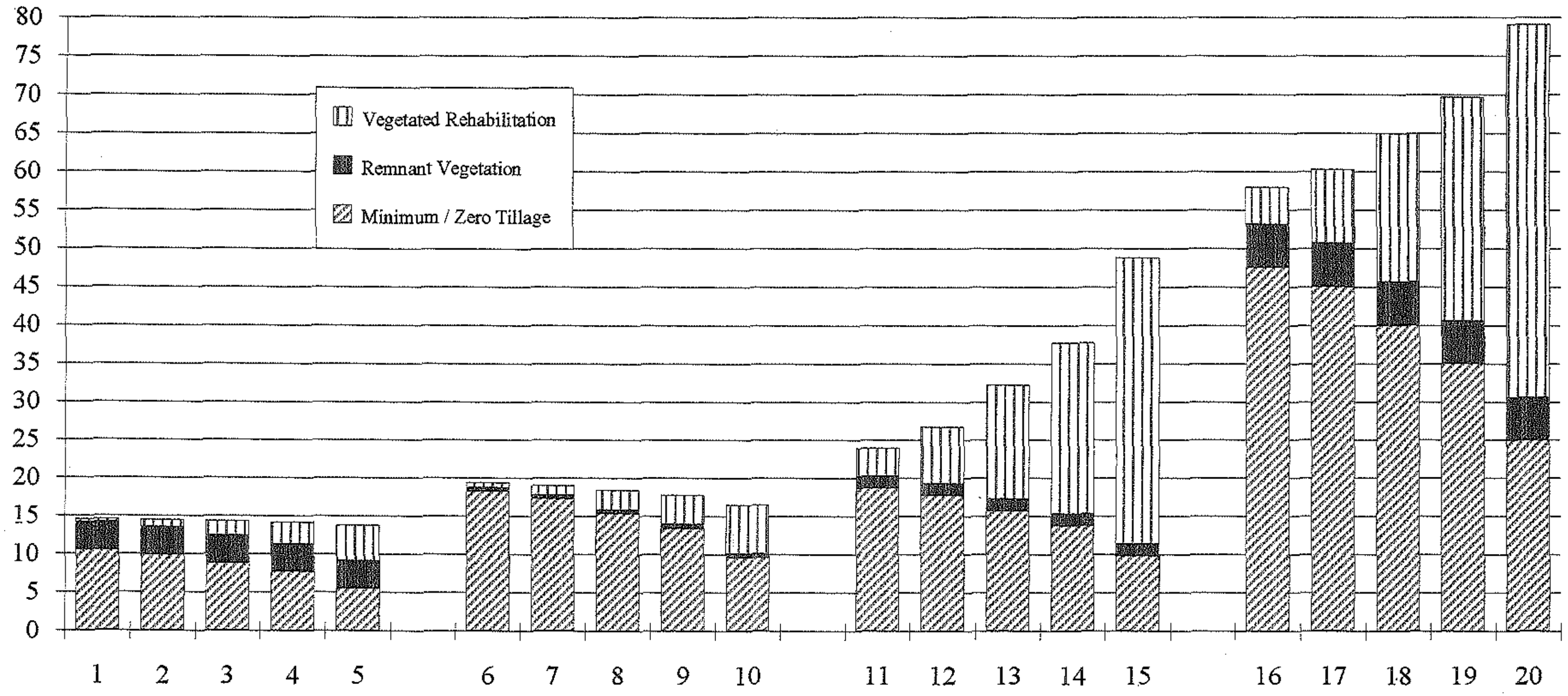

FIGURE 4.5 Histogram showing the results from the Scenario Series One applied to Zones 1 - 3 and combined to show catchment-wide impact using the Total Suspended Sediment loads. Columns 1-5 represent 5 scenarios for Zone 1, columns 6-10 represent 5 scenarios for Zone 2, columns 11-15 represent 5 scenarios for Zone 3, and columns 15 - 20 represent 5 scenarios on a catchment wide basis.

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.5 Legend

1	Zone 1 Existing Scenario	11	Zone 3 Existing Scenario
2	Zone 1 Scenario 1	12	Zone 3 Scenario 1
3	Zone 1 Scenario 2	13	Zone 3 Scenario 2
4	Zone 1 Scenario 3	14	Zone 3 Scenario 3
5	Zone 1 Scenario 4	15	Zone 3 Scenario 4
6	Zone 2 Existing Scenario	16	Catchment Existing Scenario
7	Zone 2 Scenario 1	17	Catchment Scenario 1
8	Zone 2 Scenario 2	18	Catchment Scenario 2
9	Zone 2 Scenario 3	19	Catchment Scenario 3
10	Zone 2 Scenario 4	20	Catchment Scenario 4

FIGURE 4.6 Legend

CHAPTER 5

DISCUSSION

Traditional dryland agriculture has been the dominant land management practice in the Bremer River catchment for close to 40 years. The initial change in land use from one dominated by natural vegetation to one now dominated by a cyclical pasture and cropping regime has brought about dramatic changes in soil fertility, catchment hydrology and subsequently water quality.

The annual application of phosphorus has substantially increased agricultural productivity on naturally infertile soils of the entire catchment, but in doing so has increased the loss of nutrients to aquatic systems. Eutrophication and sedimentation of waterways, salinisation of land, and wind and water erosion have been recognised as the major forms of land degradation in the catchment brought about by the change in land management practices.

The need to address these issues brought about necessary changes in attitudes towards agricultural production in the form of more sustainable methods of production. The World Commission on Environment and Development (1990, p.40) defines Sustainable Agriculture as "...the maintenance and management of ecologically sound farming systems". The wide-spread adoption of Minimum / Zero Tillage (Conservation Tillage) is the Bremer Catchment rural community's first step towards this ideal.

Any attempted move towards agricultural sustainability is meaningless unless spatial and temporal scales are considered and defined (Lefroy & Hobbs, 1992). Hobbs and Lefroy (1992) see problems with the adoption of sustainability as different constraints tend to dominate at different scales. On the individual paddock a diversity of ecological field changes has occurred with the dominant constraint being mainly agronomic with the productivity of crops and pastures seen primarily as the dominant objective. On the farm level the survival of the farm business on a long term scale is seen as the dominant goal. At the catchment level the constraints are usually ecological with the major goal being the long term maintenance of the agricultural ecosystem and the natural ecosystem.

