CUMULATIVE EFFECTS ASSESSMENT (CEA) IN SPATIALLY UNCONSTRAINED AREA USING GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND WATER QUALITY MODELLING

Thesis submitted for the degree of
Doctor of Philosophy

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Department of Geographical and Environmental Studies
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June 2002

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ABSTRACT

Over the past twenty years, there has been development of Cumulative Effects Assessment (CEA), specifically on its methodologies. The major methodological problems have been the lack of the consideration of spatial and temporal dimensions, the use of qualitative and quantitative methodologies and the testability of the predicted effects. The main aim of this study is an attempt to improve the current methodology for CEA for spatially unconstrained areas by using types of cumulative effects as the basis for analysing cumulative effects. An estuarine environment was used as case study. Structured interviews were used in scoping and determined water quality as the selected Values Environmental component (VEC). The main methods used were Water Quality Modelling and Geographical Information Systems (GIS). Expert knowledge and statistical techniques were also employed. Four main types of cumulative effects were investigated: space crowding, temporal crowding, synergistic, and threshold. The space and temporal crowding effects were analysed together. Four water quality characteristics were, then selected as indicators: Ammonia, TKN, Chlorophyll a and Phosphate. Results from water quality modelling were used to determine magnitude of cumulative effects, whereas its combination with qualitative information through scaling and weighting were used to determine the significance of total cumulative effects. The results show that there were space and temporal crowding effects. As shown from the values of Moran indices, space crowding effects is observed, and threshold effects as well. Synergistic effects were evident when dredging was conducted. The analysis from smallest spatial scale, e.g. segments used in modelling and smallest temporal variation (only the maximum of concentrations for 12 months were selected for every water quality parameter) has assisted in determining magnitude and significance. The weakness of this proposed methodology was that significant amounts of quantitative data are needed for input into the model, which are not always available. This proposed methodology has the potential to be applied to other areas as long as monitoring data are available and could analyse qualitative data, if quantitative data are not available. The recommendation of this study is that reasonable data quantity and quality are two main components that need to be considered for the applications of this proposed methodology to result in reasonable predicted cumulative effects.

ACKNOWLEDGEMENT

My first acknowledgement is to my Principal Supervisor, Associate Professor Nicholas Harvey, for his valuable advice and constructive criticism, constant encouragement and deep interest in my research work. My acknowledgement is also to my Co Supervisor, Dr. Kym Nicolson for his patience, criticism, encouragement, strong support and deep interest in the field of Geographical Information Systems (GIS) and water quality modelling and their application on Cumulative Effects Assessment (CEA). Their profound knowledge and experience in the field of environmental assessment and GIS and the way they allowed me to share it with them, have been extremely important in my research.

I wish to thank to everyone who helped me with timely comments and suggestions during the research and those who provided me with key information that allowed me to keep up-to-date with evolving situation. Special thanks to Dr. John Cugly and Mr. Dough Fotheringham from Department of Environment Heritage and Aboriginal Affairs (DEHAA), Anita Harmar and Berity Sanders from Port Adelaide Local Councils and Stephen Darley and Tony Bazley from Local Community who provided me significant amount of information for my research. Special thank to Ms. Pat Harbisson, from pH Environment who has provided me a significant amount of information. I wish to thank to people at GISCA, especially Mr. Simon Ronald Jacobs (System Administrator) for his assistance on efficient data handling in water quality modelling. I wish to thank to Mrs. Ursula McGowan from ACUE, Monica and Chris for helping my English. A big thank you to all postgraduate students at Adelaide University, especially Ari Nugraha, Ratna Susandarini and Tan Yan for sharing ideas. Thanks also to other postgraduate students at GISCA: Asep, Emma, Rachael and Geraldine for their supports. I wish to thank to my scholarship, DUE Project in the University of Jember, Indonesia for all the support and encouragement that I received during this period. I wish to thank to my wife, Sri Andayani and my daughter, Adelia Bella Rahadiani and my parents for their patience, support and love to whom I apologise for being far from home for such long time.

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I. INTRODUCTION

1.1 The Importance of Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a systematic process that examines the environmental consequences of development actions in advance (Glasson, Therivel and Chadwick, 1999:4). As a management tool, the purpose of impact assessment is to avoid potential mistakes that can be expensive and damaging in environmental, social, and/or economic terms (Roe, Dalal-Clayton, Hughes, 1995:10).

EIA has been accepted world-wide as a formal process. Principle 17 of the Rio Declaration on Environment and Development has been regarded as international recognition of the importance of EIA (Harvey, 1998:1). As mentioned by UN (1992), this principle states that:

> Environmental impact assessment, as national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to decision of a competent national authority.

Since it was introduced in 1969 as part of US National Environmental Policy Act 1969 (Harvey, 1998:3), EIA legislation has been introduced in most developed and developing countries (Glasson, Therivel and Chadwick (1999:37-39). An European Directive approval in the 1985 stimulated the enactment of EIA legislation in many European countries in the late 1980s, whereas in Canada it was in 1973, West Germany in 1975 and France in 1976. In the UK EIA legislation has existed since 1988, following the 1985 EC directive (Glasson, Therivel and Chadwick, 1999:37). In Australia, EIA has been covered by federal legislation since 1974. EIA has also been accepted as a formal procedure for determining the adverse impacts on the environment in many countries in Asia, such as China, Sri Lanka, Thailand, Philippines, Indonesia, Bangladesh, India and the other developing countries although in some of these countries it is recognised that there have been tremendous limitations on manpower, budgets and resources (Werner, 1992).

1.2 Issues of EIA

Glasson, Therivel and Chadwick (1999:8-13) state that some of the key purposes of EIA are:

(1) an aid to decision-making;

(2) an aid to the formulation of development actions;

(3) an instrument for sustainable development.

However, EIA is considered to have failed to fulfil these purposes due to two problems: its inaccuracy in the prediction of effects and its lack of consideration of cumulative effects. The words impacts and effects will be used interchangeably for the rest of this thesis.

The essence of EIA is the prediction of impacts. Some previous studies (Tomlinson and Atkinson, 1987; Culhane, 1987; Buckley, 1991), however, suggest that producing a reasonable or accurate prediction is the main problem with EIA. Culhane (1987:217) reported that in the United States, only 30% of the impacts were unqualifiedly close to their forecasts. This may relate to the inability of current predictive techniques to produce information suitable for the assessment of impacts (Tomlinson and Atkinson, 1987). This can also relate to the less scientific prediction of impacts in the practices of EIA (Spaling, Smit and Kreuwitzer, 1993; Court, Wright and Guthrie, 1994). Buckley (1991) reported that the situation in Australia is not dissimilar to other countries in that on average the predictions of impact are less than 50% accurate (Buckley, 1991:22). The above evidence suggests that there has been a problem of prediction accuracy in the assessment of impacts.

In conjunction with accuracy, providing testable evidence of impacts is another relevant issue. Bisset (1988), for example, claims that the results of impact prediction should be treated as a hypothesis which needs to be tested. Scientifically based impact prediction has also been stimulated by other studies (Fairweather, 1989; Spaling, Smit and Kreuwitzer, 1993; Beanland and Duinker, 1984:268).

A significant problem with existing EIA is that it considers to only a small extent, the cumulative effects and interaction of impacts (Burris and Canter, 1997a,b; Spaling and Smit, 1993; Therivel and Morris, 1995). As a result, there has been little consideration on the issue of variability in impacts. Impacts vary depending on the time and on the location. Fairweather (1989) discusses the shortcoming of EIA in regard to the variability by claiming that EIA is weak in the consideration of variation on environmental attributes. Due to limited consideration of spatial and temporal dimensions in assessment, EIA is likely to overlook environmental changes which result from multiple perturbations, complex causation, higher order impacts, interacting processes, time lags, extended spatial boundaries, long term-processes, additive or interactive effects and cross-boundary movement (Beanlands and Duinker, 1984; Bedford and Preston, 1988 in Spaling and Smit, 1993:589).

The awareness of the holistic view of the environment has led to the emergence of the concept of Cumulative Effects Assessment (CEA) which was promulgated by the Council on Environmental Quality (CEQ) in July 1979 (Burris and Canter, 1997b:12). However, since this promulgation, there has been little evidence of the use of CEA in practice. In fact, the CEQ did not provide guidance regarding approaches or methodologies for addressing CEA (Burris and Canter, 1997b:12).

1.3 Cumulative Effects Assessment

Concerns related to cumulative effects assessment have emerged in the last twenty years (Vlachos, 1985; Spaling, Smit and Kreuwitser, 1993; Smit and Spaling, 1995; Spaling and Smit, 1993; MacDonald, 2000). Cumulative effects according to the Council on Environmental Quality (CEQ) in Burris and Canter (1997a:12) is

> The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time.

Reid (1998:117) comments on this definition and states that the problem with this definition is because this definition tries to include everything.

With the concept of cumulative effects, a single activity may not have significant impact, but in conjunction with other activities, its impacts could be significant. Cumulative effects could result from many activities, similar or dissimilar, big or small, as an aggregated impact. This indicates the importance of determining the spatial and temporal boundaries in order to achieve realistic CEA. In other words, space as area influenced by activities must be determined because it will determine what activities that will be included in the CEA, the methodologies for aggregating effects and the value of aggregated effects.

The basic premise underlying CEA is that everything is linked to each other, each activity is connected to others and impacts resulting from these activities also relate to other impacts (Vlachos, 1985). An assessment procedure, which addresses interrelationship/interconnectedness amongst multiple activities and impacts, should be more appropriate for the analysis of environmental impacts. This aspect of interconnectedness or interrelationship is the key component which differentiates the assessment of cumulative effects from that of a single activity.

Although Cumulative Effects Assessment is an important component in environmental assessment, it has been rarely been practised in the assessment of environmental impacts. The importance of CEA has been underscored by El-Fadel, Zeinati and Jamali (2000:600) who state that:

> cumulative effects assessment of projects over broad spatial and temporal scale is important in determining accumulation of significant environmental changes that site-specific EIAs may dismiss.

A number of studies illustrate the importance of cumulative effects. For example, Tollefson and Wipond (1998:372) provide some examples of the consequences which result from cumulative effects, such as habitat loss and fragmentation, climate modification, soil loss, decline in water quality and quantity, and pesticide accumulation. Contant and Wiggins (1993:337) illustrate how some small and repeated actions could result in significant cumulative consequences both in local (effects of development on transportation congestion, urban infrastructure, overall quality of urban life) and global (ozone depletion and acid rain) scales. Odum (1982) claims that significant changes in the environment could result from aggregated insignificant changes. In addition, Spaling and Smit (1993:587) state that spatial and temporal accumulation of impacts will lead gradually to the alteration of structural and functional aspects of biophysical systems.

Evidence of the lack of use of CEA can also be observed in the literature. Burris and Canter (1997b) and Spaling, Smith and Kreuwitzer (1993) discuss insufficient, lacking and inconsistent consideration of cumulative effects in the practices of environmental impact assessment. Possible reasons for this can also be found in literature. These reasons are:

(1) New or improved methodologies, methods and techniques are required for providing scientifically based impact prediction (Smit and Spaling, 1995; Sadler, 1996 in Canter and Sadler, 1997:1; Dixon and Montz; 1995:451).

(2) Data may be insufficient or may not be readily available to conduct CEA. This issue has been recognised globally (Court, Wright and Guthrie, 1994:6.2).

(3) Compared to single-activity assessment, higher uncertainty in the prediction is likely to result from the assessment of cumulative effects. The broader the area and the longer the time period considered, the greater the uncertainty that accompanies any impact prediction. This may inhibit the implementation of CEA as well as the acceptability of CEA results (MacDonald, 2000:309).

(4) Moving from single activity to multiple activities means that the assessment of cumulative effects should consider: the variability in the activities included in CEA (Irving and Bain, 1993; LaGory, Stull, and Vinikour, 1993); the variability of

impacts in relation to the time aspects included (McCold and Saulsbury, 1996); and the variability of the locations and their associated spatial variability of environmental parameters (Spaling and Smit, 1995).

There are a number of components that need to be addressed in CEA. Ross (1998:269) for example, claims that these components are:

(1) To identify Valued Ecosystem Components (VECs) affected by the proposed project (scoping).
(2) To determine what other past, present and future human activities have affected or will affect these VECs.
(3) To predict the impact on VECs of the project in combination with the other human activities and determine the significance of impacts.
(4) To suggest how to manage the cumulative effects.

These components have also been underscored by other studies (Council on Environmental Quality, 1997; Morgan, 1998; Court, Wright and Guthrie, 1994; Ross, 1998; MacDonald, 2000 and Irving and Bain, 1993). These fundamental components, indeed need to be developed for Cumulative Effects Assessment (CEA).

For these reasons, there is a clear need for the continued development of appropriate methodologies for Cumulative Effects Assessment. This study is therefore aimed at contributing to the development of CEA methodologies.

1.4 Problems in Cumulative Effects Assessment (CEA)

Problems in assessing cumulative effects are mostly related to the methodology. Some of the methodologically related problems are:

(1) The lack of the consideration of the use of quantitative or qualitative methodology or the combination of both.

(2) The need for the incorporation of spatial and temporal dimensions.

(3) The need for providing the testability of the predicted cumulative effects. This problem is also observed in EIA.

The first problem relates to the uses of quantitative, qualitative, or the combination of both, for predicting the magnitude and significance of cumulative effects. Some studies have proposed methodologies for cumulative effects assessment which are appropriate in situations where extensive data exist (Klock, 1985; Sidle and Hornbeck, 1991; Childers and Gosselink, 1990; Johnston, Detenbeck and Niemi, 1990; Spaling, 1995, Spaling and Smit 1995, Sebastiani, et al., 1989). These methodologies could be utilised in practice if sufficient amounts of data are available, however, this is not always the case. In contrast, the studies conducted by Irving and Bain (1993) and LaGory, Stull, Vinikour (1993), use matrices to quantify qualitative/judgement information. They basically used weighting techniques for representing impacts, the interaction of impacts and the representation of cumulative effects in one value (aggregation). Some methodologies use a purely qualitative evaluation for determination of impact significance, such as Canter and Kammath (1995).

There has been progress towards quantitative and qualitative methodologies for CEA. However, it seems that there is a dichotomy in the uses of either the qualitative or quantitative methodology. Lawrence (1993) discusses the methodological dichotomy by claiming that the combination of qualitative and quantitative methodology is the most appropriate approach in EIA. For CEA, the most appropriate methodology is likely also to be the combination of qualitative and quantitative, because data may be limited. The combination of quantitative and qualitative methodology will also assist in aggregating impacts and for the evaluation of cumulative effects.

The second problem in CEA deals with the use of spatial and temporal dimensions. Activities and their associated effects change across space and time. Therefore, a crucial issue, which needs to be addressed for the development of CEA methodology, is how to incorporate spatial and temporal dimensions into CEA. The spatial and temporal variability of water in coastal and estuarine environments can be used as an example. In this regard, the Commission on Geosciences, Environment and Resources (1995:46) for instance, claims that:

> Coastal waters exhibit tremendous spatial and temporal variability, with the additional complexity that different scales are important for different processes or group of organism. If the effects of overexploitation on the structure and composition of coastal ecosystems are to be determined, studies will need to be planned in the context of variability.

Spaling, Smit and Kreuwitzer (1993) underscore the importance of spatially related aspects in CEA, while McCold and Saulsbury (1996) emphasises the importance of time. These two studies draw attention to spatial and temporal variability in any impact assessment, including CEA. For this reason, the CEA methodology should be capable of analysing spatial and temporal dimensions. Some proposed methodologies have emphasised spatially related dimensions (Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993; Abbruzzese and Leibowitz, 1997; Green, et al., 1995), whereas others focus on temporally related dimensions (McCold and Saulsbury, 1996; Bolstad and Swank, 1997; Childers and Gosselink, 1990). A major issue in relation to the importance of spatial dimension in CEA is spatial boundary determination.

Regarding the spatial boundaries used for the analysis of CEA, previous methodologies mostly use watersheds as boundaries. In this regard, Reid (1993) describes the complexity in analysing watershed cumulative effects and provides a number of examples of previous methodologies applied to watershed analysis. Some examples of these methodologies are: Equivalent Clearcut Area (ECA), Klock Watershed Cumulative Effects Analysis (KWCEA), Equivalent Roaded Area (ERA), R-1/R-4 Sediment Fish Model (S/F) and Rational Approach(RA). As he recognised, the scientific basis for most of these methodologies is poor (Reid, 1993:33). In term of the sources of these methodologies, he concluded that:

> Methodologies for CEA, which originate from management agencies, tend to be simple, incomplete, theoretically unsound, invalidated, implemented by field personnel and heavily used. Methodologies developed by researchers are more likely to be complex, incomplete, theoretically sound, validated, require expert operators and not used.

The above provides evidence of the use of the watersheds as a spatial boundary for CEA, however examples of methodologies for CEA in other situations, such as coastal and estuarine areas are very limited. Although coastal and estuarine environments can be regarded as part of a watershed, they have a prominent characteristic in that these are the environments that have a direct contact with open sea as well as accepting freshwater input. The estuarine environment will be the main emphasis of this study. The definition of estuary used in this study refers to Kjerfve in Alongi (1998:186):

> An estuary system is a coastal indentation that has a restricted connection to the ocean and remains open at least intermittently. The estuarine system can be subdivided into three regions (a) a tidal river zone - a fluvial zone characterised by lack of ocean salinity but subject to tidal rise and fall of sea level; (b) a mixing zone (the estuary proper) characterised by water mass mixing and existence of strong gradients of physical, chemical and biotic quantities reaching from the tidal river zone to the seaward location of a river mouth or ebb-tidal delta; and (c) a near shore turbid zone in the open ocean between the mixing zone and the seaward edge of the tidal plume at full ebb tide.

As Alongi (1998:186) claims, this definition places an estuary in the context of the coastal zone. The third zone of an estuary, zone C (as defined above), exhibits the through contact of an estuary to the open sea. Because of its direct contact to the sea, in terms of CEA spatial boundary, estuaries are unconstrained areas and for the purpose of CEA, a different approach is needed.

Vestel and Rieser (1995:53) have underscored the possible problems encountered for the applications of CEA in coastal and estuarine environments as follow:

> Coastal or marine ecological processes may not involve the same organising principles and may not lend themselves to mapping with the same ease of terrestrial features. For example, the issues of patch size, ability to move between different patches, and amount of edge and interior may not be as relevant in a coastal/marine context. But at the same time, many of the impacts on coastal marine systems are caused by activities on the land such as land use change, non-point source pollution, and increased recreational use of waterfront land. It may be appropriate to use landscape ecology approaches to assess terrestrial effects on marine aquatic resources in these circumstances. Additional research is required to identify appropriate organising principles to facilitate assessments of different types of environmental impacts at regional scale for estuarine and near-shore ecosystems..