To achieve sustainability in the catchment the various aspects of sustainability must be suitably addressed at each level. With a catchment community striving for sustainability, agricultural planning would be ideally aimed at a catchment wide scale, but no one person (Lefroy & Hobbs, 1992) takes responsibility for what happens within a catchment. Ultimately, responsibility can only be assumed at the farm level where the ecological constraints of land degradation can adversely disrupt the agricultural economic productivity. Therefore the ecological recovery of a catchment may be considered on a catchment-wide scale but with the restorative actions initially farm based. With this in mind the significant findings of this study were that the type of land management practice undertaken at the farm level fundamentally influenced the concentrations of sediment and total phosphorus in surface runoff originating from these areas. Variations within these land management practices were considered to have influenced a variation in concentrations.

On a catchment basis, these farm based practices were modelled on a zone and catchment wide basis. Using a number of modelling scenarios the restorative potential of rehabilitation was highlighted on both an immediate and temporal basis. The modelling scenarios provided a necessary guide to the effect farm based changes to areas under vegetated rehabilitation could have on reducing total loads of sediment and phosphorus. The variability of sediment, salt, and total phosphorus loads, throughout the three zones of the catchment, lead to the identification of zones within the catchment which required more urgent management attention.

5.1 Significance of current land management practices to catchment degradation.

This study successfully sampled two rainfall / runoff events in three defined zones of the Bremer Rver catchment. The sampling of runoff water and the analysis of samples for sediment (total suspended sediment), total phosphorus, and salt concentrations and pH levels indicated distinct differences in parameter concentrations between runoff events and variations between the three main land management practices sampled.

In agreement with Rayment and Poplawski (1992) the concentrations of the salt, sediment and total phosphorus analysed for in the runoff water samples following the first runoff event were higher than those concentrations from the second runoff event. This can be primarily attributed to the fact that the seasonally surface accumulated, precipitated, soluble and particulate chemicals were transferred from the soil surface to the first runoff of the rainfall season, with minimal leaching through the temporally impervious soil crust (Ahuja, 1985).

In discussion of the results from this study consideration must be given to potential for changes and transformation of phosphorus, and other parameters, in runoff. Changes are known to occur between the point where phosphorus leaves a paddock or area to where it enters a water body (Sharpley & Halvorson, 1994). The extent of this transformation is usually unknown but must be considered in the assessment of the potential impact of this nutrient in runoff in response to agricultural management.

5.1.1 Remnant Vegetation : Main findings

The main findings of this study with respect to the Remnant Vegetation land management practice can be summarised as :

1. Areas of Remnant Vegetation represented the base load for total phosphorus and sediment analysed in runoff.
2. Salt loads varied considerably between zones as a result of spatial variation in soils and geology.

5.1.1.1 Base Load

Areas of Remnant Vegetation represented the base load for total phosphorus confirming the suggestions of Sharpley and Halvorson (1994) who stated that the phosphorus runoff from areas of uncultivated or pristine land were considered as the background loading of all land use practices in catchments. Remnant Vegetation areas also carried the lowest concentrations of sediment but in contradiction with the findings of Sharpley and Halvorson (1994), these areas were not dominated by the soluble form of phosphorus (orthophosphate) as they suggest, as concentrations were relatively low. As soluble phosphorus is immediately available for biological uptake (Sharpley & Halvorson, 1994), which in aquatic systems may promote eutrophic conditions, the fact that soluble phosphorus levels were lower than literature supported highlights the role played by remnants in this catchment.

5.1.1.2 Salt loads

Concentrations of salt varied significantly in concentrations between zones. With 75.8% of the catchment cleared for agricultural purposes, selecting areas for the sampling of runoff from Remnant Vegetation areas was difficult. The highest concentrations of salt recorded, which occurred in zone 2, was a result of sampling in a known saline remnant considered representative of remnants in the zone. These remnants formed a riparian strip along Devils Creek underlain by a known salty soil and geology type.

Table 5.1
Comparative Total Phosphorus results for this study and past studies, showing the loads recorded and the dominant feature, or land use practice applied to the sub-catchment. Results for this study are the mean range of total phosphorus loads recorded in all three zones for each land management practice. (The kg/ha/yr results for the Bremer Catchment are based on 6 runoff events per year).

Feature / Land Management Practice	Total Phosphorus	Study Location	Reference
Remnant Vegetation	2.046 - 2.436 mg/ha/yr	Bremer Catchment	This study
Vegetated Rehabilitation	3.15 - 34.836 mg/ha/yr	Bremer Catchment	This study
Minimum / Zero Tillage	14.98 - 59.604 mg/ha/yr	Bremer Catchment	This study
Forests	0.9 - 30 mg/ha/yr	n/s	Cullen, 1983. p. 54
Native grass	0.11 - 90 mg/ha/yr	n/s	Sharpley and Halvorson, 1994. p. 44
Pastures	10 - 60 mg/ha/yr	n/s	Cullen, 1983. p. 54
Wheat - summer fallow	50 - 1200 mg/ha/yr	Western Canada	Nicholiachuk and Read, (cited in Sharpley & Halvorson, 1994 p. 43)

n/s - not stated

5.1.2 Vegetated Rehabilitation

The main findings of this study with respect to the Vegetated Rehabilitation land management practice can be summarised as :

1. Mean loads of phosphorus varied throughout the three zones of the catchment and was assumed to be decreasing on a temporal scale.
2. Mean loads of sediment were the highest recorded of all land management practices but variations between zones and a decreasing trend with maturity lead to an assumption that total loads would decrease with age.

5.1.2.1 Temporal changes in phosphorus loads

Phosphorus concentrations were lower than those found in Minimum / Zero Tillage areas, but were dependent on the location of the rehabilitated area in the landscape. Black (cited in Sharpley and Halvorson, 1994 p. 48) found that a decline in artificially high levels of phosphorus in soils occurred on a temporal scale upon cessation of application but was dependent upon the amount of, and total period of, phosphorus application. In support of Black's findings this study made the assumption, for modelling purposes, that phosphorus loads will continue to decrease on a temporal scale as the exhaustion of artificially high levels of phosphorus in the soil decreases.