Their statement highlights the different patterns of organisation of coastal and estuarine environments compared to the terrestrial environment, leading to the demand for the establishment of an appropriate approach. However, as they state, the existing land-based framework and methodologies for CEA could potentially be applied in coastal and estuarine environments.

The third problem in CEA, that also occurs in EIA, relates to the procedures to provide testable evidence of predicted impacts. This highlights the importance of available monitoring data for testing the results of cumulative effects prediction, and also relates to the choice of appropriate methods for CEA. Smit and Spaling (1995:101) claim that "the wide range of available methods, and their evolving nature, provides a rationale for methodological pluralism". In relation to the testability of the predicted impacts, the use of quantitative predictions is recommended for the purpose of comparison of predicted impacts with the actual ones. In other words, the predicted cumulative effects should be audited for the refinement of the methodologies used. In relation to prediction of water quality in the coastal areas, the Commision on Geosciences, Environment and Resources (1995: 47) claims that

> To improve predictions for use in environmental management, the effects of multiple stressors must be assessed in ways that differentiate the individual and collective effects of stressors. The consequence of these effects must be applied over a range of the spatial and temporal scales. This notion is at the heart of understanding what are often called cumulative effects.

This statement draws attention to the importance of improving the quality of prediction (accuracy) of effects from multiple stressors, and considers the spatial and temporal dimensions. Improving the quality of the prediction of cumulative effects means quantitative data must be available to objectively assess and to compare the performance of the conditions of the environments due to the combination of stressors. The quantitative information on the stressors must also exist to allow the effects of individual and collective stressors to be assessed.

Magnitude is one of components which determine the significance of cumulative effects (Council on Environmental Quality, 1997:44; Andrews, et al. in Duinker and Beanland, 1986). Due to the nature of cumulative effects as the aggregation of effects that have different measures, it is considered difficult to provide information on cumulative effects, which can be compared directly to measured data. For this reason, the relative comparison of the significance may be more appropriate for CEA, although the magnitude of cumulative effects can be directly compared to the measured data. Therefore, it can be argued that the testable evidence of cumulative effects is more likely to relate to the magnitude than the significance of cumulative effects. By considering the fact that the significance determination must relate to the "context" and "intensity" (Council on Environmental Quality, 1997; Duinker and Beanland, 1986), the direct comparison of the significance cumulative effects is considered difficult for cumulative effects. Another component that relates to the difficulty in comparing the significance of cumulative effects and the measured values is the fact that the significance of cumulative effects is the results of the combination (amalgamation) of effects. Consequently, the aggregated value "hides the strengths and weaknesses of options by reducing all the information to a single figure" (Morgan, 1998:248) so that the predicted significance of cumulative effects can not be directly compared to the measured data. From the above, it is clear that magnitude of cumulative effects can possibly be compared to the measured data, but comparing the significance of cumulative effects to the measured data is difficult.

The determination of impact significance underlies the importance of the combination of qualitative and quantitative methodologies to resolve the problems in CEA. More importantly, determining impact significance is the main aim of any impact assessment and the most obvious characteristic of significance determination is the use of objective and subjective considerations (Duinker and Beanland, 1986; Council on Environmental Quality, 1997). Therefore, this stage must be as quantitative as possible. The determination of the significance of effects is a different issue which involve the "context" so that quantitative information alone is considered insufficient for analysing the significance of environmental effects. A combination of quantitative and qualitative information is likely to be the most appropriate approach for the determination of significance. Besides the issue of qualitative and quantitative, other fundamental issues for determining the significance of CEA are obvious. The addition of spatial and temporal dimensions requires different approach to conduct CEA. These components are the main emphasis of this study.

To resolve these three problems above, an appropriate framework must be developed and the most appropriate framework is likely to be based on the types of cumulative effects. The most important reason underlying this is that types of cumulative effects represent the nature of cumulative effects. The following discussion will illustrate the importance of types of cumulative effects.

There are at least four types of cumulative effects that are often found in the CEA literature, such as space crowding, temporal crowding, threshold and synergistic effects. The study of the types of cumulative effects is limited, despite a number of definitions and descriptions. Each type of cumulative effect occurs as a result of different mechanism and also has different characteristics. For example, Spaling and Smit (1993:593) claim, "space crowding is a high spatial density of environmental change that can alter a region's spatial pattern". This shows that the mechanism of the accumulation is due to the high spatial density of activities. The definition of temporal crowding type of cumulative effects is as follow (Smit and Spaling, 1995:87).

> Temporal crowding occurs when the interval between one perturbation and succeeding perturbations is too small for an environmental system, or system component or process, to assimilate or recover from the perturbations.

From the definition of temporal crowding, it is apparent that the timing of perturbation is an important component of the cumulative effects. The Council on Environmental Quality (1997:9) define threshold or triggers as "disruption to environmental components or processes that fundamentally alter system behaviour or structure of functions" and according to Morgan (1998:202) synergistic cumulative effects are defined as "the effects of two or more impacts being exacerbated by their coincidence in the same place on same environmental system".

More mechanistic types of cumulative effects have also been proposed by Reid (1993), such as same–influence effects, complimentary effects, cascading effects and interdependent effects. Other definitions of the types of cumulative effects can be seen in Chapter II (Literature Review). During the history of effects in a particular area and particular time, a different type of cumulative effects may occur, or more than one types may occur together and the intensities are likely to vary spatially and temporally. This can result in either temporary or permanent types of cumulative effects.

Temporary cumulative effects, as defined by Geppert, Lorenz and Larson (1985:22) in a forestry application, are those for which we can foresee at some point in the future the re-establishment of a baseline condition before recurrence of forest practices. On the other hand, as they defined, persistent cumulative effects are obviously long term, but of greater importance, their duration is indefinite. In addition, they also claim that the temporary cumulative effects have the potential to become persistent cumulative effects and conversely persistent cumulative effects to become temporary cumulative effects. Although these definitions were designed for forestry applications, they can be applied to other areas of application as long as there exists baseline information.

The presence or absence of these types of cumulative effect depends on the complex interaction of activities and their associated impacts and environmental components. The key component to analyse the types of cumulative effects is likely to be the understanding the variability of environmental processes, environmental components and their responses. In an estuarine environment, an activity or a combination of activities may not have significance impact on the overall water body, the impacts may only occur in localised areas surrounding activity(s). It may be also the case that, different types of cumulative effects may occur because of the introduction of new activities along the continuum. This can result in different types of cumulative effects to occur in an estuary. Therefore the spatial and temporal variability is a fundamental feature, which is likely to assist not only in the determination of types of cumulative effects, which then assist in aggregating impacts for the determination of magnitude and significance of cumulative effects, but also the acquisition of knowledge on a complex interaction amongst environmental stressors and responses. Considering this, CEA in estuarine environment must consider types of cumulative effects as the framework.

From this discussion, it can be concluded that:

(1) Since its promulgation, CEA has been considered to have a major problem in its methodologies. It appears that there has not been agreement about how to conduct CEA in conjunction with some basic issues: the uses of qualitative and quantitative methodologies, the incorporation of spatial and temporal dimensions, and the testability of the predicted cumulative effects.

(2) Variations exist in terms of the dimensions included in CEA and how to use them. Two dimensions needed to improve CEA are: spatial and temporal and how to incorporate them for the determination of impact magnitude and impact significance, how to provide testable evidence on predicted cumulative effects and how to cover the variability of the environmental stressors, responses and their interactions.

(3) Estuarine and coastal areas, as dynamic ecosystems have been rarely studied for Cumulative Effects Assessment. The different ecological principles may determine the way CEA should be conducted in estuarine and coastal environments.

(4) Types of cumulative effects have rarely been investigated as to how they are determined and how important they are for cumulative effects assessment.

Therefore there is a need to conduct research on CEA and develop appropriate methodologies for unconstrained areas, such as an estuarine environment by incorporating spatial and temporal dimensions, variability of the environment, activities and their associated effects and types of cumulative effects. Because estuarine environments have rarely been considered with regard to CEA, this environment will be the main focus in this study.

1.5 Research Objectives

The main aim of this study is to improve the existing methodologies for CEA in estuarine areas by incorporating spatial and temporal dimensions and using types of cumulative effects as the main component for analysing the significance of cumulative effects.

Several guiding objectives are:

(1) To study the existing methodologies for cumulative effects assessment:

- To study the literature which relates to the methodologies for cumulative effects assessment.
- To establish the criteria to be used in the evaluation of methodologies for cumulative effects assessment.

(2) To evaluate existing methodologies for cumulative effects assessment:

- To compare the criteria in the existing methodologies.
- To evaluate the existing methodologies.

(3) To determine the conceptual framework for the improvement of the existing methodologies and to determine the proposed methodology:

- To determine the theoretical framework used in the proposed methodology in the estuary.
- To review, understand and use the processes in estuaries and develop a theoretical framework based on this.
- To determine stages used in the proposed methodology.
- To study the methods for CEA.

(4) To test the improved methodology using the case study:

- To apply the improved methodology to the selected estuary.
- To evaluate the proposed methodology.

To summarise, the major problem in CEA is regarding the methodology. Some characteristics that need to be included for the improvement of current methodologies are:

(1) The inclusion of spatial and temporal dimensions and the procedure to include these dimensions in CEA This also includes the consideration of the component of variability.

(2) The use of qualitative and quantitative methodologies.

(3) The testable evidence of cumulative effects.

1.6 The Structure of This Thesis

This thesis consists of nine chapters. The brief description of the content of each chapter is as follows. Chapter 2 reviews existing literature on CEA. This will cover the description of the existing methodologies for CEA and their strengths and weaknesses. This chapter will start form the description on the methods that have been used in the assessment of environmental impact on single activity. This chapter will also cover the following components: qualitative and quantitative methodologies for CEA, quantification of subjective judgement, scoping and types of cumulative effects.

Chapter 3 provides a description of study area used as the case study, that is Port Adelaide and Barker Inlet estuaries. These areas have experienced major environmental problems, such as water quality degradation and mangrove and seagrass losses. The activities and their impacts on the environment will be described in order to provide information of the reasons for choosing the study area as the case study for cumulative effects assessment.

Chapter 4 is aimed at providing the theoretical framework used for the proposed methodology. This is mainly intended to show conceptually how CEA can be conducted by considering processes occurred in estuary.

Chapter 5 deals with scoping. As an important part of the proposed methodology, this chapter will demonstrate the methodology used and the results obtained from scoping and some other crucial information for further analysis in CEA. This chapter will also provide information on the importance of scoping in determining some techniques and methods used for further analysis in CEA.

Chapter 6 deals with water quality. This covers some aspects of the most important Valued Environmental Component (VEC) in the study area, that is water. The spatial and temporal characteristics and water quality modelling are covered. The main aim of this chapter will be to demonstrate the use of trend analysis, Geographical Information Systems (GIS) and water quality modelling for analysis of cumulative effects.

Chapter 7 addresses cumulative effects. There are two main components in this chapter: the analysis of impact types (spatial crowded, temporal crowded, synergistic, threshold) and the aggregation of effects. This chapter will examine the roles of the existing methods for cumulative effect assessment, especially Geographical Information Systems (GIS), environmental modelling and for analysing types for cumulative effects and aggregating effects. This chapter will show that types of cumulative effects can provide the aggregation of effects. Using GIS and modelling demonstrated that uncertainty can be minimised by using the quantitative values while variability of spatial attributes are maintained by using Geographical Information Systems.

Chapter 8 provides an evaluation of the proposed methodology for CEA. This chapter describes some of obstacles and benefits of the proposed methodology. This is followed by the conclusion (Chapter 9).

II. REVIEW OF EXISTING METHODOLOGIES FOR CUMULATIVE EFFECTS ASSESSMENT (CEA)

2.1 Introduction

Compared to the methodologies for single project assessment, those for CEA are far more complex due to the need to:

1. Determine which impacts should be pursued for further analysis.
2. Bound the analysis in the spatial and temporal dimension and use spatial and temporal dimensions for the determination of impact magnitude and impact significance.
3. Determine appropriate indicators for CEA.
4. Determine appropriate methods and techniques in the situations where data are limited.
5. Aggregate impacts for the purpose of determining impact magnitude and impact significance, which will also include some other issues, such as the uses of qualitative and quantitative methodologies, providing the testable evidence of cumulative effects predicted and the uses of spatial and temporal dimensions.

This chapter is a review of these issues. It will first consider methodologies for impact assessment pertinent to a single activity and discuss their possible applications to CEA. This is followed by a review of the development of methodologies for CEA.

2.2 Existing Methodologies for Environmental Impact Assessment (EIA) and their Deficiencies in Addressing Cumulative Effects

The following definitions of methodology, methods and techniques are adopted by Morgan (1998:3). These definitions will be used in the rest of this thesis.

> (1) Methodology is overall strategy used to manage an impact assessment, together with the methods and techniques that are to be used to examine specific issues within the impact assessment. The methodology provides the organizing framework for the impact assessment, ensuring that all the various subsidiary activities are working to produce information for the same basic purpose: to inform decision makers, the proponents and the public of the environmental consequence of the proposed action.
>
> (2) Methods are approaches devised to tackle more specific issues.
>
> (3) Technique is the technical tools used within methods to achieve certain ends.

Table 2.1 shows the methods used for the prediction of impacts. As can be seen from this table, most methods only deal with the direct impacts. Some of them (Simulation modelling, Scenarios, Component Interaction Matrix, Interaction Matrix and Sorensen Network) are potentially capable of analysing long term and indirect impacts. There are only two methods, which address the cumulative effects: Network and Sound Ecological Principles. The network methodology may be meaningful for the assessment of cumulative effects, particularly in the assessment of impact interaction. As shown in this table, there are limited numbers of EIA methods which can assess the environmental effects of multiple activities on the environment.

2.3 Development of Cumulative Effect Assessment (CEA)

Concern about cumulative effects has been raised since 1976 when the Council on Environmental Quality (CEQ) promulgated regulations (Burris and Canter, 1997a:12). Since then, there have been debates and opinion in the literature which relate to the theoretical framework and the methodology-related issues in CEA. As a result, there have been efforts to build and evaluate methodologies for CEA (Smit and Spaling, 1995, Klock, 1985; LaGory, Stull and Vinikour, 1993; Irving and Bain, 1993; Sebastiani et al., 1989; Proett, 1987; Sidle and Hornbeck, 1991; Childers and

Gosselink, 1990; Johnston, Detenbeck and Niemi, 1990; Spaling and Smit, 1995, Spaling 1995; Damman, Cressman and Sadar, 1995; Cocklin, Parker, and Hay, 1992b; McAllister, Overton and Brill, 1996; Abbruzzese and Leibowitz, 1997); the application of a particular method, such as Geographical Information Systems in real and hypothetical areas (Green et al., 1995; Cocklin, Parker and Hay, 1992a,b; and Johnston et al., 1988); and also efforts to view and review concepts and frameworks (Vlachos, 1985; McCold and Saulsbury, 1996; Preston and Bedford, 1988; Contant and Wiggins, 1993; Spaling and Smit, 1993; Spaling, 1995; MacDonald, 2000).

Table 2.1 Methods in Existing EIA and Possible Impacts Predicted
(Sources: Analysis from Literature)

No.	Methods	Class of Method ology	Predicted Impacts	References
1	Checklist	Structural	Direct	Bisset, 1988
2	Matrix	Structural	Direct	Bisset,1984
3	Network	Structural	synergetic, cumulative	Wathern, 1984; Rau (1980)
4	Delphi	Structural	Direct	Miller, 1984
5	Scenarios	Structural	Future	Brewer, 1986
6	Simulation Modeling	Structural	direct, indirect	Bisset, 1988
7	Cost-Benefit Analysis	Structural	long-term	Jarvis and Younger, 2000
8	Overlays	Structural	Direct	Wathern, 1988
9	Threshold Analysis	Structural	Direct	Kozlowski, 1990
10	Amalgamation Method	Structural	Direct	Canter, 1991;
11	Scaling Checklist	Functional	Direct	Bisset, 1984; Canter, 1991
12	Component Interaction Matrix	Functional	Indirect	Wathern, 1984
13	System Diagram	Functional	Direct	Bisset, 1988
14	Land-Suitability Analysis	Functional	Direct	Dickert and Tuttle, 1985
15	KSIM-Cross Impact Simulation	Functional	direct	Holling, 1978
16	Decision Support Systems	Functional	Direct	Colorni, Laniado, Muratori, 1999; Howells, Edwards-Jones and Morgan, 1998
17	Scaling/Rating/Ranking -Weighting Checklists	Integrated	Direct	Bisset, 1984; Canter, 1991
18	Interaction Matrix	Integrated	direct, indirect	Bisset, 1984; Canter, 1991; Leopold et al., 1971.
19	Sorensen Network	Integrated	direct, indirect	Wathern, 1984
20	Multi-attribute Utility Theory	Integrated	Direct	Bisset, 1988; Canter, 1991
21	Sound Ecological Principles	Integrated	direct, indirect, possibly cumulative	Beanlands and Duinker,1984; Bisset, 1988

Despite many debates, opinions, and reviews of the reported methodologies, their application to the cumulative effects assessment has been very limited. As a result, there have been very few efforts to validate and evaluate the methods, and more importantly, methodologies they proposed are rarely used. The main aim of this chapter is to evaluate the existing methodologies and suggest improvements to the current methodologies for cumulative impact assessment.

2.4 Methodology for Cumulative Effects Assessment

Chapter 1 (section 1.4) has provided the problems in CEA. The following discussion will explain the problems of CEA as illustrated in Chapter 1 and grouped according to the following component: application of CEA, the qualitative and quantitative methodologies, spatial and temporal boundaries, scoping, the determination of VEC, the determination of magnitude and significance of cumulative effects and then the methods used for CEA. The reasons for using this structure are that:

(1) The information about which area the CEA has been applied is crucial because every area of application requires different methodologies. Therefore, this is aimed at obtaining information about the general information about stages used in the methodologies.

(2) The information about the qualitative and quantitative methodologies for CEA is important because this is a component that must be improved in the development of methodology for CEA as illustrated in Chapter 1 (section 1.4). Detailed discussion of this can be seen in the following discussion.

(3) The determination of spatial and temporal boundaries is also a fundamental problem in CEA (this also has been explained in Chapter 1, section 1.4).

(4) Although the determination of spatial and temporal boundaries, the determination of VEC and the selection of methods used for CEA could be part of scoping stage in CEA, they are discussed in separate section because this is to strengthen that they are a different issues that need particular attention in building a methodology for CEA.

Therefore, the division of the sub and the sub-sub section is based on the main problems in the methodology for CEA and this is not based on the stages used in CEA.