5.1.2.2 Temporal changes to Vegetated Rehabilitation.

This study made an assumption that on a temporal scale sediment and phosphorus concentrations in runoff water originating from rehabilitated areas would eventually reach concentrations approximating areas of remnant vegetation. At this point their effectiveness as a filtering strip between agricultural areas and aquatic systems will commence, reducing the potential impact from Minimum / Zero Tillage areas.

Robinson, Ghafferzadeh and Cruse (1996), found that a filtering strip could effectively remove between 70 % and 85 % of sediment in runoff, depending on the width. Correlations found in this study between sediment and total phosphorus would therefore conclude that if a reduction in sediment loads would occur a reduction in total phosphorus loads would also occur. This conclusion would promote the effectiveness of rehabilitated vegetation at reducing phosphorus and sediment loss to aquatic systems.

5.1.3 Minimum / Zero Tillage

The main findings of this study in respect to the Minimum / Zero Tillage land management practice can be summarised as :

1. Mean loads of phosphorus although the highest recorded of all land management practices may have been effected by prior runoff events and time since fertiliser application.
2. Although sediment loads were consistently high, literature (Soileau et al, 1994) suggests sediment losses under conventional tillage are usually higher.
3. Both sediment and phosphorus loads may have been affected by weather conditions.

5.1.3.1 Phosphorus loads

This study found the highest loads of both total and soluble phosphorus recorded were in the areas of Minimum / Zero Tillage. These loads were in the lower range of loads recorded in similar runoff studies, as indicated in Table 5.1. Variable total phosphorus loads, between zones, were initially considered to reflect the different fertiliser regimes of the management practices in each zone. Sharpley and Halvorson (1994) state that losses of phosphorus to runoff are influenced by the rate, time and method of application; the form of fertiliser; the amount and time of rainfall after application and the vegetative cover. These facts highlighted an important issue in regards to the loss of phosphorus in the period between the last the fertiliser (phosphorus) application and the runoff event studied.

This study sampled runoff of paddocks which, in the previous year (ie in 1995) had been cropped and fertilised. Past studies (McColl cited in Cullen, 1983 p. 46; Ahuja and Lehman, 1983; Gilbertson et al, cited in Sharpley & Halvorson, 1994 p. 42; Holt et al, cited in Sharpley & Halvorson, 1994. p.42) concluded that increased phosphorus loss to surface runoff occurs immediately after the application of fertilisers containing phosphorus. Black (cited in Sharpley & Halvorson, 1994. p. 44) found that a decline in residual phosphorus occurs over a time, with the decrease dependent on the amount of fertiliser applied and the number of surface runoff events. In agreement with the conclusions from these studies this study assumes that phosphorus loads from runoff immediately after the fertiliser application in 1995 would have been considerably higher than those recorded by this study. Phosphorus loads measured by this study were assumed to be representative of residual loads from cropped paddocks one year immediately after fertiliser application. The number of runoff events between the period of fertiliser application and runoff sampling by this study is unknown.

It was not possible to sample in paddocks which were tilled this year, therefore having fertilisers applied this year, due to the soil disturbance and potential channelisation of surface flow associated with the tillage practice. In addition to this, below average rainfalls severely disrupted the cropping calender with late seeding and low follow up rains. This would have made runoff sampling in these areas extremely difficult.

5.1.3.2 Sediment loads

Sediment loads in runoff from Minimum / Zero Tillage areas were also consistently high in all sampling areas. Results of this study were similar to those found by Soileau, Touchton, Hajek and Yoo (1994) who compared conventional tillage and conservation tillage (Minimum / Zero Tillage). Their study concluded that conventional tillage practices discharged twice as much sediment as conservation tillage in runoff. Sidle and Sharpley (1991) claim that catchments can experience on-going cumulative effects from such practices as past tillage practices, and past fertiliser regimes. As conventional tillage was the main form of tillage up until a few years ago, and in support of Sidle and Sharply's claims, this study makes the assumption that the effects of this practice (ie. inflated sedimentation rates) may still be affecting the catchment.

5.1.3.3 Impact of weather conditions on nutrient and sediment loss from Minimum / Zero Tillage areas.

Rainfall for the year was well below average and had severely disrupted the traditional agricultural cycle. Seeding commenced in mid to late June, and the initial rain falls prompting seeding were not followed up with additional, useful, rain. This a common problem in rain-fed agriculture throughout Australia (Smith & Finlayson, 1988). The below average rainfall for the year lead to lower than average surface vegetative cover growth resulting in large areas of exposed soils in the Minimum / Zero Tillage sampling areas.

Smith and Finlayson (p. 25, 1988) state that runoff, and the nutrient and soil loss that accompanies it, are highest on bare ground with a tendency to decrease as the percentage of vegetation cover increases. McColl (cited in Cullen, 1983, p.46), in his study on nutrient exports from a grazed pasture on silt-loam soil in New Zealand, states that nutrient concentrations in runoff are inversely correlated with grass length. Considering these two findings, this study acknowledges that the results of the runoff water quality analysis from Minimum / Zero Tillage areas may have been increased by agronomic conditions of paddocks due to the low rainfall conditions.

5.2 Catchment wide modelling

5.2.1 Spatial variation

This study recognised the existence of a large amount of information describing the physical and cultural attributes of the catchment and effectively integrated this information into the Bremer GIS.

The Bremer GIS visually presented all the GIS data coverages and allowed for the extensive analysis, interpretation and manipulation of the data coverages to uncover a number of relationships and spatial variations. In the endeavour to acknowledge these spatial variations, both GIS and Non-GIS information were used to define three distinct zones in the catchment.

Differences in sediment, salt and total phosphorus concentrations in the runoff samples collected from all land uses areas in all three zones were attributed to either or both variations in land management practices and the physical attribute variations which were used to define the zones. An example of this is the overall higher salt loads recorded in Zone 2 in comparison to the other zones, supported by the high salinity hazard rating for the Devils Creek area made by a past study (Ferdowsian et al, 1994).