2.4.1 Applications of CEA

Table 2.2 shows a summary of conceptual frameworks and applications of methodologies used in CEA sorted by dates. As can be seen, applications of CEA are various. Watershed/landuse planning seem to dominate the applications. Nine out of 36 applications and conceptual frameworks for CEA under investigation have used CEA on watershed/landuse planning. Five studies are in forestry. The number of studies which apply CEA to wetlands, agriculture and electricity development is seven, two and two respectively. On the other hand, only two CEA studies were in the estuarine environment while there was only one study on oilfields. Studies which relate to the conceptual framework, have the potential to be applied to other fields. As shown in Table 2.2, there are variations in the methodology for CEA.

Another main characteristic of previous studies on CEA is that they usually start from an understanding of the main issues, processes, data and indicators in the study area, then, methodologies were developed. This kind of understanding also assists in the determination of the particular methodology used.

2.4.2 Quantitative and Qualitative Methodologies

The literature indicates that there are two major classes of methodologies, qualitative and quantitative. MacDonald (2000:308) claims that

> Thus, current methodologies for evaluating CEs range from qualitative, low-cost, and less explicit procedures to quantitative, high cost, and more explicit models. At least in theory, the qualitative procedures should have greater uncertainty and less defensible.

This statement shows that there are two main methodologies for Cumulative Effects Assessment. This statement also underscores the differences between qualitative and quantitative methodologies for Cumulative Effects Assessment. This section describes previous studies on CEA and evaluates the uses of qualitative and quantitative methodologies. A more specific way to classify the methodologies for CEA was proposed by Morgan (1998) who classifies methodologies for cumulative effects assessment (CEA) into two broad categories: (1) quantitative/matrices and (2) effect oriented/qualitative. In the first group, the calculation of total impacts (cumulative impacts) was conducted by means of matrices to produce quantitative values, whereas overlay and network analysis are examples of qualitative methodologies.

2.4.2.1 Quantitative/Matrices Methodologies

The study by Irving and Bain (1993) is an example of using the quantitative/matrices methodology for CEA. This study used matrices to determine the impact accumulation. Some stages in their methodology are:

(1) Geographic scoping.

(2) Resource scoping.

(3) Multiple project assessment, involving: (a) impact values are assigned to resource component; (b) impact interaction among projects is assessed; (c) matrices calculation is used to obtain the total impact; (d) running scenario.

(4) Documentation.

LaGory, Stull and Vinikour (1993) provide another example of the quantitative methodology for cumulative impact assessment. Some stages in their methodology are:

(1) Investigating and determining the relationship among projects.

(2) Conducting single-project assessments.

(3) Calculating the interaction coefficients.

(4) Calculating the adjusted cumulative effects.

(5) Modifying the effects of shared project features.

(6) Combining the effects of existing projects.

In their proposed methodology, LaGory, Stull and Vinikour (l993) use the concept of "Impact zone" and employ the impact zone to determine the overlapped impacts. These two studies used matrices to calculate the total cumulative effects. The uses of matrices to calculate total cumulative effects can also be observed in the study by Proett (1987).

Although these three studies (Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993 and Proett, 1987) could be considered as quantitative in terms of the uses of mathematical formulation to derive a total impact, they contain qualitative elements in terms of the input data used since the values entered for quantification were obtained from subjective judgment. The weakness is clear in that it is difficult to validate the results, although the quantification of qualitative information has been a common technique in environmental impact assessment (Sondheim, 1978; Shopley and Fuggle, 1984).

The main advantage of this kind of methodology is its simplicity. The main disadvantage is that this is scientifically very difficult to validate. The quantification of qualitative values can be seen in some other studies (Klock, 1985; Irving and Bain, 1993; Abbruzzese and Leibowitz, 1997; Cobourn, 1989; Green et al., 1993; Sawyer et al., 1996; Purves and Doering, 1998). From these studies, it is apparent that quantification of qualitative judgment could be used in CEA for the determination of a single value of total cumulative effects, in the form of index.

Some of the above studies indicate that, despite the flexibility offered in terms of the way to combine impacts, the methodology of quantifying the qualitative measures may only be appropriate for the assessment of similar activities and for a single

Table 2.2 Summary of Conceptual Framework and Applications of Methodologies for Cumulative Effects Assessment sorted by date (Sources: Literature Study)

No.	Title and Authors	Methodologies	Applications	Spatial Boundary	Temporal Boundary	Aggregation for assessing significance and magnitude	Indicator(s)	The use of GIS and Environmental Model (Yes/No)	Terminologies for Cumulative Effects (Yes/No)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	Cumulative Silvicultural Impacts on Watershed: A Hydrologic and Regulatory Dilemma (Coats and Miller, 1981)	• Quantitative	• forestry (timber harvest activities)	• watershed was used as the unit for cumulative effects assessment	• historical records on the number of fish	• assessing only magnitude of impact, not significance; • results: the changes of land from road and other activities improved sedimentation, reducing water quality and consequently has cumulative effects on fish	• fish (fish decline) • habitat degradation obtained from aerial photograph	• No	• No
2.	Modelling the Cumulative Effects of Forest Practices on Downstream Aquatic Ecosystems (Klock, 1985)	• quantitative analysis of risk of stream quality and quantity from forest practices; • uses "annual index values" from formula to represent the cumulative impact; • the model developed was Watershed Cumulative Effects Analysis (KWCEA); • basically this is the risk analysis index of watershed if additional activities are added; • the values of indices were used to assess the cumulative impact risk classes: low, medium and high.	• forestry	• Watershed;	• from the first forest activity to the year of 1980; • considering past, present and future watershed forest activities;	• the index and threshold were used to determine significance; • aggregation was conducted by using formula; • results show that in 1960 the cumulative index = 0; between 1968 and 1980, the cumulative index value was greater than 1, moderate cumulative risk.	• Index obtained from the combination of key watershed parameters which affect water quality and quantity: site erosivity, site surface erosion factor, slope stability factor, hydrologic sensitivity characteristic, topography factor, area of activity, total area of watershed.	• No	• No
3	Cumulative Impact Assessment in Environmental Planning : A Coastal Wetland Watershed Example (Dickert and Tuttle, 1985)	• a model of land use planning system which involve a time series approach; • This consists of four main components: evaluation of erosion susceptibility, measurement of land disturbance, establishment of a land disturbance target and a comparison of existing and target land disturbance values;	• watershed planning	• many activities	• historical, present and future	• threshold of bare ground exposure; • results : target approach has benefit in its ability to evaluate the potential of cumulative effects of both proposed plan changes and the specific project proposal	• land disturbance target (area)	• No	• Assumed to be additive

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
4	Modelling the Cumulative Effects of Forest Practices on Downstream Aquatic Ecosystems (Klock, 1985)	• quantitative analysis of risk of stream quality and quantity from forest practices; • uses "annual index values" from formula to represent the cumulative impact; • the model developed was Watershed Cumulative Effects Analysis (KWCEA); • basically this is the risk analysis index of watershed if additional activities are added; • the values of indices were used to assess the cumulative impact risk classes: low, medium and high.	• forestry	• Watershed;	• from the first forest activity to the year of 1980; • considering past, present and future watershed forest activities;	• the index and threshold were used to determine significance; • aggregation was conducted by using formula; • results show that in 1960 the cumulative index = 0; between 1968 and 1980, the cumulative index value was greater than 1, moderate cumulative risk.	• Index obtained from the combination of key watershed parameters which affect water quality and quantity: site erosivity, site surface erosion factor, slope stability factor, hydrologic sensitivity characteristic, topography factor, area of activity, total area of watershed.	• No	• No
5	Use of Geobotanical Maps and Automated Mapping Techniques to Examine Cumulative Impacts in the Prudhoe Bay Oilfield, Alaska (Walker, et al. 1986)	• use the rate and extent of impacts in that have already occurred to determine cumulative impact •	• oilfield development	• Bay	• Historical spatial data	• time series analysis of the maps of disturbance; • results: considering first order effect, the loss of area due to the development of road levelled off, whereas the areas covered by gravel road linearly increased; considering indirect effect (particularly flooding), the areas occupied by flooding far exceed the direct effect.; the anthropogenic impacts within this area from 1968 to 1983 were two orders of magnitude greater than the natural disturbance within the same area from 1949 to 1983, that is 746 Ha versus 8 Ha).	• disturbance map	• GIS were used, environmental model was not used	• Additive

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
6	Cumulative Impacts of Hydroelectric Development: Beyond The Cluster impact Assessment Procedure (Proett, 1987)	• the methodology used was called "Cluster Impact Assessment Procedure (CIAP); • scoping of cumulative effects was conducted by using : (1) geographic sort; (2) the resource sort; (3) the assessment of impact magnitude by means of matrices; • Multiple Projects Assessment (MPA) is the analytical heart of the CIAP aimed at determining the potential significant cumulative adverse effects; • MPA consist of two main stages: (1) the impact assessment stage and (2) the matrices analysis stage/multi-project impact modelling; • interaction between projects is the main component	• hydroelec-tric develop-ment	• the boundary of some activities related to electricity	• total value of impact does not account for historical information of effects	• significance of impacts is determined by using matrices to produce a total cumulative effects level; • results : the methodology contained in this article is mainly oriented on the way of organising many information rather than accurate prediction of cumulative effects.	• subjective impact level	• No	• Additive
7.	Geographic Information Systems for Cumulative Impact Assessment (Johnston, et al, 1988)	• stages of the methodology in this article : (1) collection of water quality data and aerial photographs; (2) GIS analysis to determine wetland loss and gain; statistical analysis; (3) cumulative impact assessment which relate to the position on landscape	• wetland	• watershed • many activities included in this assessment	• long term historical data	• statistical analysis : Principal Component Analysis (PCA) was used; • results: cumulative effect of wetland on regional water quality depends on the location of wetland in the watershed;	• water quality	• the results of GIS analysis were used for input to statistical analysis	• Assuming the additive cumulative environmental change

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
8.	Evaluating cumulative effects on wetland functions: a conceptual overview and generic framework (Preston and Bedford, 1988)	• There are two main components of methodology • First component : Structuring evaluation, consisting of stages: (1) establish boundaries and quantitative measurable variables; (2) establish descriptive measures of system structural attributed and (3) establish descriptive measures of action; • Evaluation consists of stages: (1) catalogging human activities; (2) Estimating the effects on environmental attributes; (3) Estimating cumulative impact on function	• watershed manag. with reference to the functional characteristics of wetlands	• watershed area: watershed with many wetlands in it; • all activities within wetlands of concern must be included in CEA	• temporal aspect include season to season variation and year to year variation	• quantitative and qualitative threshold could be used to assess the significance;	• functional characteristics of wetlands in watershed: flood storage, water quality and life support	• No	• No
9.	Management of The Estuarine Ecosystem Against Effects of Pollution and Development (Waldhichuk, 1988)	• using food chain to understand the disruption of salmon • using graph of trend analysis to determine the degradation of salmon; • relating the destruction of food-chain and loss of salmon	• industrial and urban development	• spatially unconstrained: estuary	• not long term data	• the significance was calculated from the loss of salmon	• salmon	• No	• No
10.	Cumulative Impact and Sequential Geographical Analysis as Tools for Land Use Planning. A Case Study: Laguna La Reina, Miranda, State, Venezuela (Sebastiani, Sambrano, Villamizar and Villalba, 1989)	• spatial data to derive the areal extent; • the methodology used was called SGA (Sequential Geographical Analysis); • the sequence of land occupation and the changes associated with it are studied for a time span from 1949 to 1986;	• land use planning	• watershed area;	• historical data of spatial information (landuse)	• only determine the magnitude of impact through the changes of landuse • results : the result indicate that the SGA could be useful tool for planning.	• Changes of area of landuse	• They do not use GIS, although GIS have potentials to be applied	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11.	Is Cumulative Watershed Effects Analysis Coming of Age ? (Cobourn, 1989)	• quantification from qualitative information; • use indexes and weights; • subjective determination of TOC (Threshold of Concern)	• watershed planning	• watershed	• historical information on the landscape disturbance;	• relative cumulative impact significance; • results : this methodology provides the relative cumulative effects significant; co-ordination is very important for the future cumulative effect assessment of watershed.	• land disturbance history; • sensitivity;	• No	• No
12.	The Cumulative Effects of Wetlands on Stream Water Quality and Quantity: A Landscape Approach (Johnston, Detenbeck and Niemi, 1990)	• quantitative (statistical analysis) • use the results of Geographical Information Systems (GIS) analysis for data input in statistical analysis ; • a lot amount of quantitative data on water quality; • many wetlands were involved in the assessment	• wetlands	• consider spatial aspect: location of wetlands • includes many activities and many wetlands • spatial distribution of physical factors of wetlands; • watershed area	• historical water quality data; • historical aerial photos	• assesses the magnitude of cumulative impact. • results : the position of wetland in the landscape was an important consideration for the cumulative effect assessment;	• landscape variables and water quality variables	• used GIS only, not environmental model	• No
13.	Landscape Conservation in a Forested Wetland Watershed: Can We Manage Cumulative Impacts ? (Gosselink, et al., 1990)	• indices are used to identify major structural and functional changes related to human activities; • methodology developed suites to local regulatory offices • focus on landscape level : watersheds and drainage basins. • relatively few historical data supplemented with land-cover data and maps, can provide the basis for an analysis in the landscape level sufficient to identify major structural and functional changes related to human activities.	• watershed planning	• watershed area;	• limited historical data; phosphorus	• magnitude of cumulative effects • results: forest conversion, especially the loss of streamwide buffer stripe, lead to poor water quality through increased erosion and fertiliser runoff from the cleared land; land clearing also contributed to reduction in the diversity of indigenous flora and fauna.	• indices that are based on forest structure (and land use), stream stage/discharge, water quality records, breeding survey and Christmas bird counts.	• No	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
14.	Cumulative Effects of Land Management on Soil and Water Resources: An Overview (Sidle and Sharpley, 1991)	• This article mainly the overview of studies on the watershed cumulative effects; • some methods which could potentially be used : GIS, aerial photographs, models of water quality and quantity and computer simulation	• watershed	• many activities have effects on the resources; • watershed area: watershed	• long term monitoring data is very important		some indicators could be used: • soil quality • water quantity and quality; • nutrients in groundwater and surface water • erosion • sedimentation • areas	• The potential of using aerial photographs, GIS and model was discussed	• No
15.	Cumulative Effects : A Broader Approach to Water Quality Research (Sidle and Hornbeck, 1991)	• basic research on the cumulative impact assessment is still needed; • cumulative effects are the total effects (natural and human-induced activities); • Obvious concern: cumulative effect would be greater than effects from any single activity, which increase the change of exceeding acceptance limits for water quality, sedimentation, nutrient loss, or other environmental parameters; • To quantify cumulative effects, understanding of the variation of the natural processes of watershed and the role of natural episodic events is necessary.	• watershed planning	• watershed as unit of analysis consisting of many activities and many natural events	• long terms data is necessary	• the importance of threshold for the determination of impact significance • results: no results are □vailable from this article because this is only conceptual framework of the methodology for cumulative effect assessment.	• natural and human –induced activities causing changes in the watershed, e.g. erosion, sedimentation, water quality	• No	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
16.	Notes on Cumulative Environmental Changes : I. Concepts and Issues (Cocklin, Parker and Hay, 1992a)	• their conceptual framework recognises the importance of sources of cumulative changes, pathways of accumulation and impact accumulation	• Some potential spatial boundaries: (1) administrative; (2) ecological or physical, (3) human activity pattern; (4) the combination of 1-3	• recognise that cumulative impact could originate from single or multiple perturbations • recognise that cumulative impact is probably more widely associated with multiple sources (types) of perturbation	• recognise temporal accumulation	• could be additive, interactive, time lag, space lag, triggering and threshold (although not stated explicitely)	• Valued Environmental components (VECs)	• GIS could potentially be applied	• Additive, synergetic, dynamic patchiness
17.	Notes on Cumulative Environmental Change II: A Contribution to Methodology (Cocklin, Parker and Hay, 1992b)	• Geographical Information Systems and Checklist were used for the spatial representation of cumulative effects and scoping; • this paper provides example of using GIS in CIA • the analysis of cumulative impact could be conducted in four ways: (1) the assessment of the effect of a single activity upon single environment; (2) the assessment of the effects of a single activity upon multiple environmental attributes; (3) an assessment of the effects of multiple activities upon single environmental component; (4) the assessment of multiple activities upon multiple environmental attributes.	• Example of application on wetland	• their example provides the accumulation of impacts called space crowding	• historical spatial data was used to determine the lost area of wetland	• addition or total loss of wetland area; • <u>results</u> : spatial accumulation of particular impacts could well be represented by using GIS;	• wetland area • fragmentation	• GIS were used, environmental model was not used;	• Additive (spatial accumulation)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
18.	Analysing the Cumulative Effects of Forest Practices: Where Do We Start ? (Green, et al., 1993)	• Modelling using GIS to monitor and predict changes resulting from forest practices; • index was used to assess the cumulative effects and this was used to prioritise watershed • indices were derived from formula	• forestry	• many activities	• past and present	• aggregation of many different layers of GIS into an index based on formula; • results : the susceptibility to cumulative effects resulted from GIS analysis help prioritising the management;	• areas changes for every layer: wildlife, slope stability, hydrology, fisheries	• GIS	• Assumed to be additive)
19.	Assessing Cumulative Impact on Fish and Wildlife in the Salmon River Basin, Idaho (Irving and Bain , 1993)	• Weighting and Quantitative analysis of weights; • use matrices; • consider impact interaction; • effect-oriented approach • the formula used was : sum of project impacts ± interaction impacts • the final result is an index representing the relative cumulative effect	• the facilities of electricity development;	• pre-determined area (not watershed)	• does not recognise temporal impact	• determine impact significance • results: cumulative impacts to all target resources except elk, mule deer and riparian habitat would be significant, population and habitat of chinook salmon would be significantly reduced beyond reductions that were already	• resources affected (fish)	• No	• No
20.	Proposed Methodology to Assess Cumulative Impacts of Hydroelectric Development in the Columbia River Basin (LaGory, Stull and Vinikour, 1993)	• quantitative ; • use matrices to assess total impact and impact interactions; • use the concept of impact zone to determine impact interaction; • consist of six stages: (1) determine the relationship among projects; (2) perform single –project assessment; (3) calculate interaction coefficient; (4) calculate unadjusted cumulative effect; (5) adjust for the effects of shared project features; (6) incorporate the effect of existing project. • applicable for qualitative and quantitative data;	• hydro-electric development	• watershed (river basin)	• does not recognise temporal aspect	• determine only the magnitude of impact • results: the methodology could be applied on some data: qualitative, quantitative; temporal changes could also be incorporated by using this proposed methodology; this methodology would be more effective if site specific data are available.	• key species	• No	• Non- additive cumulative effects was the main emphasis