5.2.2 Modelling of load data

The modelling of the extrapolated load data from the first runoff event, although in many ways a gross simplification of the catchment, indicated the potential effect each land management practice could have on a catchment-wide basis under a number of land use scenarios. The use of two modelling scenarios (Scenario Series One and Two) effectively identified the restorative potential of vegetated rehabilitation on a catchment wide basis.

Effective comparisons between the total loads generated by this model and results from past studies can not be made due to the individuality of this model and the assumptions made to confirm the validity of this model. The most pronounced conclusions possible from the various scenarios is the comparative input from each land management practice under each scenario.

Both scenario series effectively highlighted the role that remnant vegetation played on minimising total loads in the catchment. The most pronounced minimal impact was from zone one, where 44.8 % of the 28,678 hectares of the zone was under remnant vegetation. Total phosphorus, sediment and salt total loads in Zone 1 were the lowest of all zones due to the high percentage of this land management practice. In contrast the Minimum / Zero Tillage land management practice had the highest load contribution of all land management practices in each zone.

The initial modelling of total loads under the first series of scenarios indicated that an increasing proportion of the catchment under the Rehabilitated Vegetation land use could effectively decrease the total load of phosphorus into the catchment's waterways. It identified that the salt loads in runoff could not be effectively addressed by changes in land management practices. The modelling of the results also indicated an increase in sediment total loads.

The temporal assumptions which lead to the second scenario series effectively indicated that the assumed temporal changes to rehabilitated sites could, significantly decrease total loads of total phosphorus greater than the first scenario series, and reverse the increase of total suspended sediment but again salt total loads increased under increasing area of rehabilitated vegetation on a catchment wide basis.

5.2.3 Rehabilitation priorities

Modelling the load data on a zone and catchment basis has identified a number of rehabilitation priorities in certain zones. These priorities were defined by a zone area / total load ratio appraisal of the results. These priorities are :

1. Salt total loads in zone 2, in a zone area / total load appraisal, were extremely high in comparison to the other zones. This study therefore agrees with the high salinity rating assigned to this area by the past investigation into hydrological systems of the region (Ferdowsian et al, 1994). Vegetated Rehabilitation measures in this zone are necessary to combat a rising water table.

2. Sediment loads in runoff could pose an initial problem in zone 3 as areas of Vegetated Rehabilitation are increased. (This can be attributed to the medium to fine grained sandy loam soil type of this zone.) Under careful management, sediment loads in runoff from these areas should decrease over the longer term.

3. On a zone area / total load appraisal total phosphorus was considered to be a management issue in zone 2. Careful management of soil fertility, and an application-on-need fertiliser regime should be considered to effectively reduce the loss of total phosphorus in runoff from Minimum / Zero Tillage areas in this zone.

5.3 Further Studies

This study has successfully identified the potential impact of the main land management practices on catchment health. This study has not added to the knowledge of the actual health of the aquatic systems in the Bremer River catchment rather the potential inputs into the aquatic system from runoff. To confirm the findings of this study further research into the temporal changes in nutrient concentrations and loads, and the biological health of both the river and the Wellstead Estuary would be invaluable.

Further research is also necessary to quantify the loads of phosphorus lost to the first runoff event following fertiliser application. Under comparative experimental design this data could also be modelled on a catchment wide basis using methods similar to those undertaken in this study. Finally further research is also necessary to validate the assumptions made by this study in regards to temporal changes to the runoff from vegetated rehabilitation areas.

5.4 Conclusion

It appears that in runoff water sampled during this study concentrations of phosphorus and sediment were more dependent upon land management practices and within these land uses dependent upon the degree of management practices applied to an area and the period of time under a particular management practice. In contrast salt (TDS) concentrations were independent of current land management practices. The degradive impact of salinity in the Bremer catchment was concluded to be more a combined product of a rising ground-water table and geological type; a result of extensive clearing for agricultural purposes.

This study concludes that Minimum / Zero Tillage in the catchment, in combination with Vegetated Rehabilitation, will have the capacity to reduce catchment degradation caused by eutrophication and sedimentation. This study therefore calls for the further wide-spread adoption of the Vegetated Rehabilitation land management practice. Its extensive implementation, whilst addressing these two forms of degradation, may also effectively address the major salinity problems of the catchment, by altering the ground-water table. Additional changes to current land management practices are also necessary. Practices such as soil fertility testing and fertiliser application-on-need should be incorporated into the Minimum / Zero Tillage land management practice, if they haven't been already.

This study concluded that remnant vegetation areas represented the base runoff loads of sediment and total phosphorus in the runoff event sampled. Nutrient concentrations in runoff were influenced by outside factors (ie wind erosion and rainfall). This study also concluded that it is imperative that areas of natural remnant vegetation be maintained in the catchment.

The degradation of the Bremer River catchment is a result of the cumulative effects of past land management decisions in the agroecosystem. Runoff and erosion are two of the ecosystem responses that are subject to these cumulative effects (Sidle & Sharpley, 1991). It is imperative that the management of the Bremer River catchment successfully combine the management of not only the agroecosystem, on a farm basis, but also the natural ecosystem, on a catchment basis. To neglect the natural system will lead to the further degradation of all ecosystems in the catchment. A half way point has been reached were the signs of degradation are evident and have been recognised by the community. At this point in time two options are available, one is to ignore the problem, a second might be to confront the degradation issues and attempt to move towards more sustainable forms of land management. Ignoring the issue will lead to the further degradation of the catchment and in time will severely restrict current forms of agricultural production. The second option is a long term viable option essential for a sustainable rural tomorrow. This is a choice open to the people of the Bremer River catchment, as it is their past actions that lead to the catchment's degradation and it is their future actions that will lead to the catchment's rehabilitation.

In summary the following passage from United Nations Agenda 21 best sums up the concepts which will lead to a sustainable rural future in the Bremer river catchment.
".... the participation of local people and communities is crucial for the success of sustainable agriculture. The major development efforts must be to strengthen the capacity of rural institutions, extension services and local groups to take control over the safe and efficient use of the local natural resources....the ultimate goal of sustainable agriculture is to ensure that sufficient food can be produced to feed the population of the world indefinitely. To reach this goal, everyone involved in the production of food must understand the concept of sustainable agriculture. This entails a local grasp of long-term goals and objectives. From researchers to politicians, from farms to consumers; there must be a thorough understanding of the impact of human activity on the ecology of the earth.

Efforts at short-term economic gain which damage the environment in the long-term have a widespread effect, both economically and environmentally"(Sitarz, 1994, p. 93). These core concepts must be fully understood for sustainability to succeed.

REFERENCES

Ahuja, L.R. and Lehman, O.R. (1983). The Extent and Nature of Rainfall-soil Interaction in the release of Soluble Chemicals to Runoff. In Journal of Environmental Quality. 12, (1) , 34-40.

Ahuja, L.R. (1985). Characterization and modeling of Chemical Transfer to Runoff. In B.A. Stewart. Advances in Soil Science : Volume 4. (pp. 148-183) New York: Springer-Verlag.

Agricultural Chemistry Branch. (1988). Annual Report, 1988. Brisbane, Queensland: Department of Primary Industries.

Black, C.A. (Editor). (1965). Methods of Soil Analysis. Madison: American Society of Agronomy.

Carter, M. R. (Editor). (1994). Conservation Tillage in Temperate Agroecosystems. Boca Raton: Lewis Publishers.

Clesceri, L.S., Greenberg, A. E. and Trussel, R. R. (Eds). (1989). Standard Methods for the examination of Water and Wastewater. 17th Edition. American Public Health Association, American Water Works Association and Water Pollution Control Federation.

Conacher, A. and Conacher, J. (1995). Rural Land Degradation in Australia. Melbourne: Oxford University Press.

Cullen, P. (1983). Sources of nutrients to aquatic ecosystems. Proceedings of the Eutrophication Workshop 3-4 December 1980. Canberra: Australian Water Resources Council.

Cullen, P. and Lake, P.S. (July, 1995). Water Resources and Biodiversity : past, present and future problems and solutions. In Bradstock, R.A., Auld, T.D., Keith, D.A. Kingsford, R.T. , Lunney, D. and Sivertsen, D.P.(Eds.), Conserving Biodiversity :

Threats and Solutions. (pp. 115 - 125). Sydney: Surrey Beatty and Sons Pty Ltd in association with N.S.W. National Parks and Wildlife Service.

Davies, J. (Ed.). (1992). Management of Aquatic Systems : Practical Exercises and Manual of Practical Methods. Perth: School of Biological and Environmental Sciences, Murdoch University.

DeRoo, A. P. J. (1993). Validation of the ANSWERS catchment model for runoff and soil erosion simulation in catchments in The Netherlands and the United Kingdom. In K. ovar and H. P. Nachtnebel (Eds.). Application of Geographic Information Systems in Hydrology and Water Resources Management. Oxfordshire: International Association of Hydrological Sciences.

Erskine, W. (1994). River response to accelerated soil erosion in the Glenelg River Catchment, Victoria. Australian Journal of Soil and Water Conservation. 7, (2), 39-47.

Evans, J. (1994). Sharing spatial environmental information across agencies, regions and scales : Issues and solutions. In W. K. Michener, J. W. Brunt, and S. G. Stafford (Eds.), Environmental Information Management and Analysis : Ecosystem to Global Scales (pp. 203-220). London : Taylor and Francis Ltd.

Ferdowsian, R. ,McFarlane, D. and Ryder, A. (1994). Hydrological systems of the Fitzgerald Biosphere Sub-region and their future salinity. Perth: Agriculture Western Australia.

Folwer, J. and Cohen, L. (1990). Practical Statistics for Field Biology. Chichester: John Wiley and sons.

Hudson, N.W. (1993). Field Measurement of Soil Erosion and Runoff. Rome, Italy: F.A.O. (Food and Agriculture Organisation of the United Nations).

Hodgkin, E.P. and Clark, R.C. (1987). Wellstead Estuary . The Esturay of the Bremer River. Estuaries and Coastal Lagoons of South-Western Australia. Perth: Estuarine Studies Series No. 1, Environmental Protection Authority.

Hodgkin, E.P. and Clark, R.C. (1988). Beaufort Inlet and Gordon Inlet. Estuaries and Coastal Lagoons of South-Western Australia. Perth: Estuarine Studies Series No. 4, Environmental Protection Authority.

Kemp, K. (1993). Environmental modelling and GIS : dealing with spatial continuity. In K. Kovar and H.P. Nachtnebel (Eds.). Application of Geographic Information Systems in Hydrology and Water Resources Management. Oxfordshire: International Association of Hydrological Sciences.

Konrad, J. G., Baumann, J. S. and Ott, J. A. (1986). Non-point source planning and implementation in Wisconsin. In J.F. de L.G. Solbé (Ed.), Effects of Land Use on Fresh Waters : Agriculture, Forestry, Mineral Exploitation, Urbanisation. Chichester: Ellis Horwood Limited.

Lal, R. and Stewart, B. A. (1994). Soil Processes and Water Quality. In R. Lal and B.A. Stewart (Eds). Advances in Soil Science : Soil Processes and Water Quality. Boca Raton: Lewis Publishers.

Lefroy, T. and Hobbs, R. (1992). Ecological indicators for sustainable agriculture. In Australian Journal of Soil and Water Conservation, 5 (4) 22-27.

Manahan, S. E. (1990). Environmental Chemistry. Boston: Lewis Publishers.

McDonald, R.C ,Isbell, J.G., Speight, J.G., Walker, J. and Hopkins, M.S. (1990). Australian Soil and Land Survey : Field Handbook. (Second Edition). Melbourne: Inkata Press.

Moody, P.W. and Chapman, L.S. (1994). Nitrogen and Phosphorus in Agricultural Soils of North Queensland. Queensland: Department of Agriculture.

Morse, G. , Eatherall, A. and Jenkins, A. (1994). Managing Agricultural Pollution using a linked Geographical Information System and non-point source pollution model. In Water and Environmental Management. 8, (3), 277-286.