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
21.	Defining and Analysing Cumulative Environmental Impacts (Contant and Wiggins, 1993)	• cumulative impact analysis of individual project must consider two main aspects : (1) the relationship between a proposed project and other development activities; (2) the complex and often non-incremental effects of a development activity on many natural systems.	• not specified (because it is only conceptual)	• many activities is recognised in this conceptual framework • spatial aspect is also included	• temporal accumulation of impact is recognised in this concept	• conceptually through: addition, aggregation (synergism), and cycling • recognising the importance of time series data for understanding systems's responses, thresholds and interactions	• not specified, because this article is only conceptual framework.	• No	• Yes (although this is only conceptual)
22.	Cumulative Impacts To Wetlands (Johnston, 1994)	• use GIS for assessing loss of wetland areas, changes of spatial configuration of wetlands, and wetland classes;	• wetland	• two activities: forestry and agriculture	• cumulatively reflected in the area	• aggregation of area	• area changes	• GIS	• Assumed to be additive
23.	Analysing Cumulative Environmental Effects of Agricultural Land Drainage in Southern Ontario, Canada (Spaling, 1995)	• quantitative and historical; • empirical evidence; • results obtained from other areas could be used in the assessment; • use Geographical Information Systems (GIS) to determine spatial change of patches over time. • use a lot amount of data	• agriculture	• one activity (drainage) • many drainages were involved • watershed : agricultural watershed	• historical spatial and non-spatial information	• determine magnitude and not significant; • <u>results</u>: accumulation of changes in timing and volume of flow, nitrate and antrazine content in water, and area and distribution of wetlands demonstrate that drainage results in various cumulative effects.	• hydrologic variables; • water quality; • nitrate-nitrogen, antrazine • the area and distribution of wetland	• used GIS only, not environmental model	• Yes • Some terminologies (crowding) analysed were: (1) spatial; (2) temporal; (3) time lag; (4) fragmentary

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
24.	Cumulative Effects Assessment: The Development of Practical Frameworks (Damman, Cressman and Sadar, 1995)	• Methodology used consists of the following stages: (1) defining boundaries; (2) assessing interaction between the environmental effects of the project; (3) identifying past projects and activities and their environmental effects; (4) identifying the future projects and potential environmental effects; (5) assessing interactions between the environmental effects of past projects and future projects and activities; (6) determining the likelihood and significance of the cumulative environmental effects; • indicators for assessing cumulative effects significance : size of areas affected, frequency and duration and certainty in prediction; • methodology relies on the use of subjective judgement.	• could be applied in the analysis of cumulative effects in land and water	• many activities included; • could be applied in both watershed and unconstrained area; • could involve similar and different activities	• historical data is best source of information if available; • if not, the uses of past experience of local people could be used to assess significance of cumulative effects	• significance of cumulative effects were assessed based on: size of area affected, frequency and duration and certainty in prediction • results : methodology for cumulative effects assessment need to be developed.	• any change in the land and water	• No	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
25.	A Conceptual Model of Cumulative Environmental Effects of Agricultural Land Drainage (Spaling and Smit, 1995)	• methodology used in this article consists of three stages: (1) understanding the role of drainages as sources of cumulative effects; (2) understanding the roles of drainages as pathways of cumulative environmental changes; and (3) the terminologies of cumulative environmental effects of drainages : spatial crowding, temporal crowding, time lag, compounding effects, Triggers and thresholds, indirect effects;	• agriculture	• this conceptual model could be applied in the watershed areas	• historical information of impacts of drainages	• the assessment of impact significance was based on two aspects: spatial and temporal	• not stated specifically, only conceptual model	• No	• the definitions and explanation of terminologies for cumulative effects are provided
26.	Questionnaire Checklists for Cumulative Impacts (Canter and Kamath, 1995)	• This is a very simple methodology for cumulative impacts assessment: Questionnaire checklist; • Checklist provides a background of the environment into biophysical and socio-economic categories; • Impact assessors determine the impacts on each category based on the information provided by checklists; • provide the basic for further detailed study on cumulative impacts	• could be applied in any situation	• could be applied in spatially contrained or spatially uncontrained areas	• temporal accumulation is embedded in the assessors	• could not account for the significance of cumulative effects	• could be any indicators as long as these relate to biophysical and socio-economic	• No	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
27.	Cumulative Impact of Marina on Estuarine Water Quality (McAllister, Overton and Brill, 1996)	• modelling water quality using WASP4 • two models are included: (1) water quality to obtain information about potential impacts on estuary and (2) planning and management; • impact coefficients were obtained by running and simulating the potential of waste loads by using WASP 4 many times; • The coefficients were used for planning purposes.	• Estuary planning and management	• Many marinas projects • possible to include many other activities; • spatially unconstrained	• present and future	• water quality model evaluates the magnitude of impact; • results: the combination of water quality model and planning model could be used to determine the cumulative effect of marinas on estuary	• water quality parameters: BOD, FC, waste loading on segment number	• GIS were not used, environmental model was used	• No
28.	Southern East Slopes Cumulative Effects Assessment (Sawyer, et al., 1996)	• this article is GIS based reconnaisance level of the assessment of cumulative effects; • the assessment of cumulative effects was based on the four Valued Environmental Components : watershed assessment, cumulative effects on vegetation, cumulative effects on terrestrial wildlife, cumulative effects on birds, and cumulative effects on fish; • analyse changes in the habitats from year to year by using GIS;	• assessment of resources in the watershed	• watershed • the development of roads networks have been assessed as the most important spatial aspects determining cumulative effects.	• mainly used historical spatial data	• significance of cumulative effects was assessed using the changes of area • results : this assessment suggests that cumulative human actions have caused a widespread loss and decline of habitat quality for wolves, grizzly bears and elk;	• areas	• GIS was the main tool	• Assuming additive cumulative environmental change

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
29.	Including Past and Present Impacts in Cumulative Impact Assessment (McCold and Saulsbury, 1996)	• past and present impact must be determined in combination eith future possible activitues; • past and present impacts in their aggragation could have impacts exceeding the threshold; • the "significant impact level" or "threshold" is the main tool for assessing impact significant.	• could be applied in any conditions	• could be any spatial boundaries	• should include past, present and future	• the assessment of the significant of cumulative impacts must be based on past, present and possibly future impacts	• could be any indicators	• No	• No
30.	Estimating the Cumulative Effects of Development on Wildlife Habitat (Theobald, Miller and Hobbs, 1997)	• use the concept of "disturbance zone" to determine the areas impacted by development; • density and pattern are used to evaluate the potential impact on habitat; • distance from the building was also calculated to evaluate the impact	• landuse planning	• could be applied on many different activities	• aggregated cumulative impact from past, present and possibly future	• summing the total area within the disturbance zone and observe how it changes over time; • results : clustered development reduces the negative impacts on wildlife habitat; for large building-effect distances, spatial pattern was found to be stronger indicator of disturbance than density.	• area	• GIS could potentially be applied	• Assumed to be additive
31.	A Synoptic Approach for Assessing Cumulative Impacts to Wetlands (Abbruzzese and Leibowitz, 1997)	• index (quantification based on qualitative information) • based on the analysis of loss and gain; • appropriate for the situation when quantitative data is lacking	• watershed planning	• watershed	• does not include temporal aspect	• there is no techniques for aggregating impact; • mainly assess the magnitude o each impacts based on the predefined criteria: future risk, functional loss (hydrology); • results: this approach suits to the situation where quantitative data is unavailable; could be applied with very low cost, could be tested and improved over time.	• future risk, functional (hydrology)	• GIS were used, but not Environmental model	• No
32.	Cumulative Effects of Forestry Practices- An Example Framework for Evaluation From Oregon, USA (Boyle, et al., 1997)	• the knowledge of cause and effect relationship is the key component in the assessment of cumulative impact; • detailed knowledge of cause effect relationship and simulation models are necessary to be developed in order to understand the cumulative impact.	• forestry	• could be applied many activities	• could be long time span	• not stated (because it is only framework)	• not stated (because it is only framework)	• No	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
33.	Development of Hydrological Indices to Aid Cumulative Impact Analysis of Riverine Wetlands (Nestler and Long, 1997)	• the quantification of subtle, long-term changes in hydrology period; • methods and techniques for analysis are : harmonic analysis, time-scale analysis.	• wetland	• not spatial	• stated (using long term historical data)	• hydrological indices were used to assess the significance of cumulative effects; • results: harmonic analysis could be used to assess long term subtle changes in biotic communities or wetland structure as part of comprehensive wetlands • studies	• baseflow during low period	• No	• No
34.	Cumulative Impacts of Landuse on Water Quality in Southern Appalachian watershed (Bolstad and Swank, 1997)	• methodology used in this article followed some stages: (1) determine the watershed boundary; (2) determine five stations for sampling from upstream to downstream; (3) collection of spatial data : landuse (4) statistical analysis relating landuse variables and water quality; • GIS were used to relate the land use and related aspect for the purposes of statistical analysis	• watershed planning	• watershed area of study • include many activities : forest, unpaved area (upstream); residential along the stream, residential along the stream, grazing and agricultural practices, and paved areas.	• this study cover only the period of time of 109 weeks for the collection of water quality data.	• statistical analysis was used as tool to aggregate impacts of many different activities from up stream to downstream; • results : consistent, cumulative downstream changes in water quality variables were observed along Cowede Creek, concomitant with downstream, human-caused changes in landuse; larger downstream changes in water quality variables were observed during stormflow when compared to baseflow, suggesting cumulative impacts due to landscape alteration under study condition were much greater during storm events.	• water quality parameters: turbidity, faecal colliform, faecal streptococcus, dissolved oxygen, pH, temperature, and other cations and anions; • land uses	• GIS and statistical analysis were used to relate basin and near-stream landscape variables to water quality	• No
35.	Grizzly bear Habitat Effectiveness: Assessing Cumulative Effects of Human Use in Jasper National Park (Purves and Doering, 1998)	• using scoring and mathematical operation • Model consist of: (1) habitat effectiveness; (2) Security area and (3) Linkage zone. • GIS is the method used; • Analysis of spatial characteristics;	• national park	• watershed as the spatial boundary used	• present and future; • scenario analysis is the main tool for the future activities.	• The combination of score would indicate the cumulative effects of activities; • Three classes of dangers exist: minimal danger, low danger, moderate danger and high danger; • Each classes refers to the danger of the combination of activities to grizzly bears.	• Grizzly bears	• GIS were used, environmental model was not used	• No

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
36.	An Integrated Environmental Assessment of the US mid-Atlantic Region (Wickham, et.al., 1999)	• correlation and minimum Euclidea-distance-to mean cluster analysis were used to identify groups of watershed with similar data values; • canonical discriminant analysis (CDA) was used to check the distinctness of the clusters; • this methodology is appropriate only for the regional scale; • relative cumulative effects score	• watershed planning	• watershed as the spatial boundary for CEA	• Not include temporal aspect, but this has potential to include temporal aspect;	• The magnitude of cumulative impacts is aggregated among nine selected indicators; • The concept of relative cumulative effect is used; • Results: relative cumulative effect score is highest in the urban area	• Indicator used : population density, population change; road density, average atmospheric wet SO_4 deposition , percent of watershed streamlength with agriculture within 30 m; percent of watershed streamlength with forest within 30 m; pinpointing decaying; proportion of watershed that supprots forest a \t three scales;	• No	• No

environmental component (Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993) and for activities which result in more or less similar pathways of impacts. The main strength of the methodology for quantification of qualitative values is in the situation where the data are limited, although uncertainty is an unavoidable issue.

The uses of statistical techniques can be observed in the literature on CEA. As shown in Table 2.2, statistical analysis has also been used in the studies by Childers and Gosselink (1990); Johnston (1994); Theobald, Miller and Hobbs, (1997); Nestler and Long (1997); Sidle and Sharpley (1991); Bolstad and Swank (1997) and Johnston et al. (1988). These studies used extensive historical data. Therefore, it can be stated that the use of this technique for CEA is appropriate when historical data are available. The strength of the use of statistical techniques for CEA is the ability of this technique to obtain the pattern of changes of resources, and possibly impact prediction using Principal Component Analysis (PCA), trend and time series analysis.

There is very limited evidence of the uses of mathematical models for CEA. The study conducted by McAllister, Overton and Brill (1996) is one example of using a mathematical model for CEA in an estuary. It can be inferred from this study that mathematical models provide flexibility in combining activities and their associated impacts. Not only could their Water Quality Analysis Simulation Programs version 4 (WASP4) aggregates effects, but WASP4 could also provide insights into the processes responsible for the accumulation of impacts. In their study, McAllister, Overton and Brill (1996) use WASP4 to analyse the cumulative effects of marinas on water quality. They used Biological Oxygen Demand (BOD) and Faecal Colliform (FC) as two indicators of water quality. This study shows that by using the WASP4 model, the combined effects of all marinas could be analysed in view of cumulative effects. Besides, the ability of the WASP4 model to integrate other factors, such as variable inflow, outflow, dispersion, advection, point and diffuse mass loading has made it possible to quantify the cause and effect relationship. This thesis also utilises the WASP program in the methodology used (WASP version 5). Another study, which used the WASP model, is the one by Yassuda et al. (2000). Both of these two studies proved that mathematical model is one of the most appropriate methods for dealing with cumulative effects.

Martin and McCutcheon (1999) provide a review of models used in water quality management, such as WASP, WQRS, QUAL2E. Compared to other water quality models, such as WQRS, QUAL2E, WASP has more flexibility. In addition, as McAllister, Overton and Brill (1996: 369) claim, WASP is capable of linking the hydrodynamic component with a wide range of water quality parameters.

The focus on cause and effect relationships makes mathematical models superior to other methods for cumulative effects. Smit and Spaling (1995:95), for example, claim that simulation models could be used to differentiate between additive and interactive processes. In addition, they point out that because of its focus on functional change or structural change or both, simulation modeling is the most appropriate method for identifying and analysing some types of cumulative environmental changes, such as time lags, thresholds, spatial crowding and fragmentation effects. Another obvious characteristic of mathematical modeling is the fact that the results can be compared to monitoring data. Therefore, the testable evidence on effects can be gained. The most prominent weakness of simulation models is that they only focus on a single environmental component. For the purpose of ideal and complete CEA, other methods, models, or data should be employed for determining impacts of activities on other resources.

In summary, existing quantitative methodologies for CEA rely mainly on the use of matrices for the purpose of combining impacts to produce a single value. If long-term records of data are available, statistical techniques are appropriate. It is also apparent that some methodologies described as quantitative are based upon the quantification of qualitative data. There have been very few examples of using mathematical models for cumulative effect assessment. Simulation based mathematical models will be used in this study and are the one of methods for contributing to the proposed methodology in this research. In terms of input data used for models, it is also important to note NEPA's (1999:3) statement (http://hydra.gsa.gov/pbs/call-in/factshet/0399c/03_99c_6.htm) :

> If possible the magnitude and significance of cumulative effects should be presented in some kind of quantitative terms, even if the precise values assigned to each variable are somewhat speculative.

2.4.2.2 Qualitative Methodologies

The second class, qualitative methodology, is based on an effect-oriented approach. Lawrence (1994) in Morgan (1998:212-213) provides example of this kind of methodology. Lawrence's methodology consists of three stages:

(1) Determining direct cumulative effects, particularly space crowding.

(2) Determining indirect cumulative effects the through network diagram.

(3) Determining total cumulative effects. At this stage, the possible impact interaction was assessed.

Compared to the quantitative methodology, the methodology proposed by Lawrence is less technical and this could be directly integrated into management strategies, however, this methodology could mislead users due to its simplicity (Morgan, 1998:213).

The study by Canter and Kammath (1995) proposes a methodology for cumulative effects assessment based on a questionnaire checklist. This methodology divides the environment into biophysical and socio-economic categories, and invites the impact assessor to decide whether the project will result in the effects specified for each of the categories. Despite its simplicity, this methodology may only be appropriate if quantitative data are unavailable. This checklist is not appropriate for impact prediction and as they claim, a questionnaire checklist would provide a consistent initiation for systematically addressing cumulative effects. In terms of impacts on the resources, this methodology is pertinent to CEA because it considers the cumulative effects on resources of concern separately. The study conducted by Damman, Cressman and Sadar (1995) shows that a qualitative methodology which uses experts and local knowledge could assist in CEA, particularly in situations where data are lacking.

To summarise, the availability of data and knowledge seem to be the most important factors determining the selection of either qualitative or quantitative methods, or their combination in CEA. It is apparent that quantification of effects from qualitative effects dominated the development of CEA methodology. This agrees with Cooper and Canter's finding (1997:25) stating that professional knowledge or judgment was mostly used in CEA due to limited access to data.

2.4.3 Spatial and Temporal Dimensions in CEA

The assessment of cumulative effects involves two main dimensions, that is spatial and temporal. The following discussion will explain the uses of these dimensions, either individually or the combination of both obtained from existing CEA methodologies

2.4.3.1 The Uses of Spatial Dimensions in Methodologies for CEA

The word "spatial" can have different meanings. It could refer to the way the impacts accumulate spatially: spatial crowding (Smit and Spaling, 1995; Cocklin, Parker and Hay, 1992b; Spaling and Smit, 1995). It could also refer to the use of "area" as the indicator of cumulative environmental change (Sebastiani et al., 1989; Walker et al., 1986; Green et al., 1993; Cocklin, Parker and Hay, 1992b; Sidle and Sharpley, 1991; Sawyer et al., 1996). Some other spatial dimensions, such as pattern, configuration, distance and extent are also examples of spatial dimensions that can be used in representing cumulative effects. Sawyer et al. (1996), for example, show that the configuration of patches can be related to the cumulative effects.

The word "spatial" could also relate to the boundary determination. As shown in Table 2.2, the assessment of cumulative effects is mostly in spatially constrained areas, such as the watersheds (catchments), as shown in a number of studies (Klock, 1985; Childers and Gosselink, 1990; Coats and Miller, 1981; Johnston, Detenbeck and Niemi, 1990; Spaling, 1995; Sebastiani, et.al., 1989; Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993; Abbruzzese and Leibowitz, 1997; Cobourn, 1989; Green et al., 1993; Johnston, 1994; Boyle et al., 1997; Dickert and Tuttle, 1985; Cocklin, Parker and Hay, 1992b; Walker et al., 1986; Nestler and Long, 1997; Sidle and Hornbeck, 1991; Damman, Cressman and Sadar, 1995; Sidle and Sharpley, 1991; Bolstad and Swank, 1997). From Table 2.2, it can be seen that there are only two studies on the application of CEA in a spatially unconstrained area, e.g. estuary, as shown in the studies by McAllister, Overton and Brill (1996) and Waldhichuk (1988).

The determination of a spatial boundary necessary for CEA is flexible. Cocklin, Parker and Hay (1992a:38) claim that the spatial boundary for cumulative effects assessment could be:

(1) Existing administrative boundaries.
(2) Boundaries defined on the basis of ecological and/or physical environmental characteristics.
(3) The delineation of boundaries with reference to human activity patterns or communities of interest, including those recognised by indigenous groups (e.g. tribal boundaries).
(4) Some combination of 1 to 3.