Northcote, K.H. , Bettenay, E. , Churchward, H.M. and McArthur, W.M. (1967). Atlas of Australian Soils - Explanatory Data for Sheet 5. Perth-Albany-Esperance Area. Melborune: CSIRO, Melbourne University Press.

Northcote, K.H., Hubble, G.D., Isbell, R.F., Thompson, C.H. and Bettenay, E. (1975). A Description of Australian Soils. Clayton, Victoria: Wilkie and Co. Ltd.

Ott, R. L. (1993). An Introduction to Statistical Methods and Data Analysis. (4th Edition). Belmont, California: Duxbury Press.

Overhue, T. (1995a). Soil Survey Sheet, JSI 1151 R. Williams. Unpublished report, Agriculture Western Australia, Jerramungup.

Overhue, T. (1995b). Soil Survey Sheet , JSI 1144 Cherene 2 G. Hall. Unpublished report, Agriculture Western Australia, Jerramungup.

Overhue, T. (1995c). Soil Survey Sheet, JSI 1139 Couranga K. Thomas. Unpublished report, Agriculture Western Australia, Jerramungup.

Rayment, G.E. and Higginson, F.R. (1992).Australian Laboratory Handbook of Soil and Water Chemical Methods .Melbourne: Reed International Books Australia Pty Ltd.

Rayment, G.E. and Poplawski, W.A. (Editors) (September, 1992). Training Notes on Sampling for Water Quality Monitoring. Queensland: Department of Primary Industries.

Regional Assessment Panel, South Coast Community and South Coast Regional Intiative Planning Team (1996). Draft South Coast Regional Land and Water Care Strategy : The Fitzgerald Biosphere. Unpublished Report, Albany, Western Australia.

Robinson, C.A., Ghaffarzadeh, M. and Cruse, R.M. (1996). Vegetative filter strips effects on sediment concentration in cropland runoff. In Journal of Soil and Water Conservation. 51, (3). 227-230.

Rural Traders RTC Fertilisers (no date). Fertiliser Price List : Operative from 26 September 1994. (Available from CSBP and Farmers, Perth.)

Schuman, G.E., Spomer, R. G., and Piest, R. F. (1973). Phosphorus Losses from Four Agricultural Watersheds on Missouri Valley Loess. Journal of the Soil Science Society of America. 73, 424-427.

Schwab, G. O., Fnagmeier, D. D., Elliot, W. J. and Frevert, R. K. (1993). Soil and Water Conservation Engineering. Fourth Edition. New York: John Wiley and Sons Inc.

Sharpley, A. N. (1985). Depth of Surface Soil-runoff Interaction as Affected by Rainfall, Soil Slope and Management. In Journal of the American Soil Science Society. 49, 1010-1015.

Sharpley, A. N. and Halvorson, A. D. (1994). The Management of Soil Phosphorus availability and its impact on Surface Water Quality. In Soil Process and Water Quality. Boca Raton: Lewis Publishers.

Sidle, R.C. and Sharpley, A.N. (1991). Cumulative effects of land management on soil and water resources : An overview. In Journal of Environmental Quality. 20, 1-3.

Sitarz, D. (Ed). (1994). Agenda 21 : The Earth summit strategy to save our planet. Boulder, Colarado: Earthpress.

Skalar, (n.d.). SA 1000 sampler manual and methods sheets. USA : Skalar.

Smith, D.I. and Finlayson, B. (1988). Water in Australia. Its role in environmental degradation. In R.L. Heathcote and J.A. Mabbutt. Land Water and People : Geographical essays in Australian resource management. Sydney: Allen and Unwin.

Soileau, J.M, Touchton, J.T., Hajek, B.F. and Yoo, K.H. (1994). Sediment, nitrogen and phosphorus runoff with conventional and conservation- tillage cotten in a small watershed. In Journal of soil and water conservation. 49, (1) 82-89.

Thom, R and Chin, R.J. (1984). 1 : 250,000 Geological Series - Explanitory Notes. Bremer Bay Western Australia. Sheet SI / 50-12 International Index. Geological Survey of Western Australia.

The World Commission on Environment and Development. (1990). Our Common Future. Melbourne: Oxford Univeristy Press.

Vieux, B.E. (1993). Geographic Information Systems and Non-point source water quality and quantity modelling. In K.J. Bevan and I.D. Moore (Eds). Advances in Hydrological Processes : Terrain Analysis and Distributed Modelling in Hydrology. New York: John Wiley and Sons.

Vollenweider, R.A. (1980). The loading concept as a basis for controlling eutrophication : Philosophy and preliminary results of the OECD program on eutrophication. Prog. Water Tech. 12, 5 - 38.

Wallis, R.L. and Robinson, S.J. (1992). Integrated Catchment Management in Western Australia. Proceedings of the 5th Australian Soil Conservation Conference (pp. 14-16). Perth : Department of Agriculture.

Weaver, D.M. and Prout, A.L. (1993). Changing farm practice to meet environmental objectives of nutrient loss to Oyster Harbour. In Fertilizer Research 36, 177 - 184.

Williams, W.D. (1966) Conductivity and the concentrations of Total dissolved solids in Australian Lakes. Australian Journal of Marine and Freshwater Research 17, 169 - 176.

BREMER RIVER CATCHMENT : GEOGRAPHICAL INFORMATION SYSTEM

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DOLA Topographic Series 1: 25,000 Darlingup 2729 - IV SE
DOLA Topographic Series 1: 25,000 Darlingup 2729 - IV SW
DOLA Topographic Series 1: 25,000 Darlingup 2729 - IV NE
DOLA Topographic Series 1: 25,000 Darlingup 2729 - IV NW
DOLA Topographic Series 1: 25,000 Peniup 2629 - I SE
DOLA Topographic Series 1: 25,000 Peniup 2629 - I SW
DOLA Topographic Series 1: 25,000 Peniup 2629 - I NE
DOLA Topographic Series 1: 25,000 Peniup 2629 - I NW
DOLA Topographic Series 1 : 50,000 Jerramungup - II

SOILS DATA COVERAGE.

Northcote, K.H., Bettenay, E., Churchward, H.M. and McArthur, W.M. (1967). *Atlas of Australian soils*. Sheet 5. CSIRO, Melbourne.