The Council on Environmental Quality (1997:15) provides a list of the geographic areas that can be used in Cumulative Effects Analysis (Table 2.3 below). As can be seen, there are a number of geographic areas that can potentially be used for the analysis of cumulative effects. An estuary is the geographic area used in this study. In this regard, the geographic area is the spatial boundary. Considering the resource, it is clear that water quality, as a resource, can be analysed in view of cumulative effects by using an estuary as the spatial boundary. In fact, determining an appropriate spatial boundary has been one of the main issues in CEA (Vlachos, 1985; Preston and

Bedford, 1988; Damman, Cresman and Sadar, 1995; Cooper and Canter, 1997; Burris and Canter, 1997a,b,c).

For efficient spatial boundary determination, it may be more appropriate if the spatial distribution of activities and the possible distribution of the resources affected are considered at the beginning of CEA.

2.4.3.2 The Uses of Temporal Dimensions in Methodologies for CEA

The study conducted by Bolstad and Swank (1997) shows that by using a time frame of 109 weeks, the accumulation of impacts of activities on water quality could be detected. The main aim of their study was to compare whether there was accumulation of water quality parameters during base flow and stormflow.

Table 2.3 Geographic Areas that Could be Used in A Cumulative Effects Analysis (Sources: Council on Environmental Quality, 1997:15)

No.	Resources	Possible Geographic Areas for Analysis
1	Air Quality	Metropolitan Area, airshed or global atmosphere
2	Water Quality	Stream, watershed, river basin, estuary, aquifer, or parts therof
3	Vegetative resource	Watershed, Forest, range, or ecosystem
4	Resident wildlife	Species habitat or ecosystem
5	Migratory wildlife	Breeding grounds, migration route, wintering areas or total range of affected population units
6	Fishery resources	Stream, river basin, estuary, or parts thereof; spawning area and migration routes
7	Historic resources	Neighborhood, rural community. City state, tribal territory. Known or possible historic district
8	Sociocultural resources	Neighborhood, community, distribution of low-income or minority population, or culturally valued landscape
9	Land use	Community, metropolitan area, county, state or region
10	Coastal Zone	Coastal region or watershed
11	Recreation	River, Lake, geographic area, or land management unit
12	Socioeconomics	Community, metropolitan area, county, state, or county

This may be evidence of what Geppert, Lorenz and Larson (1985:22) claim as temporary cumulative effects. Most other studies, on the other hand, use much longer time frames than that used by Bolstad and Swank (1997). Despite the much shorter time in the study of Bolstad and Swank (1997) compared to other studies (Klock, 1985; Childers and Gosselink, 1990; Johnston, Detenbeck and Niemi, 1990; Sawyer et al., 1996), their results indicated that there was accumulation of impacts from stormflow during that period of time. McCold and Saulsbury (1996) claim that actual cumulative impact studies must cover past, present and future time frames. Their reason for this is that past activities which have been impacting the environment will be overlooked if a short time for CEA was used. Including past, present and future activities makes CEA different to the assessment of environmental effects from a single activity.

There are five categories for including time frames for CEA. Referring to Table 2.2, these five are:

(1) Studies which use a time span from past to present (Childers and Gosselink, 1990; Coats and Miller, 1981; Johnston, Detenbeck and Niemi, 1990; Spaling, 1995; Sebastiani, et.al., 1989; Green et al., 1993; Boyle et al., 1997; Dickert and Tuttle, 1985; Cocklin, Parker and Hay, 1992b; and Sidle and Sharply, 1991).

(2) Studies which use time spans: past, present and future (Klock, 1985; Cobourn, 1989; Theobald, Miller and Hobbs, 1997; Walker, et. al., 1986; Sidle and Hornbeck, 1991; Damman, Cressman and Sadar, 1995; and Spaling and Smit, 1995).

(3) Studies which use present time only (Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993; Abbruzzese and Leibowitz, 1997; Proet, 1987; and Bolstad and Swank, 1997).

(4) Studies which use present and possibly future. Only one study matched this category, that is the study conducted by McAllister, Overton and Brill (1996).

(5) Studies which use past data only (Nestler and Long, 1997).

The ideal CEA should include time frames including past, present and future. However, most studies listed in Table 2.2, show that there are few which have included complete time frames, although the definition of cumulative effects demands the inclusion of past, present and future activities. The main difficulty regarding the determination of the time frames used for CEA is that past data on impacts are not always available for the temporal resolution required for a complete CEA.

From the above discussion, it would appear that there is no consensus on appropriate time frames for CEA. This may be different for different applications. It is also apparent that impact accumulation can occur both in the short term and long term.

2.4.4 Scoping for CEA

Scoping is a process with the main aim of identifying issues that are to be addressed in CEA and to focus the assessment on the most potentially significant impacts and this is a key process in CEA (Council on Environmental Quality, 1997). One of the most important roles of scoping is to determine spatial and temporal boundaries for CEA. Scoping also has a role in determining Valued Environmental Components (VECs).

The selection of VEC is the central component in scoping stage in CEA. The selection of VEC is a complex process in CEA because the following component must be considered:

(1) the complexity of interrelationship of many environmental components;

(2) different view of different stake-holders on the most important environmental component selected as VEC.

The interconnectedness and interrelationships in ecosystems are dynamic. Therefore, CEA must also be dynamic, meaning that it must be capable of adjusting to the dynamics of the ecosystems under investigation. In order to obtain information about the dynamics of ecosystem as well as the dynamics of cumulative effects, indicator

(s) must exist. The determination of indicators used must relate closely to the determination of any Valued Environmental Components /VEC(s). According to Beanlands and Duinker (1984) from the Canadian Environmental Assessment Agency (http://www.ceaa.gc.ca/0011 /0001/0004/guide.htm)

> VEC(s) are component(s) of the natural and human world that are considered valuable by participants in a public review process and VEC(s) can be any parts of the environment that are considered important by the proponent, public, scientist and government involved in the assessment process.

As Beanland and Duinker claim, importance may be determined on the basis of cultural values or scientific concern. From this statement, it is also appear that the selection of VEC must consider stakeholders, such as public, proponent, scientist and government. Because of the fact that the selection of VEC must consider the view of stakeholders, this could be problematic in the sense that different stakeholders may have different opinion about which VEC should be selected. Interrelationship amongst many environmental components can also augment the complexity of the selection of the most representative VEC for CEA.

Selection of the appropriate VEC is crucial because this will determine further stages used in CEA. Another reason for this is that it is not possible to analyse every environmental component which could potentially be included in CEA. Limiting the analysis to particular VECs is more likely to have positive effects on the practicality of CEA. Scoping is a stage in CEA which one of its aim is to determine the selected VEC.

The Council of Environmental Quality (1997) states that scoping for CEA consists of five main stages:

(1) Identify the significance cumulative effects issues associated with the proposed action goals.
(2) Establish the geographic scope for the analysis.
(3) Establish time frame for the analysis.

(4) Identify other actions affecting the resources, ecosystems, and human communities of concern.

(5) Identify methods and techniques used in CEA.

This process must be explicitly stated. The explanation of the assumptions used for selecting the spatial and temporal boundaries, the reasons for choosing the methods and techniques used, the selection of VEC(s) and the determination of the most significant issue must also be explicitly stated. Vlachos (1985:61) has drawn attention to the important role of scoping. The following is his statement.

> ....capable of initiating a new stream or web of effects. One of the aspects of any type of impact analysis is the need to exercise a great deal of professional judgment in selecting the significance causative factors and tracing significance effects, as well as knowing which branches to pursue in a reasonable analysis of cumulative effects

Despite the importance of this process in CEA, there is little evidence of previous studies which use this as a formal procedure (stated explicitly). The lack of consideration of this process can be seen in Table 2.4. (Study numbers shown in Table 2.4 match those listed in Table 2.2. There are only a few studies which conducted a complete scoping. Some only consider the spatial boundary, others only consider temporal boundary. Some others use the possible cumulative effects. This finding seems to agree with Burris and Canter' s statement (1997a:27) :

> Scoping is used only minimally to identify relevant CEA (cumulative effects assessment) for inclusion in EISs and EIA; accordingly, it should be noted that scoping is an important component of CEA that needs to receive more attention to ensure appropriate environmental resources are included in the analysis of CEA, especially EIAs

From this statement, it is clear that scoping is an important part in cumulative effect assessment, although this has been minimally considered. It is likely to be the case that

some of the previous studies considered scoping, although their consideration is informal (no explicit explanation on how scoping was conducted). Scoping is crucial because this can be used as the tool to avoid confusion in classifying, defining, assessing and managing cumulative effects (MacDonald, 2000:300).

2.4.5 The Determination of Indicators for CEA

The number of indicators used for CEA varies from one study to the others. Some previous studies (Sawyer et al., 1996; Preston and Bedford, 1988) for example, use more than one indicator. It would appear that indicator selection was application

Table 2.4 Presence and Absence of Formal Scoping in Previous Studies
(Sources: From Analysis of Literature)

Numbers of Studies as shown in Table 2.2	Presence and Absence of Formal Scoping (Presence : +, Absence : -)	Activities included
1	-	different activities
2	-	similar activities
3	+	different activities
4	-	different activities
5	-	similar activities
6	-	similar activities
7	+	similar activities
8	-	similar activities
9	+	different activities
10	-	different activities
11	+	similar activities
12	-	different activities
13	-	different activities
14	-	similar activities
15	-	different activities
16	+	different activities
17	-	could be the same or different activities
18	+	similar activities
19	+	not stated
20	+	different activities
21	+	similar activities
22	-	similar activities
23	-	different activities
24	-	could be different activities
25	-	could be both different and similar activities
26	-	different activities
27	-	different activities
28	-	similar activities
29	+	similar activities
30	+	could be different and similar activities
31	-	different activities
32	+	different activities
33	-	different activities
34	-	Could be different and similar activities
35	-	Different activities
36	-	Different Activities

driving. Some studies (Childers and Gosselink, 1990; Spaling and Smit, 1995b; McAllister, Overton and Brill, 1996; Nestler and Long, 1997; Bolstad and Swank, 1997) have shown that existing monitoring water quality data determine the selection of indicators. From these studies, the choice of indicators relies mainly on the availability of data for water quality parameters.

The Commonwealth of Australia (1996a) in Ward, Butler and Hill (1998: 3) defines indicator(s) as :

> .....physical, chemical, biological and socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue. An indicator is embedded in a well-developed interpretative framework and has meaning beyond the measures it represents.

The set of key indicators must be kept to a minimum so that if they are properly monitored, they will provide rigorous data describing the major trends in and impacts on the environment (Ward, Butler and Hill, 1998: 3). In addition, there are 15 prerequisites of environmental components considered necessary to be the appropriate indicators (Ward, Butler and Hill, 1998: 3), seven of which are pertinent to this study. These eleven prerequisites were selected because they relate to the condition of data and methods used in this study.

(1) Serve as a robust indicator of environmental change.
(2) Reflect a fundamental or highly valued aspect of the environment.
(3) Provide an early warning of potential problems.
(4) Be capable of being monitored to provide statistically verifiable and reproducible data that shows trends over time and preferable apply to a broad range of environmental regions.
(5) Be scientifically credible.
(6) Be monitored regularly.
(7) Have relevance to policy and management needs.

As can be seen, there are a number of prerequisites for the determination of indicator(s). From the above, it is clear that subjective and objective judgments could affect the choice of appropriate indicator(s). Although the objective measures are an important component of the ways the indicator(s) are selected, the subjective consideration (judgments) are likely to be a major factor determining the choice of indicator(s). Therefore, it can also be suggested that the selection of indicators could be more appropriately determined by using experts' advice and by considering the availability of monitoring data. This is the area where the qualitative (subjective) rather than quantitative data and methodology could play significant roles.

2.4.6 Determination of the Magnitude and Significance of Cumulative Effects

The determination of impact magnitude and impact significance is the main activity in any impact assessment. Due to the longer time span and wider geographical space, the determination of impact magnitude and impact significance in CEA is much more complex than that in the assessment of environmental impact on a single activity.

The Canadian Environmental Assessment Agency claims that in CEA, there are many factors that can influence the interpretation of significance (http://www.ceaa.gc.ca/0011/0001/0004/guide_e.htm) . Some of them are:

1. Exceedance of a threshold. Significance may increase if a threshold is exceeded.
2. Size of the study area. Significance may appear to decrease as the study area size increases.
3. Relative contribution of effects of other actions. Significance may decrease as the relative contribution of an action decreases.
4. Significance of local effects. Significance may decrease as the significance of local effects decrease.
5. Magnitude of change relative to natural background variability. Significance may decrease if effects are within natural background variability.

From the above list, there are at least five factors which affect the interpretation of significance. As shown, all of them relate to the use of objective measures for assessing the significance: threshold, size of area, effects contribution, local effects and natural background variability. Some subjective measures were also used for determining the significance of cumulative effects, because of the consideration of "context" and "intensity" in the determination of the significance (Duinker and Beanland, 1986; Council on Environmental Quality, 1997).

2.4.6.1 The Aggregation of Effects in CEA

Aggregation of overall cumulative effects can be controversial (CEQ, 1997:43). Intentional or unintentional manipulation of assumptions can dramatically alter the results of aggregated indices (Bisset, 1983 in CEQ, 1997:43). Aggregation relates to the determination of magnitude and significance of cumulative effects. There are two methods for representing the values of impact magnitude and impact significance. Firstly, cumulative effects are represented by using one value, using indexing (Klock, 1985; Irving and Bain, 1993; and LaGory, Stull and Vinilkour, 1993). The study by Klock (1985), for example used an index for consecutive time period (years) included in the assessment of cumulative effects of forest practices. Then by visualising the indices for all times included in CEA, the development of cumulative effects can be related to the particular activities and time.

The second is based on the aggregated values of impacts on Valued Environmental Components (VECs) or other environmental indicators (Bolstad and Swank, 1997 and Sawyer et al., 1996). Sawyer et al. (1996) assess the magnitude of cumulative effects in four separate VECs:

(1) Cumulative effects on birds.
(2) Cumulative effects on fish.
(3) Cumulative effects on terrestrial habitat.
(4) Cumulative effects on vegetation.

From this, it can be concluded that depending on the importance of VEC and the availability of data, one or more indicators can be used for assessing the significance of cumulative effects.

2.4.6.2 Magnitude and Significance Determination Based on Time Frames

The determination of the magnitude of cumulative effects could be based on time frames. This technique assumes that impacts can be directly summed for each time frame. The use of time frames for determining magnitude of impacts could cope with quantitative, quantitative and narrative descriptions of impacts. Examples of the use of time frames for determination of magnitude and significance of cumulative effects can be seen in the following tables. From Table 2.5, it would appear that the main assumption used for aggregating effects is additive. From Tables 2.5 to 2.7, it is clear that the basis for analysing the magnitude of impacts are time frame for each Valued Environmental Component, such as air quality fish, and wetland.

2.4.6.3 Magnitude and Significance Determination Based on Space

Previous discussion provides evidence of the use of spatially constrained areas, that is a watershed to determine the magnitude and significance of cumulative effects.

Table 2.5 Example of Using Quantitative Description of Effects (within a given level of uncertainty) on various resources (Sources: CEQ, 1997:43)

Resource	Past Actions	Present Actions	Proposed Actions	Future Actions	Cumulative Effects
Air Quality	No effects on SO_2	20% increase in SO_2	10% increase in SO_2	5% increase in SO_2	35% increase in SO_2
Fish	50% of 1950 fish population lost	2% fish population lost	5% increase in fish population	1% of fish population lost	48% of 1950 fish population lost
Wetland	75% of pre-settlement wetland lost	1% of existing wetland lost annually for 5 years	0.5% of existing wetland lost	1.5% of existing wetland loss annually for 10 years	95% of pre-settlement wetland lost in 10 years

Table 2.6 Example of Using Qualitative Description of Effects on Various Resources, with Impact Ranks Assigned from 1 to 5 (least to greatest) (Sources: CEQ, 1997:44)

Resource	Past Actions	Present Actions	Proposed Actions	Future Actions	Cumulative Effects
Air Quality	1	2	1	1	2
Fish	3	2	1	1	4
Wetland	4	1	1	1	4

Another way for representing the magnitude and significance of cumulative effects is by using changes in the extent of the area of particular resources. The main assumption is likely to be that cumulative environmental changes could be seen from area changes. Using changes in the areas provides a direct quantification of total cumulative effects by summing the area of impacts from one time to another.

Table 2.7 Example of Using Narrative Description of Effects on Various Resources(Sources: CEQ, 1997:44)

Resource	Past Actions	Present Actions	Proposed Actions	Future Actions	Cumulative Effects
Air Quality	Impacts dissipated	Noticeable deterioration on visibility during summer, but standards met	visibility affected during operations, but standards met	increase in auto-emissions expected	Standards possibly violated
Fish	Decrease in numbers and species diversity	Occasional documented fish kills	Increase in number of fish kills	Loss of cold-water species due to change in temperature	Significance decline in numbers and species diversity
Wetland	large reduction in acreage of wetlands	loss of small amount of wetland annually	Disturbance of a 5 acre wetland	Continued loss of wetlands	Significant cumulative loss of wetlands

Area as an indicator for CEA can be seen in the studies by Sebastiani et al. (1989); Green et al. (1993); Johnston (1994); Boyle et al. (1997); Walker et al. (1986); Cocklin, Parker and Hay (1992b); Sidle and Hornbeck (1991) and Damman, Cressman and Sadar (1995).

Compared to the quantification of qualitative judgment, the use of "area" or changes of areas can provide direct comparison of effects from one time to the others.

2.4.7 The Roles of Methods for Determination of Magnitude and Significance of Cumulative Impact

The selection of methods for use in the studies of cumulative effects will depend on the problem to be resolved, the aim of the analysis, the accessibility and the quality of data and available resources (Smit and Spaling, 1995:101). There are studies which have provided the descriptions and evaluation on the methods for CEA. These studies describe:

(1) Methods-related concepts (Cocklin, Parker and Hay, 1992a; Spaling, Smit and Kreuwitzer, 1994; Contant and Wiggins, 1997; Miller, 1984; Lawrence, 1993; Canter and Kammath, 1995; Court, Wright, and Guthrie, 1994; Abbruzzese and Leibowitz, 1997).

(2) The application of methods for cumulative impact assessment (Green et al., 1995; Cocklin, Parker and Hay, 1992b, Court, Wright, and Guthrie, 1994; O, Neill et al., 1997; Magnuson, 1990).

The study by Smit and Spaling (1995) is important because it demonstrates the strengths and weaknesses of methods used to assess cumulative effects (Table 2.9).

Smit and Spaling (1995) propose six criteria used to assess the methods for cumulative impact assessment: temporal accumulation, spatial accumulation, perturbation types, processes of accumulation, functional effects and structural effects. The full definition of each criterion is detailed in Smit and Spaling (1995:89). The criteria listed do not relate to whether the particular method suits the basic process in environmental impact assessment: identification, scoping, prediction, and evaluation or not. The criteria listed only consider the possible capabilities of methods for dealing with spatial and temporal dimensions, structural and functional changes and types of perturbation.

As can be seen in Table 2.8, each method has different capacities in the analysis of the components included in cumulative effects assessment (CEA). Some methods such as Loop Analysis and Cause-Effect Diagramming may only be appropriate in the early stage of the assessment of CEA. Simulation modelling, on the other hand, may be appropriate for assessing the effects of the combination of different attributes contributing to cumulative effects.

The ability of simulation modelling to combine space and time may be appropriate for uses in CEA. More importantly, by using simulation modelling, spatial and temporal dimensions can be embedded and testable evidence of effects can be gained. Mathematical simulation modeling, however, has a weakness in that the results do not have an explicit spatial connotation. The information of spread of impact may have to be related to the explicit and correct location for the results of modeling to be useful. Integration via the spatial analysis capabilities of GIS is potentially able to solve this problem.

By comparing Table 2.1 and Table 2.8, it is clear that methods used to analyse single projects are different from those used in CEA, although some of them remained the same, such as, overlay (Table 2.1) and GIS (Table 2.8), also Land-Suitability Analysis (Table 2.1) and Land Disturbance Target (Table 2.8). The differences observed from Table 2.1 and Table 2.8 are as follow:

(1) It is likely that computer based analysis will assist in the application of the methods in the assessment of cumulative impact.

(2) Explicit recognition of either spatial or temporal or the combination has started to be included in CEA. This can be seen in the methods for cumulative impact assessment: Geographical Information Systems (GIS), Landscape Analysis, Simulation Modeling.

(3) Considering the strengths and weaknesses of methods as illustrated in Table 2.2, it is likely that no single method is capable of analysing the sources, the process of accumulation and the typologies of cumulative impact.

(4) Only simulation modelling could cope with the dynamics of ecosystems and having a predictive capacity. The impacts of many activities vary from space to space and from one time to another. Methods that could cope with this variability are very important for explaining the processes of impact accumulation. The method's capacity to be able to predict the future impacts or effects or changes is very important for cumulative impact assessment. As can be seen in Table 2.8, simulation modeling is the only method that meets all six selected criteria. Geographical Information Systems (GIS) have satisfactory explanation on the temporal accumulation, spatial accumulation, type of perturbation and structural change.

Table 2.8 Summary Evaluation of Selected CEA Methods
(Sources: Smit and Spaling, 1995:90)

Methods	Temporal Accumulation	Spatial Accumulation	Type of Perturbation	Process of Accumulation	Functional Change	Structural Change
Geographical Information Systems	S	S	S	X	P	S
Loop Analysis	X	X	S	S	X	X
Landscape Analysis	S	S	S	S	P	S
Argonne Multiple Matrix	X	P	S	S	X	X
Simulation Modelling	S	S	S	S	S	S
Cause-Effect Diagramming	X	X	S	S	X	X
Multi-Attribute Tradeoff Analysis	X	P	S	X	X	X
Linear Programming	P	S	S	P	P	S
Land Disturbance Target	S	S	P	P	S	S
CEA Reference Guide	S	S	S	P	S	S

S = satisfactory meets criteria; P = partially meets criteria; X = does not meet criteria

Information concerning comparison of methods as listed in Table 2.8 should be interpreted carefully. Some methods may provide accurate results in particular areas, but they may not provide accurate results for other areas. Therefore, information provided in Table 2.8 should be considered as only general guidelines.

Smit and Spaling (1995) claim that simulation modelling has pragmatic problems that relate to its dependency on reliable data, model validation, and available resources. Besides, this model is only applicable for the well-understood systems. Constanza, Sklar and White (1990) clearly show how the simulation model they built, which was called CELLS, was very extensive in terms of the amount of data needed, although this could provide information about the processes in the coastal areas and can be used to predict the impacts resulting from many different scenarios.

The literature review on the methodology for cumulative effects assessment can be summarised as follow.

1. Qualitative methodology and the quantification of qualitative information are the main characteristics of previous methodologies. In relation to the methods used for CEA, there is very limited evidence for the use of mathematical models.
2. Scoping as formal process has been marginally considered.
3. Time and space are two important components in CEA. Methodologies for CEA must consider two main dimensions. There have been many different ways in incorporating them for the purpose of CEA.
4. Current methodologies for cumulative effects rely mainly on the concept of aggregation using matrices as the main mathematical tool. Types of cumulative effects, such as, interactive, synergistic, and threshold have been rarely investigated in the literature. From the review of literature on methodologies for cumulative effects, it would appear that types and their importance in the analysis and synthesis of cumulative effects have been marginally considered.
5. GIS is the method used mostly for analysing changes in areas.
6. The development of methodologies for CEA has mainly relied on spatially constrained areas (e.g. watershed). CEA on the other areas, such as an estuarine environment has been rarely investigated. Consequently, methodologies for CEA in estuarine environment are considered underdeveloped.

Therefore, this study emphasises on the development of a methodology for CEA in an estuarine environment that employs types of cumulative effects as the basis. The following chapter describes the conditions of the selected estuary.

III. STUDY AREA

3.1 Rationale

The rationale for choosing Port River and Barker Inlet estuaries as the areas to apply the proposed methodology are:

1. Long term use of the study area for industrial purposes.
2. Monitoring data exist although this only starts in recent years (1995).
3. Variation in the condition of these estuaries can be observed, such as bathymetry, tides, velocity and morphology.
4. There are past studies on the effects of activities on Valued Environmental Components/VEC(s), particularly the effects of many activities on water quality.

3.2 General

The study area for testing the proposed methodology is situated in Port Adelaide, the suburbs in the north-western part of Adelaide, the capital city of South Australia. The location of the study area in the rational context can be seen in Figure 3.1.

The Port Adelaide area has been an industrial area for over 100 years and there are still major industrial sites in this area. These include the Osborne Penrice Soda Products, Torrens Island Power Station, Port Adelaide Sewage Treatment Works and Bolivar Sewage Treatment Works. Many of the industries in the Port Adelaide area would have affected the environment, especially decades ago when environmental considerations were not as important as are now. Although the industrial nature of the region has changed over the years, significant amounts of industrial activity in the region are still evident. These conditions can impact the environment.

The environmental conditions in this region are not the result of a single action. Expanding urban growth in the immediate vicinity and in the northern areas of

Adelaide has also increased the quantity of stormwater that flows into the Port River and Barker Inlet. Pollution from this stormwater may also have significant impact on the environment. Consequently, there have been the observed effects of past, present and future activities on the resources (KINHILL, 1989 and MFP Australia who studied water quality and other environmental components, 1992; Overton 1993 who studied mangroves; Steffensen, 1976; Steffensen, and Walter, 1980 who studied the water quality and Bayard, 1992 who studies mangroves). All of these studies emphasised on the effects of many activities on the environmental components, such as mangroves, seagrass and water quality. Due to these conditions, the study area was selected as the case study for Cumulative Effect Assessment (CEA). Figure 3.2 shows the activities surrounding estuaries with the names of locations. As can be seen, the estuary is surrounded by activities. A more regional view of the study area can be seen in Figure 3.3, which shows that different land uses surround the study area. Despite the obvious effects of many of the activities on the environment, studies focusing on the cumulative effects of numerous activities in the study area have not been conducted. However, there are Environmental Impact Statements (EIS) and other environmental studies for individual activities, such as those conducted by MFP Australia (1992) and KINHILL (1989), which can be used as sources of information for CEA in the study area.

3.3 The Importance of Barker Inlet and Port River Estuary

Since 1973 the Barker Inlet has been an Aquatic Reserve with the main purpose of protecting the mangroves and seagrass communities (Banham, 1992). Seagrass and mangroves communities are two significant resources because they act as a nursery ground for fish. Jones (1984) claims that the Barker Inlet/Port Adelaide mangrove ecosystem is one of main nursery grounds on eastern shore of Gulf St. Vincent for an important commercial fish called the King George Whiting (*Sillaginodes punctatus*). The importance of shallow seagrass meadows for fish habitat has been underscored by Connolly (1994).

Saltmarshes are the main habitats responsible for the high productivity of fish in the study area, especially for juveniles of economically important species. They are

Figure 3.1 The Location of Study Area

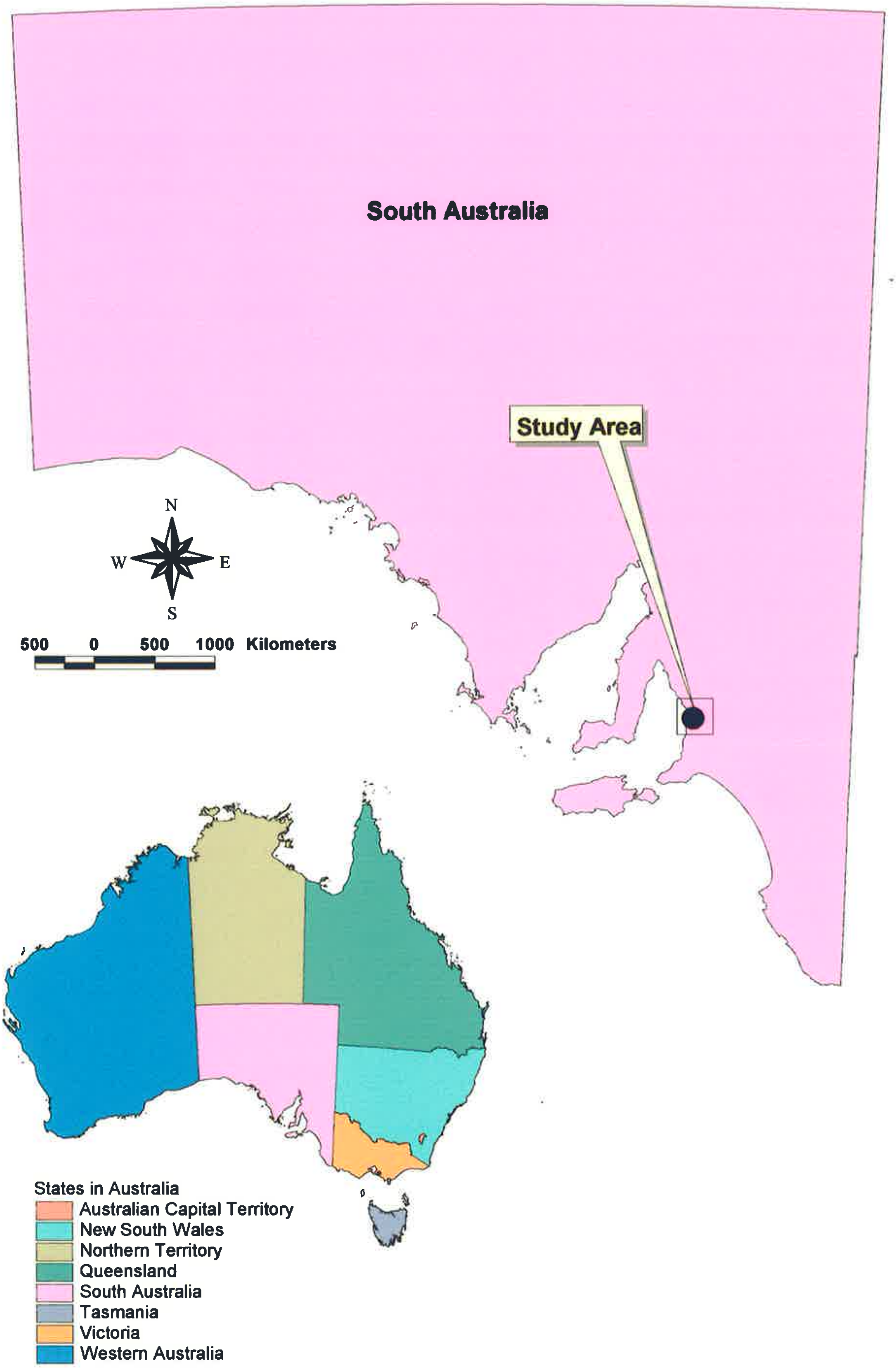
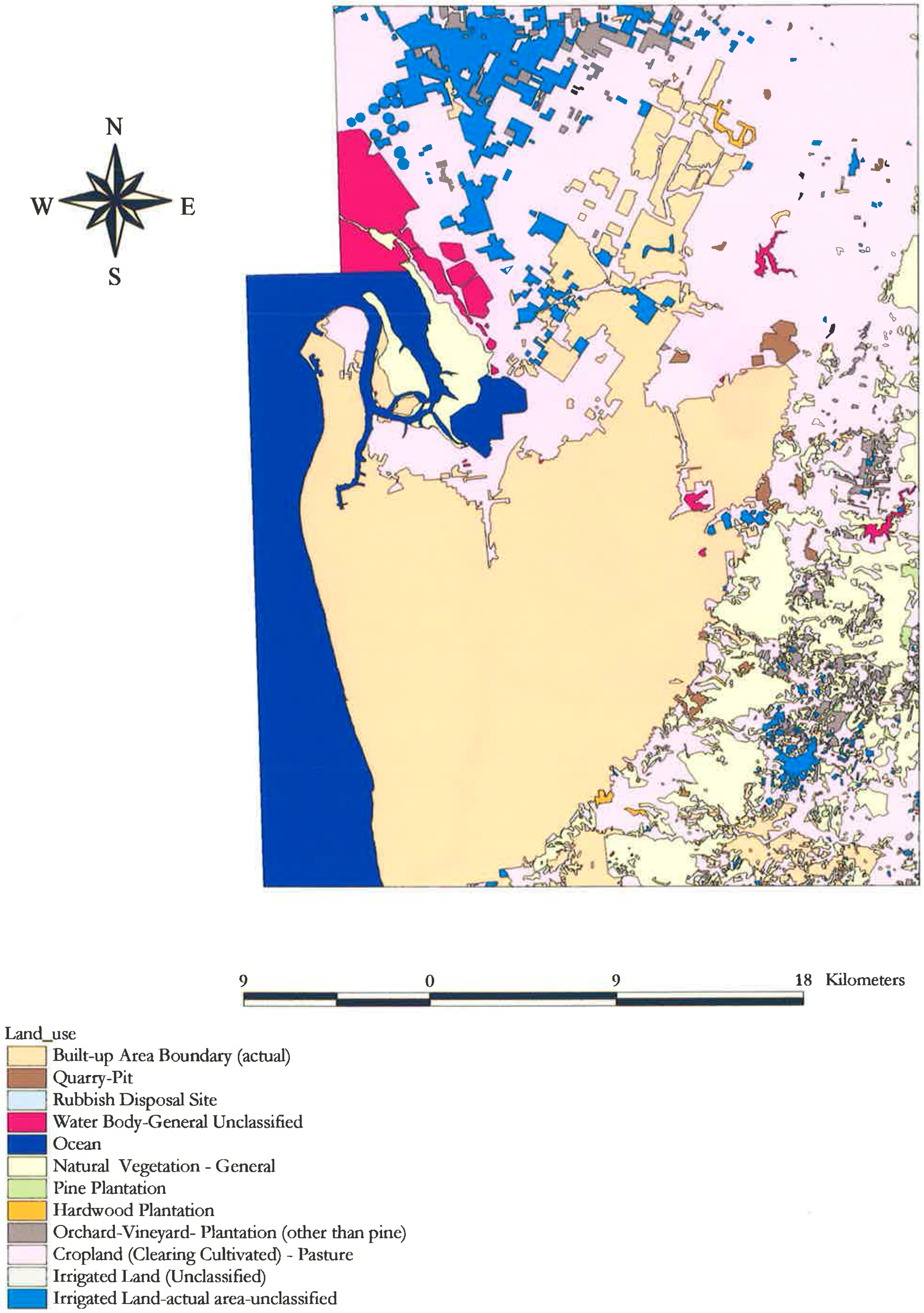


Figure 3.2 Activities and Location Information Surrounding Estuary
(Source: Department of Environment, Heritage and Aboriginal Affair, 1999)

Figure 3.3 Regional Context of Study Area (Sources: Bryan, 2000)



important both in terms of their role in filtering surface overflow prior to it entering the sea and in their contribution to nearshore coastal productivity (Morrisey, 1995 in Connoly, Bass and Dalton, 1998:3). Because of this, this estuary has very high abundance of juveniles of commercially important fish species (Jones, 1984 in 1995 in Connolly, Bass and Dalton, 1998:3). As a result of this, this area is very popular for recreational fishing.

3.4. Geology and Geomorphology

3.4.1. Geology

Geologically, there are three formations in the study area. These are: St. Kilda Formation, Glanville formation, and Hindmarsh Clay and the description of these three geological formations can be seen in Table 3.1 below. There is local variation in the thickness and composition of the St. Kilda formation. Along the eastern side of Outer Harbor including Torrens Island and Garden Island, the extend of this formation has depth of about 9 metres and is often characterised by non cohesive sand (MFP Australia, 1992). This material gradually changes to silty and clayey sands towards Port River. The Glanville formation has a depth range from 3 to 4 metres and range from a loose to medium dense condition, with a variable degree of cementing. The depth of Hindmarsh formation extends from 60 to 70 metres. The upper zone of this formation is generally calcareous with pockets and fine nodules of calcareous material (MFP Australia, 1992:20).

The obvious phenomenon which relates to the geology of the study area is land subsidence. This is considered important due to its effect on the portion of sinking land, which further affects the condition of mangroves. This geological condition is likely also to affect the mangrove mud condition. Mangrove mud can potentially affect the condition of water quality due to its role as the potential sources of nutrients (Harbisson, 1986a).

Table 3.1 Three Geological Formations in the Study Area
(Source: Summarised from MFP Australia, 1992)

Formations	Characteristics
St. Kilda Formation	This formation is the sequence of unconsolidated Holocene marine sediments. It is typically characterised by saturated, silty and clayey sands with abundant shell fragments and organic fibres (sub-tidal seagrass facies). Sub-tidal seagrass facies is likely to be overlain by intertidal mangrove facies (soft, spongy, highly organic clay peat) and a thin layer of poorly sorted, variably sized graded shell associated with intertidal facies)
Glanville Formation	This formation has a range of thickness from 3 to 4 metres. This Pleistocene marine sediment has typical characteristics comprising poorly sorted, variably cemented shell quartz sand, clayey sand, clayey silt and silty clay.
Hindmarsh Clay	An alluvial sequence of mottled clay and sandy clay of high plasticity and stiff to hard consistency which was deposited during Pleistocene times. This formation is considered impermeable.