GEOLOGY DATA COVERAGE

Thom, R. and Chin, R.J. (1984). Geological Series, Bremer Bay Sheet SI 50-12. Geological Survey of Western Australia.

REMNANT VEGETATION DATA COVERAGE :

Remnant Vegetation 1992 provided by Spatial Information Group, Agriculture Western Australia, South Perth.

DATA COVERAGES : DRAINAGE, CATCHMENT BOUNDARY, COASTLINE FEATURES, ROADS AND TRACKS, NATIONAL PARK BOUNDARY

Provided by Water and Rivers Commission, Perth.

APPENDIX 1

The results of the Source area calculations for each replicate in each of the three land use sampling areas in each of the three zones.

Zone	Land Use	Replicate	Source Area (ha)
1	RV	1	0.73
1	RV	2	0.73
1	RV	3	0.64
1	RV	4	0.65
1	RV	5	0.94
1	REHAB	1	0.96
1	REHAB	2	0.96
1	REHAB	3	0.65
1	REHAB	4	0.72
1	REHAB	5	0.84
1	MO/T	1	1.09
1	MO/T	2	0.84
1	MO/T	3	0.94
1	MO/T	4	1.18
1	MO/T	5	0.85
2	RV	1	0.91
2	RV	2	1.5
2	RV	3	1.68
2	RV	4	1.59
2	RV	5	1.09
2	REHAB	1	1.11
2	REHAB	2	1.02
2	REHAB	3	0.95
2	REHAB	4	0.85
2	REHAB	5	0.86
2	MO/T	1	1.14
2	MO/T	2	1.14
2	MO/T	3	1.14
2	MO/T	4	0.99
2	MO/T	5	0.87
3	RV	1	0.85
3	RV	2	0.67
3	RV	3	0.98
3	RV	4	0.84
3	RV	5	0.69
3	REHAB	1	0.62
3	REHAB	2	0.48
3	REHAB	3	0.45
3	REHAB	4	0.43
3	REHAB	5	0.41
3	MO/T	1	1.04
3	MO/T	2	1.08
3	MO/T	3	1.09
3	MO/T	4	1.26
3	MO/T	5	1.20

Key : RV- Remnant Vegetation; Rehab - Vegetated Rehabilitation;
MO/T - Minimum / Zero Tillage.

APPENDIX 2

Analysis of data for Normality. In bold are the variance (VAR) values which exceeded the mean values. In the instances were thisoccurred individual replicate results were converted using a logarithmic conversion.

ZONE	SITE		VOLUME mls.	SOURCE AREA (ha)	TP mg/L	PO4 mg/L	TSS mg/ L	Mineral mg/ L	Organic mg/ L	Salinity mg/l	pH
1	RV	mean	800	0.703	0.376	0.214	215.617	184.017	31.600	252.667	7.500
		VAR.	**190000**	0.002	0.001	0.006	**21833.6**	**23530.8**	**64.480**	**24842.3**	0.630
1	REHAB	mean	890	0.826	0.462	0.317	539.880	518.785	21.092	125.400	6.880
		VAR.	**13000**	0.020	0.026	0.025	**7088.2**	**6586.1**	**63.198**	**10016.3**	0.022
1	MO/T	mean	1200	0.980	2.834	2.181	512.120	471.240	40.880	180.600	7.540
		VAR.	**345000**	0.023	0.278	0.734	**12528.9**	**15354.6**	**519.712**	**5548.80**	0.213
2	RV	mean	2375	1.295	0.184	0.020	164.652	117.752	46.641	1371.00	6.600
		VAR.	**1169167**	0.127	0.005	0.0000089	**5138.2**	**3689.1**	**183.173**	**137508**	0.087
2	REHAB	mean	3230	0.958	1.735	1.209	367.310	265.018	102.292	126.200	6.340
		VAR.	**2107000**	0.012	0.095	0.098	**11608.3**	**16015.8**	**7047.4**	**178.200**	0.173
2	MO/T	mean	3230	1.056	3.360	1.857	681.572	381.600	240.240	145.200	7.000
		VAR.	**2107000**	0.015	1.151	0.831	**251974**	**720.640**	**238157**	**8707**	0.365
3	RV	mean	800	0.787	0.389	0.293	376.533	364.133	12.400	54.333	7.533
		VAR.	**190000**	0.010	0.015	0.004	120.373	121.333	1.440	**1252.33**	0.603
3	REHAB	mean	1750	0.430	0.465	0.223	715.409	608.079	107.329	88.500	7.100
		VAR.	**1125000**	0.001	0.002	0.000	**85076.4**	**64977.4**	**1352.4**	**220.500**	0.180
3	MO/T	mean	1662.5	1.145	2.127	1.455	440.400	400.400	40.000	193.250	7.375
3		VAR.	**3618958**	0.011	0.699	0.522	**2449.39**	**1159.89**	**308.373**	**520.917**	0.016

KEY.
RV- Remnant Vegetation; REHAB - Rehabilitated Vegetation ; MO/T - Minimum / Zero Tillage; TP- Total Phosphorus; PO4 - Orthophosphate; TSS - Total Suspended Sediment; Salt - Salt (Total Dissolved Solids)

APPENDIX 3

Results of the runoff water quality analysis from individual replicates in Zone 1 from the first rainfall / runoff event.

. Site	Rep 1-5.	Volume ml.	Source Area (Ha)	TP mg/L	PO4 mg/L	TSS mg/L	Mineral mg/L	Organic mg/L	TDS mg/L	pH
RV	1	1000	0.73	0.358	0.298	147	119	28	353	7.2
RV	2	1100	0.73	0.357	0.156	385	359	26	334	6.9
RV	4	300	0.65	0.412	0.187	115	74	41	71	8.4
REHAB	1	1000	0.96	0.253	0.109	523	496	27	59	6.9
REHAB	2	800	0.96	0.319	0.247	420	406	14	103	7.1
REHAB	3	750	0.65	0.581	0.473	624	609	15	74	6.8
REHAB	4	1000	0.72	0.587	0.476	516	498	18	89	6.9
REHAB	5	900	0.84	0.569	0.28	617	585	32	302	6.7
MO/T	1	1000	1.09	3.402	2.916	442	377	65	250	7.1
MO/T	2	1200	0.84	2.393	1.433	572	546	26	262	7.4
MO/T	3	2200	0.94	2.316	1.217	677	654	23	121	8.3
MO/T	4	900	1.18	3.383	3.134	400	377	23	174	7.6
MO/T	5	700	0.85	2.675	2.207	469	402	67	96	7.3

KEY.
RV- Remnant Vegetation; REHAB - Rehabilitated Vegetation ; MO/T - Minimum / Zero Tillage; TP- Total Phosphorus; PO4 - Orthophosphate; TSS - Total Suspended Sediment; TDS - Salt (Total Dissolved Solids)

APPENDIX 4

Results of the runoff water quality analysis from individual replicates in Zone 2 from the first rainfall / runoff event.