3.4.2 Geomorphology

The study area is a low-lying estuary having salt marshes and tidal-flats, which are subject to potential flooding from stormwater and the sea. On a wider regional basis, the estuaries and coastal geology of the study area are typical of the fluvial and alluvial fan development resulting from river and stream erosion of the nearby Mt. Lofty Ranges.

Sedimentation is a major geomorphological process occurring in the study area. This has resulted in shallow configuration of the Port River estuary. As a result of this, there is a plan to deepen the Port River by 3 meters by dredging (Pitcher, Pers. Comm.). A phenomenon called "dodge tide" and stormwater may have an effect on sedimentation. Harbison (1984) states that a "dodge tide" can result in the water remaining almost stationary over tide flats for 12 to 24 hours, during which time the growth process of seagrass, algae and micro-organism in the mud can significantly change the chemical environment in the layer of shallow water. The effects of this type of tide can be significant by considering phenomena which can be affected by it, such as daily fluctuation of water depth, dissolved oxygen, pH, and redox potential.

The second phenomenon is the circulation of tides. The circulation of the tides in the study area has been studied by Schluter (1993). An unusual tidal event occurs in the middle of Barker Inlet in that the two wave fronts enter from either end of the channel and produce a location of minimal movement. This has resulted in a typical phenomenon called "parting" (Schluter, 1993:726). The approximate location of "parting" can be seen in Figure 3.4 and Figure 3.5. This type of tide is more likely to have effects on the distribution of pollutants and energy in the estuary.

The second geomorphological aspect in the study area is the bottom morphology. Morphologically, Barker Inlet is the largest inlet in the Gulf St Vincent (Harbison, 1984), and Port River Estuary is deeper than Barker Inlet. Despite the difference in the bottom morphology, they both have a direct connection. This configuration may also have effects on the dispersion and accumulation of material, including pollutants.

3.5 Valued Environmental Components in The Study Area

There are a number of Valued Environmental Components (VECs) in the study area. These main VEC(s) are described below.

3.5.1 Vegetation of The Study Area

The two main types of vegetation in the study area are mangroves and seagrass. Generally, the intertidal and supratidal areas of Barker Inlet are dominated by monospecific *A. marina* woodlands (Banham, 1992:15). This monospecific mangrove grows to about 3.5 m to 5 m (Edyvane, 1995:5). The supratidal zone on the landward side of the mangrove is dominated by samphire vegetation, of which *Sarconica blackiana* is a dominant species.

Seagrasses occur within the shallow littoral zone. *Zostera mulleri* and *Heterozostera sp.* are the most abundant species. *Posodonia australis* is more limited in occurrence and it is mostly found in deeper areas. Seagrasses in this area act as traps for sediments, nutrients, recycling and stabilise the seabed (Environmental Protection Authority, 1997). Seagrass and mangroves are important communities because mangroves and

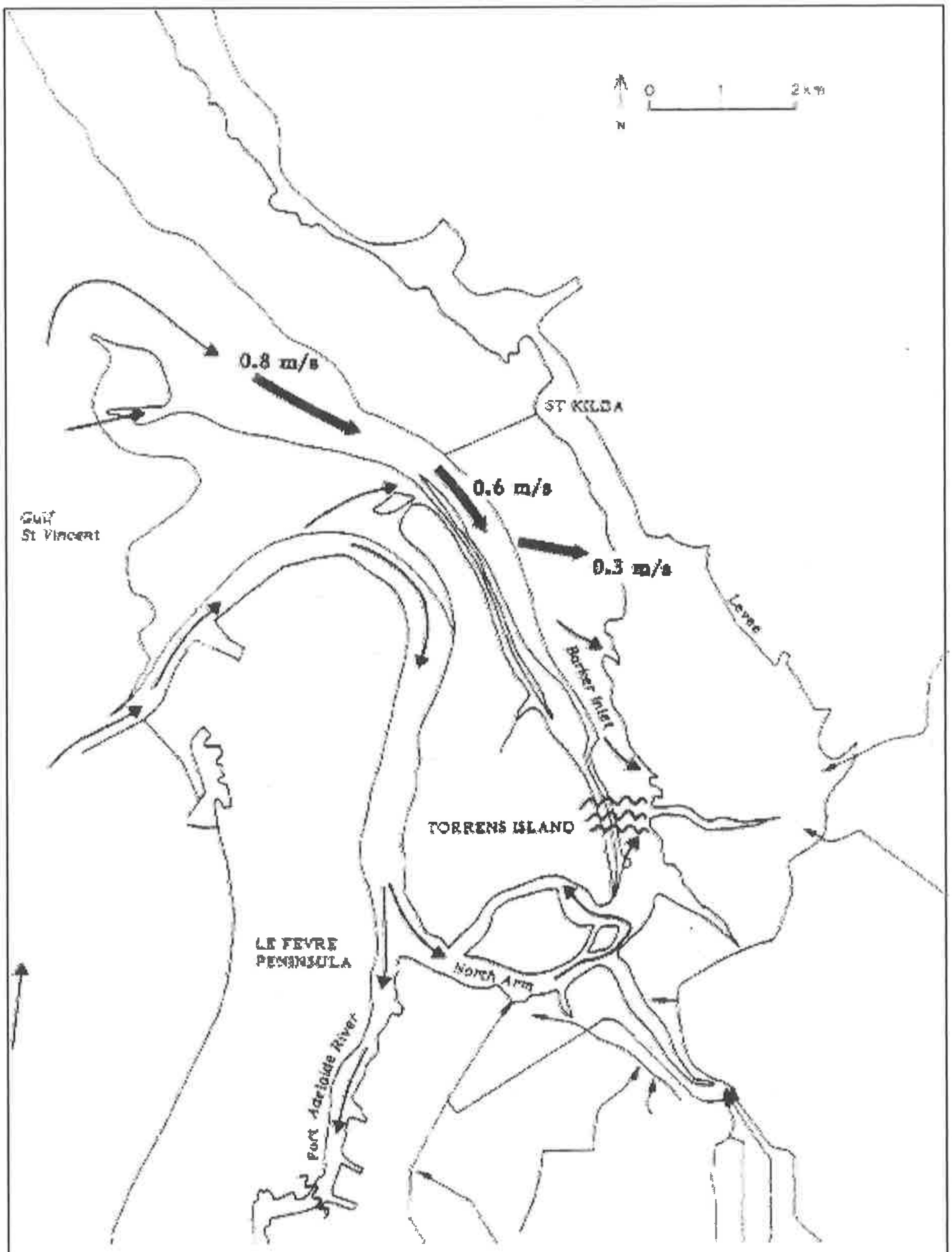


Figure 3.4 The Pattern of Tides Entering Estuaries (Sources: KINHILL, 1989)
(The sign of ~ is the location of the "parting").

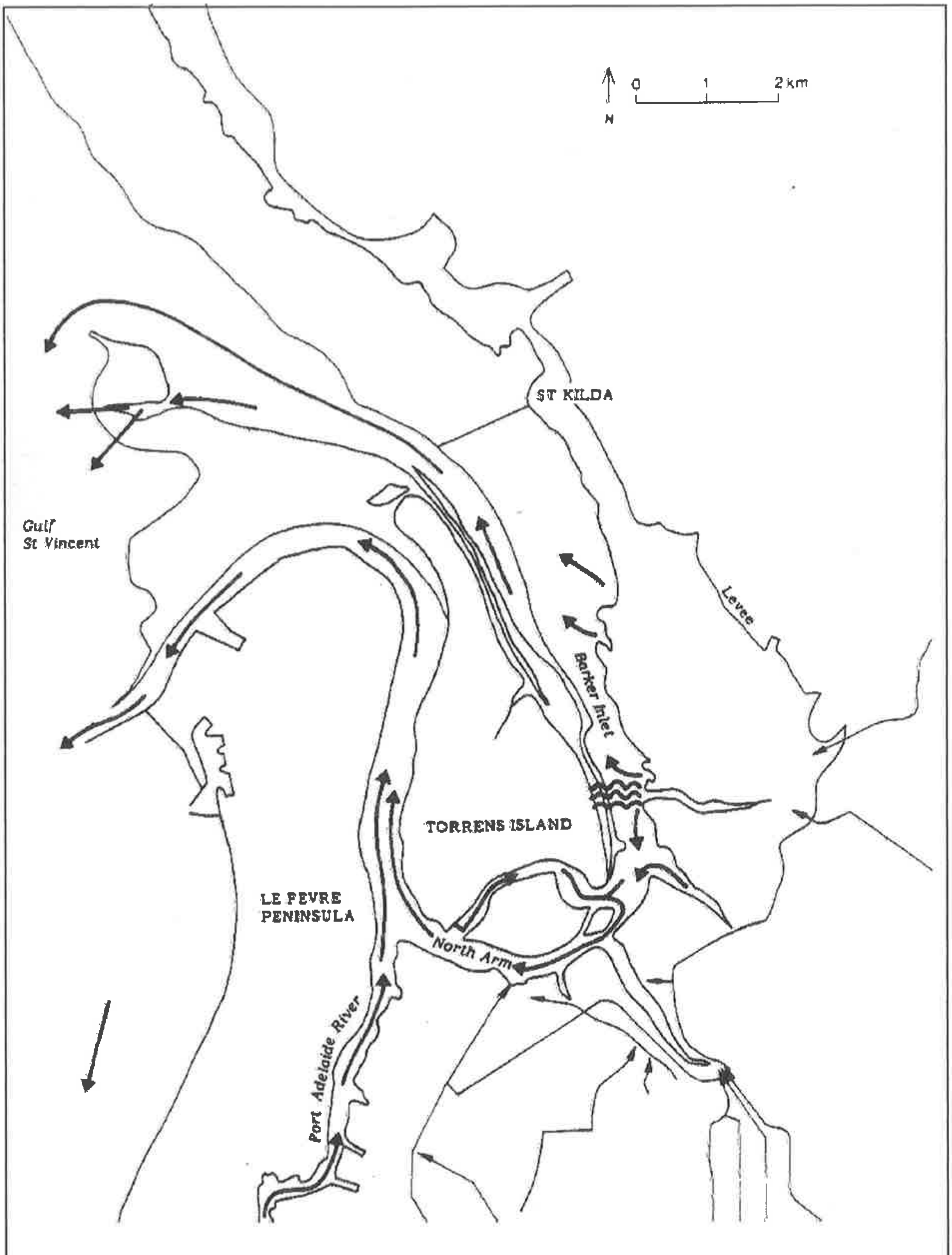


Figure 3.5 The Pattern of Tides Leaving Estuaries (Source: KINHILL, 1989)
(The sign of ~ is the location of the "parting").

their associated seagrass and saltmarsh habitats are important nursery and feeding areas for many fish and crustacean species in South Australia and the place for the stabilisation of sediment (Butler, et al., 1977:35; Edyvane, 1995). The location of mangroves and seagrass in the study area can be seen in Figure 3.6.

3.5.1.1 The Development of Mangroves in the Study Area

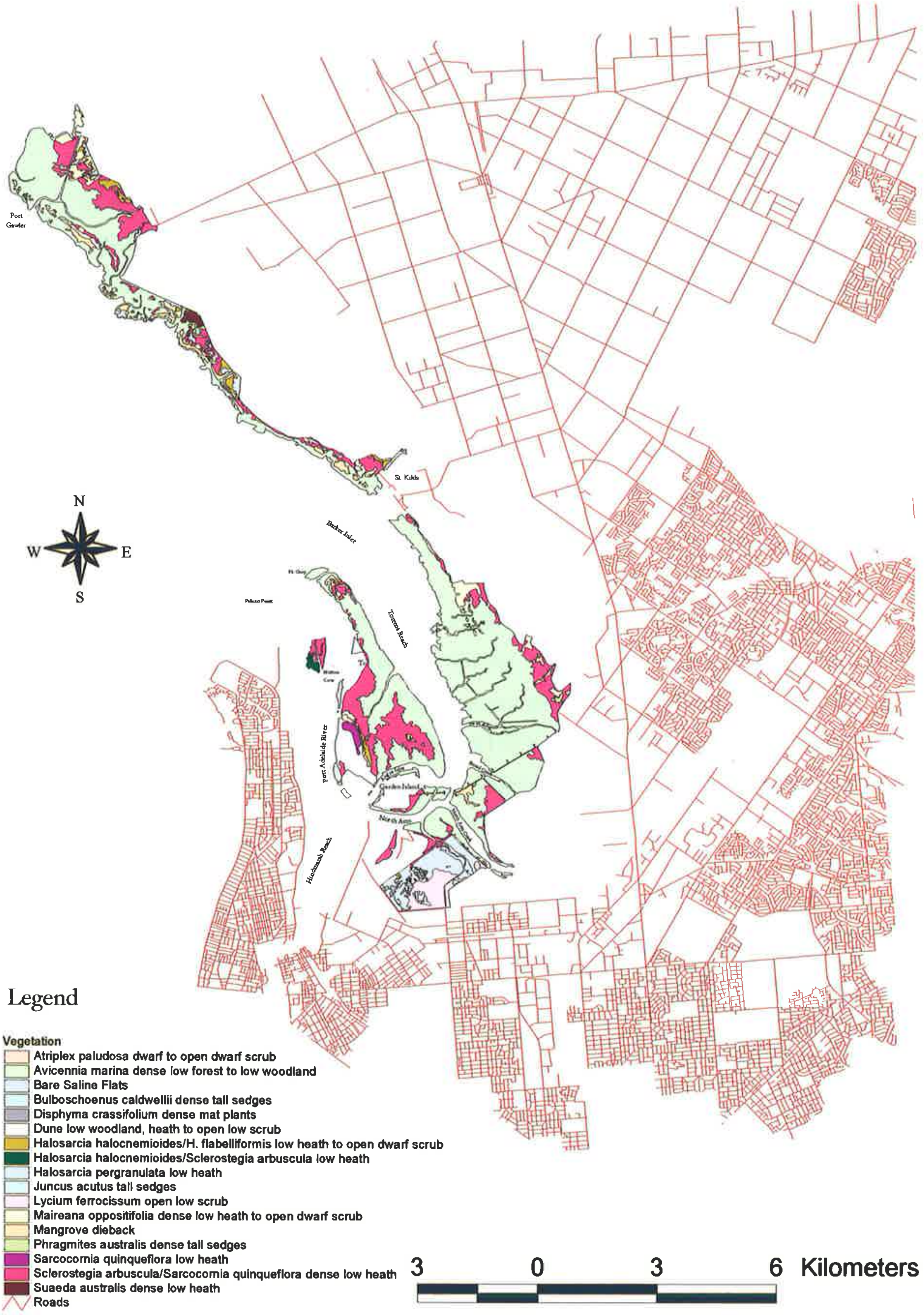
From Figure 3.6, it would appear that the distribution of seagrass and mangroves is mainly in the area extended from Gawler to the southern part of Barker Inlet. On the other hand, there are only small areas of mangroves in Port River estuary.

According to information obtained from interviews, there was previously seagrass in parts of Port River estuary. Because of dredging of the estuary for shipping, the seagrass was completely lost in the Port River part of the study area, but there is still seagrass in the Barker Inlet. Currently, mangroves are also absent in the Port River part of the study area. This may qualitatively indicate that the effects of activities on seagrass and mangroves were significant in the past.

The patterns of distribution of mangrove are twofold: seaward and landward (Burton, 1982; Coleman, 1998). Toward the land, mangrove development is limited by samphires. Toward the sea, the growth of mangroves is bounded by the intertidal sand with or without seagrass. This is particularly in the area surrounding North Arm Creek. As Coleman (1998) reported, this development has occupied the areas which were previously the habitat of saltmarsh communities. Parts of the estuarine areas that were previously mangroves are currently seagrass. This may be a unique phenomenon in this study area.

The result of the study by Coleman (1998) suggested that the development of mangroves does not depend on one single factor, rather many factors can be responsible for the landward and seaward development of mangroves, e.g. accretion of sediment, strong wave and subsidence/sea level rise (Burton, 1982).

Figure 3.6 Vegetation in the Study Area (Source: Fotheringham, 1994)



The pattern of the development of mangroves as explained by Coleman (1998) is quite different to the distribution of mangroves in the areas surrounding the Bolivar Sewage Treatment Works as explained by Overton (1993). The Coleman study claims that the natural phenomena are likely to be the main factor responsible for the loss and gain of mangroves, whereas the study conducted by Overton (1993) suggests that the losses of mangroves are due to nutrient loading from Bolivar Sewage Treatment Works (BSTW). Similar to the Coleman's study, Burton (1982) suggests that sedimentation is the primary factor responsible for the development of mangrove from River Light to Swan Alley Creek (see Figure 3.2). From this discussion, it is clear that the development of mangroves in the study area is determined by two main factors: natural and human. There may be synergism between the two or there may only be local effects of local activities. However, the distribution pattern of mangroves loss has suggested that that Bolivar Sewage Treatment Works is likely responsible for the loss of mangroves.

Overton (1993:57) states that the relationship between mangrove dieback and the BSTW is evident not only in the timing of mangrove decline since the outflow inception, but also the decline of mangroves as a function of distance from the sewage outflow. The loss of mangroves near BSTW has also been observed by Bayard (1992). They state that a remarkable loss of mangroves only occurs in the area adjacent to BSTW.

At the beginning of the industrial development in the study area, mangroves were extensively damaged. Before this, mangroves have been also damaged due to the development of levees, which prohibit landward development of mangroves. Other activities which can also threat mangroves are land reclamation, dredging and marina development (Edyvane, 1995).

The growth of macrophytes, *Ulva lactuca*, can also affect the existence of mangroves. *Ulva lactuca is* an algae which can attach to the mangrove seedlings. The growth of mangroves is also affected by the discharge of hot water from Torrens Island Power Station. As the study conducted by De Guia (1982) reported, mangroves surrounding

Torrens Island Power Station were affected by the discharge of warm water. This study reported that there was an increase of water temperature of about 8.5°C due to warm water discharge. In conjunction with the growth of mangroves, de Guia (1982) claims that both seedling and mature trees are affected by warm temperature. In the cool water area there was a larger increase of growth in both seedling and mature trees, whereas in the warm water, the growth of both seedling and mature trees was apparently limited. This study also found that the concentration of N, P, K, Mg, M and Na were significantly higher in the decaying leaves from the warm water area than from the cool water area. In addition, the rate of movement of Mg, K, and Mn were also significantly faster in the warm water than in the cool water area. Although the study conducted by DeGuia (1982) is preliminary in characteristic, it is clear that the discharge of warm water into the estuary has been impacting mangroves. This statement underscores the concept of cumulative effects in the sense that the growth of mangrove has been affected by the nutrients resulting in the growth of *ulva lactuta,* and high temperature from the discharges from Torrens Island Power Station. This example shows the effects of two activities (discharges of nutrients and hot water) on the growth of mangroves.