Site	Rep 1-5.	Volume ml.	Source Area (Ha)	TP mg/L	PO4 mg/L	TSS mg/L	Mineral mg/L	Organic mg/L	TDS mg/L	pH
RV	1	1900	0.91	0.1	0.021	243	185	58	822	6.9
RV	2	3900	1.5	0.247	0.016	148	92	56	1590	6.7
RV	3	1400	1.68	0.241	0.021	74	47	27	1470	6.6
RV	5	2300	1.09	0.148	0.023	194	147	48	1602	6.2
REHAB	1	2800	1.11	1.721	1.636	190	140	50	120	**6.9**
REHAB	2	1200	1.02	1.89	1.38	362	141	221	120	**6.6**
REHAB	3	4100	0.95	2.088	0.819	414	259	155	119	**6**
REHAB	4	5050	0.85	1.256	1.153	393	378	16	122	**6.3**
REHAB	5	3000	0.86	1.718	1.056	477	408	70	150	**5.9**
MO/T	1	2800	1.14	3.687	1.142	1532	420	1113	97	**6.7**
MO/T	2	1200	1.14	3.794	1.877	368	360	8	147	**7**
MO/T	3	4100	1.14	4.762	3.364	747	400	48	304	**8**
MO/T	4	5050	0.99	2.291	1.774	377	363	14	111	**6.9**
MO/T	5	3000	0.87	2.264	1.126	384	365	19	67	**6.4**

KEY.
RV- Remnant Vegetation; REHAB - Rehabilitated Vegetation ; MO/T - Minimum / Zero Tillage; TP- Total Phosphorus; PO4 - Orthophosphate; TSS - Total Suspended Sediment; TDS - Salt (Total Dissolved Solids)

APPENDIX 5

Results of the runoff water quality analysis from individual replicates in Zone 3 from the first rainfall / runoff event.

Zone	Site	Rep 1-5.	Volume ml.	Source Area (Ha)	TP mg/L	PO4 mg/L	TSS mg/L	Mineral mg/L	Organic mg/L	TDS mg/L	pH
3	RV	1	1000	0.85	0.253	0.217	370	357	14	**26**	7.3
3	RV	2	1100	0.67	0.422	0.32	389	377	12	**43**	6.9
3	RV	4	300	0.84	0.493	0.341	370	359	11	**94**	8.4
3	REHAB	3	2500	0.45	0.494	0.231	509	428	81	99	7.4
3	REHAB	5	1000	0.41	0.436	0.214	922	788	133	78	6.8
3	MO/T	1	4500	1.04	1.389	0.729	421	391	30	204	7.5
3	MO/T	2	1000	1.08	1.424	0.96	514	448	66	188	7.2
3	MO/T	4	600	1.26	2.943	1.911	404	367	37	217	7.4
3	MO/T	5	550	1.2	2.753	2.221	423	395	28	164	7.4

KEY.
RV- Remnant Vegetation; REHAB - Rehabilitated Vegetation ; MO/T - Minimum / Zero Tillage; TP- Total Phosphorus; PO4 - Orthophosphate; TSS - Total Suspended Sediment; TDS - Salt (Total Dissolved Solids)

APPENDIX 6

Results of the runoff water quality analysis from individual replicates in Zone 1 and 3 from the second rainfall / runoff event.

Zone	Site	Rep 1-5.	Source Area (ha.)	Volume ml	TP mg/L	PO4 mg/L	TSS mg/L	Mineral mg/L	Organic mg/L	TDS mg/L	pH
1	RV	2	0.731	2100	0.049	0.027	184	156	28	247	7.11
1	RV	3	0.63	4800	0.072	0.033	136	105	31	154	7.2
1	RV	4	0.64	4600	0.062	0.018	158	120	38	52	6.83
1	RV	5	0.93	6200	0.137	0.07	190	167	23	174	6.93
1	REHAB	1	0.96	800	0.132	0.118	677	652	25	161	7.63
1	REHAB	2	0.96	400	0.133	0.117	487	443	44	131	8.45
1	REHAB	3	0.65	800	0.134	0.109	594	567	32	67	7.79
1	MO/T	1	1.085	700	1.291	0.808	518	497	27	61	6.96
1	MO/T	2	0.84	600	0.816	0.61	407	384	23	234	7.98
1	MO/T	3	0.94	750	2.028	0.791	556	507	49	119	7.63
1	MO/T	4	1.18	400	2.575	1.798	581	519	62	63	7.28
1	MO/T	5	0.85	550	1.14	0.626	445	482	63	57	7.32
3	RV	4	0.84	900	0.06	0.036	182	158	24	14.5	7.3
3	REHAB	3	0.42	3700	0.111	0.025	852	698	154	88	6.74
3	REHAB	5	0.41	600	0.178	0.042	903	720	183	83	6.97
3	MO/T	1	1.04	500	0.284	0.159	318	228	90	85	8.39
3	MO/T	4	1.26	400	0.459	0.179	498	408	90	95	
3	MO/T	5	1.20	3100	0.37	0.079	368	313	55	46	6.58

KEY.

RV- Remnant Vegetation; REHAB - Rehabilitated Vegetation ; MO/T - Minimum / Zero Tillage; TP- Total Phosphorus; PO4 - Orthophosphate; TSS - Total Suspended Sediment; TDS - Salt (Total Dissolved Solids)