The effects of Torrens Island Power Station on another VEC have also been initially investigated. Thomas, et al. (1986) investigated the effects of warm water discharges to the estuary and stated that the discharge has been affecting the composition of fauna in the estuary. They concluded that because of the progressive increase in thermal discharge from Torrens Island Power Station over the period of 1972-1985, there has been a recognisable change in the nature, abundance and the distribution of intertidal invertebrates in adjacent reaches of Port River estuary. This has been prominent for bivalve mollusc and worm species characteristics which have been replaced by opportunistic worm species, such as *Cirriformia punctata, Pseudopolydora* sp. and *C.punctata.*

Apparently, Torrens Island Power Station has also been impacting species composition of fish. As Jones et al. (1996) reported, there was a decreasing number of species with decreasing distance from the thermal outfall. As they claimed, there can be possible indirect causes of this:

(1) Thermal discharge may indirectly affect fish distribution by means of changes in sediment structure that result from increased flow rates.

(2) Another possible indirect cause may be from the possible disappearance of seagrass beds in the thermally affected area.

The above discussion suggests that mangroves in the study area have been affected by past, present and future activities. It is also apparent that the combination of many activities (both natural and human-induced) and the interaction of these activities for long time have resulted in the degradation of mangroves. To summarise, it is important to note the statement given by Edyvane (1995:31) stating that:

> Mangroves and saltmarshes in South Australia are most under threat from small, incremental losses associated with urban development, particularly in the northern metropolitan Adelaide region.

This suggests that the loss of mangroves have been the result of the combination of small activities. Indeed, this is the phenomenon of cumulative effects.

3.5.1.2 The Development of Seagrass in the Study Area

Another sensitive vegetation in the study area is seagrass. The distribution of seagrass in the study area can be seen in Figure 3.6. A species of seagrass, *Posidonia australis*, occurs in the subtidal zone, whereas the seagrass species of *Zostera mulleri* and *Heterozostera sp.* are found in the intertidal areas. The difference in the habitat leads to the difference in the sensitivity. *Zostera mulleri* and *Heterozostera sp.* are two species, which are probably much more sensitive to changes of temperature because they are located in the exposed intertidal areas. Similar to mangroves, there has also been a decline in the areal extent of seagrass in the study area. The loss of seagrass has also been attributed to the BSTW (Sheperd, 1989 in Overton, 1993). He stated that although the decline of seagrass in this area surrounding BSTW occurred before the first discharge of effluent, the rate of the loss of seagrass has been increasing since the discharge of effluent. The growth of *Ulva lactuca* has also been observed only after the discharge of effluent (Sheperd, 1989 in Overton (1993). In addition, Overton (1993:81) reported that since 1965 to 1992, the rates of seagrass change in the area surrounding BSTW were: -0.0002 km^2/yr (1965), -0.0440 km^2/yr (1969), -0.1040 km^2/yr (1977), + 0.0505 km^2/yr (1983), -0.0343 km^2/yr (1989) and -0.3322 km^2/yr (1992). The minus

(-) sign indicates the gain of seagrass, whereas, the positive (+) sign indicates the loss of seagrass. Depite the additional areal extent of seagrass, the loss of seagrass in total is larger than the gain of seagrass, which suggests that the BSTW has been affecting seagrass.

3.6 Water

Water is one of many environmental components which have been impacted by activities. The degradation of water quality is prominent in the study area due to the presence of industrial activities. A major factor is nutrient discharged into estuary, such as nitrogen and phosphorus. The degradation of water quality in the study area is also due to the discharge from stormwater containing dissolved solids, nutrients/fertilisers, pesticides oil, floating debris and litter, organic matter, herbicides, chemicals, and metals.

Another source of water quality contamination is from land-based activities. The study conducted by Maunsell Pty. Ltd (1993) strongly suggested that the lands adjacent to the water body of the estuary have been used for dumping, although this report only covers a small part of overall study area. The sources of dumped materials to the Port River estuary are from Prot River itself when this river was dredged in the past. The land-based disposal is likely also to have effects on the water quality. The potential major sources of contaminants according to this report are: heavy metals, sulphur, phosphate, combustion products (PAH), benzene and petroleum mixtures, organic wastes, arsenic and other treatment chemicals. However, there is no available source of information about the predicted loading concentrations for each contaminant.

Tidal circulation may also have effects on the quality of water in the study area. The circulation of tides may affect the area in which the accumulation of pollutant may exist. Tidal circulation may also have effects on the dilution of pollutants in the estuary. Because waters and sediment are two related environmental components, their interaction may also have effects on the dispersion and accumulation of pollutants.

The pattern of change in water quality may be much more complicated because of the interaction of many components. Tidal circulation, season and daily variation on the temperature, sediments, discharges of nutrients, hot water and dissolved solids into the estuary, rainfall, the addition of freshwater through creeks, and the activities of micro-organism in water, the direction of wind, the topographic configuration of the estuary and sediment may all have been affecting the dispersion and accumulation of pollutants in the water.

Water is the central environmental component in the study area due to the effects of water condition on other environment components, for example:

(1) Effluents from Port Adelaide Sewage Treatment Works and Bolivar Sewage Treatment Works are discharged into the estuary with the result that the body of water would be directly affected by these effluents and this would change water quality in the estuary. The additional source of nutrients from stormwater has, in fact worsened the water quality in the estuary (Environmental Protection Authority, 1997).

(2) There are important environmental components in the study area, such as seagrass and mangroves, which are very sensitive to water quality changes (Cambridge and McComb, 1984; Steffensen, 1976; Neverauskas, 1987; Orth and Moore, 1983; Walker and McComb, 1992; Thayer, Wolfe and Williams, 1975; Coleman, 1998; Dennison, et al., 1993; Stevenson, Staver and Staver, 1993).

3.7 Sediments

Studies of sediments in the study area mostly related to the mangroves and seagrass. This may be due to the role of mangroves and seagrass in trapping and stabilising sediments. Butler et al. (1977) described sediment types in the study area. They state that the sediment type of mangroves forest in the study area is classified as boundstone sediment, consisting predominantly of clay to fine silt, although there is local variability. Another phenomena accompanying sediments is algal mats. Algal mats cover sediments in the study area, although there is also local variation in the area covered.

In the study area sediments also play a significant role in the trapping and releasing of metals (Harbison, 1986a, 1986b). Although the role of sediments in releasing and trapping metals depends on the temperature, pH and redox potential, this role must be taken into account in understanding the mechanism of the accumulation of pollutants in the study area. Because of its direct contact to water, its possible roles as a sink or source of pollutants must have a particular attention (Harbison, 1986a, 1986b).

3.8 Activities and Their Potential Environmental Impacts

The activities that occur in the study area, the year of their establishment and the impacts of these activities on possible resources can be seen in Table 3.2 below. From Table 3.2., it would appear that the impacts of these activities on the environmental components in the study area have been mainly on water quality, mangroves, seagrass. Activities in the past, such as the installation of pipelines, levee development and dredging, affected the environment in the study area. KINHILL (1989), for example, claims that the impacts of the project to install the gas pipeline from Wasleys to Adelaide, which passed through the Barker Inlet and along the Port River were considered insignificant.

3.9 Conclusion

The summary of this chapter are:

(1) The study area has many important resources, such as fish, mangroves, water, seagrass and sediment. These resources have been experiencing serious effects from many activities.

(2) Despite clear evidence on the impact of single activities on the resources, the degradation of resources is likely to result from many activities.

(3) The current state of environmental condition is more likely to have been the result of long term history of impacts in the study area.

(4) Information about the relationship amongst environmental components in the study area and the possible causes of their degradation does exist, although available information is very limited.

For the study of CEA in the estuary, it is necessary to have the framework which can conceptually provide the way the analysis of cumulative effects can be achieved. The following chapter (Chapter IV) will show the theoretical framework for uses in CEA in the estuarine environment.

Table 3.2 Description of Activities and Possible Impacts on Environmental Components in the Study Area

No.	Activities	Year of Establishment	Potential Impacts (-) / (+)	Environmental Components Potentially Affected
(1)	**(2)**	**(3)**	**(4)**	**(5)**
1	Levee Development	1940s	physical destruction to mangroves (-)	• mangroves
2	ICI (Salt Evaporation Pans)	1935-1938	leachate of salt to mangroves (-)	• water quality • mangroves
3	Bolivar Sewage Treatment Work	1967	nutrients (-)	• water quality • seagrass • mangroves • sediments
4	Port Adelaide Sewage Treatment Work	• 1935 (opened) • 1954 (extended)	nutrients (-)	• water quality • seagrass • mangroves • sediments
5	Penrice Soda Products	1930s	nutrients (-)	• water quality • seagrass • mangroves • sediments
6	Marinas/Boatings	periodic	turbidity (-)	• water quality • seagrass

Table 3.2 (Continued)

(1)	(2)	(3)	(4)	(5)
7	Torrens Island Power Station	1968	increase temperature (-)	• mangroves • biota
8	Garden Island Landfill	1990s	leachate (-)	• water quality • groundwater quality
9	Pipelines	1980s	increase turbidity (-)	• seagrass • water quality
10	Stormwater	periodic	increase turbidity, metals, nutrients	• water quality • seagrass • mangroves
11	Dredging	1980s	increase turbidity (-)	• seagrass • water quality
12	Development of Greenfields wetlands	first stage has been completed and this would continue in the future	improvement of stormwater water quality entering estuary (+)	• water quality • seagrass • mangroves • sediments
13	Land Based Discharge of Penrice Soda Products out from Port River Estuary	future	water quality improves (+)	• water quality
14	The use of Bolivar Effluent for Fertilizer	future	water quality improves (+)	• water quality
15	Dredging	future	Worsen water quality (-)	• water quality
16	Industrial Development at Gillman, Wingfiled and Dry Creek	future	Worsen water quality	• water quality • soil quality

IV. THEORETICAL FRAMEWORK FOR METHODOLOGY FOR CEA IN AN ESTUARY

4.1 Types of Cumulative Effects

Previous sections in Chapter II (2.4.6.2 and 2.4.6.3) described the uses of spatial and temporal dimensions for aggregating effects. Types of cumulative effects are likely to be useful for combining the variability and spatial and temporal dimensions for the purpose of aggregating effects. The following discussion will address types of cumulative effects and their potential roles for determining the magnitude and significance of cumulative effects.

There are two main views for analysing cumulative effects. The first one concerns the fact that cumulative effects are additive. The second view considers that cumulative effects must be synergistic. Vestel and Rieser (1995:19) view cumulative effects to include the combination of the synergistic and additive effects. In addition, they define cumulative effects as the total effect on the environment of a series of land and water use and development activities taking place within a specific region over a particular period of time (Vestel and Rieser, 1995:20).

Types of cumulative effects as stated above (additive and synergistic) are only two examples of a group of types of cumulative effects. Some other types of cumulative effects have also been identified, such as: space crowded, temporal crowded, threshold, time lag, nibbling and indirect (Morgan, 1998; Cocklin, Parker and Hay, 1992a; Vestel and Rieser, 1995). Previous studies provide little information about whether cumulative effects are the results of one type or the combination of types. It is apparent from previous studies that type of cumulative effects can be determined after total cumulative effects have been analysed. Besides, these previous studies also provide little information about how useful these types are for further analysis of cumulative effects.

Court, Wright, and Guthrie (1994:4) defines cumulative effects as :

> Cumulative effects assessment is predicting and assessing all other likely existing, past, and reasonably foreseeable future effects on the environment arising from perturbations which are: time crowded; space crowded; synergisms; indirect; or constitute nibbling.

The definition of cumulative effects by Contant and Wiggins (1993:336) also covers types of cumulative effects, that is "additive and aggregative actions which interactively or synergistically produce cumulative effects". The definition of cumulative effects by Contant and Wiggins (1993) uses the word "and", that is additive and aggregative, whereas the definition by Court, Wright, and Guthrie (1994:4) uses the word "or". It can be argued that due to the spatial and temporal variability of activities, their impacts and ecosystem responses, a single or combination of types can occur within a particular time and space.

The definition of types of cumulative effects and the possible methods of their determination have been underscored by some other studies (Irving and Bain, 1993; LaGory, Stull and Vinikour, 1993; Abbruzzese and Leibowitz, 1997, Morgan, 1998). In fact, there has been little evidence of the analysis of the types of cumulative effects, although some existing methods, such as mathematical modelling and Geographical Information Systems (Spaling and Smit, 1995; Cocklin, Parker and Hay, 1992b) can potentially be employed. Spaling (1995) provides example of analysing types of cumulative effects of agricultural land drainage on hydrologic variables (flow volume and response time), water quality (nitrate-nitrogen and antrazin content) and the area and distribution of wetlands. The results of his study were that there were types of cumulative effects that can be differentiated: time crowding, time lags, fragmentary effects and spatial accumulation, which can occur together as a result of the effects of drainage. In fact, different indicators were employed to characterise the different types of cumulative effects in his study, such as hydrologic variables, particularly flow volume and response time; water quality, and more specifically nitrate-nitrogen and atrazine content and the area and distribution of wetland. As he demonstrated, time lags are apparent in the extended recession time of drain flow; time crowded is evident in decreased response time of watershed flow following storm events; fragmentary effects are evident in changes to the number and sizes of wetland patches, and the areal pattern of wetland. Spatial analysis using GIS, statistical techniques and trend analysis are three main methods he used and provide evidence of their usefulness on the analysis of types of cumulative effects.

Morgan (1998:201) claims that the problem of predicting cumulative effects is compounded by the variety of meanings ascribed to the concept. The description and the definitions of types of cumulative effects can be seen in previous studies (Morgan, 1998; Spaling, 1995; Spaling and Smit, 1995; Cocklin et al., 1992b; Vestel and Reiser, 1995; Council on the Environmental Quality, 1997; Court, Wright, and Guthrie, 1994:4). These types have invited many critics, for example, Cocklin, Parker and Hay (1992a) state that some types of cumulative effects are very difficult to differentiate. As they indicate, in a particular area, spatial crowded effects may exist in co-occurrence with the temporal crowded type of cumulative effects. Spaling (1995) in his study on agriculture area shows that these types of effects occurred together. It is likely to be the case that one type may intialise the accumulation, another type will then follow afterwards. For a particular area, one or two types of cumulative effects may dominate the pattern.

Breitburg et al. (1999:861), for example, claim that non-additive effects of multiple stressors and the variability they cause in species' response are likely to be important features of human-influenced systems. In their study, using an experimental design, they proved that synergism of effects is more likely to occur than the additive cumulative effects.

Some other types of cumulative effects have also been proposed by Reid (1993). He proposed four types of cumulative effects:

(1) Same-influence effects.

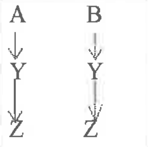
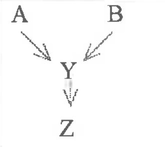
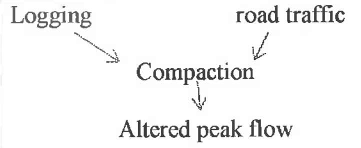
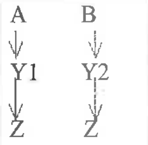
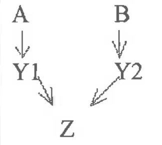
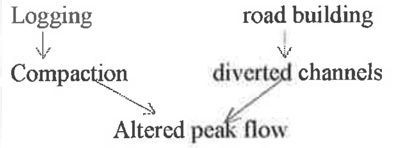
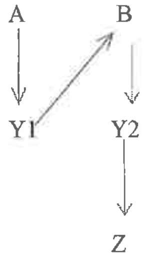
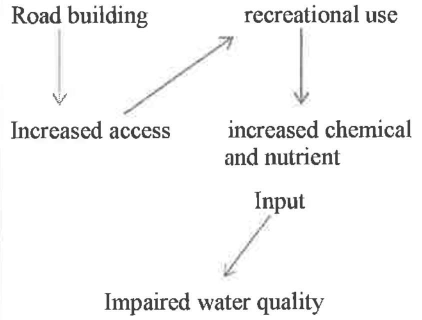
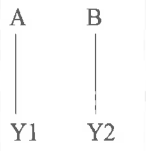
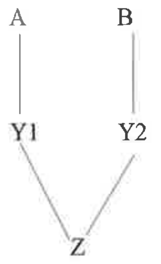
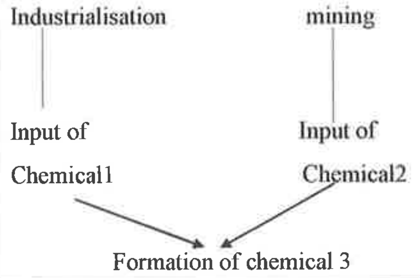
(2) Complementary effects.

(3) Cascading Effects.

(4) Interdependent Effects.

The following Table (Table 4.1) shows some types of cumulative effects and the mechanism responsible for them. From this table, there are four possible mechanisms triggering cumulative effects. Reid's division of types of cumulative effects put more emphasis on the mechanism, rather than the effects. This is different to types that have already been described, namely spatial crowding, temporal crowding, synergistic, time lags and threshold.

Table 4.1 Combination of Influence that can Generate Cumulative Watershed Effects (Source: Reid, 1993:20)

Types of Cumulative Effects	Effects of Influences Acting Alone	Effects of Combined Influences	Examples
A. Same-influence effects			
B. Complementary effects			
C. Cascading effects	none		
D. Interdependent Effects			

As illustrated, types of cumulative effects in the study of CEA and their roles in CEA are considered unclear.

4.2 Cumulative Effects in Estuary

Estuaries have long been recognised as the "septic tank of the megalopolis" (De Falco in Abbott, Dawson, and Oppenheimer, 1971:52). There are many activities surrounding estuaries that discharge wastes. These activities can be similar or different in terms of their effects on the estuary. In the study area, for instance, most of activities are considered similar because they mostly discharge nutrients into the estuarine water. However, there are different kinds of nutrient loadings, which are put into the estuary, such as nitrate, ammonia and phosphate. Because water quality due to the nutrient loadings (as the result of Scoping in Chapter V will show) are the main components of this study, the following explanation will relate to the effects of nutrient loadings on water quality. The main emphasis of this theoretical framework is on cumulative effects of industrial activities surrounding an estuary on estuarine water quality.

There are spatial and temporal phenomena associated with each activity, its associated effects and the responses of estuarine water. For example, the amount of nutrient loadings can vary from one activity to the others and from one time to another. In estuaries, the movement of tides, the depth, the direction and the velocity of wind and other physical, biological and chemical processes also vary from one location to the other. Evidence shows that some activities surrounding estuaries have impacted water quality conditions. For example, Mallin, et al. (1999) demonstrate that inorganic nutrients entering the Cape Fear River Estuary in North Carolina which come from point and non-point sources, e.g. urban and sub-urban landuse, crop agriculture, and intensive livestock operations, principally swine and poultry, have affected the nutrient status and phytoplankton growth. Other evidence of the effects of activities surrounding the estuary on water quality comes from the study conducted by Thompson (1998) in Salt Wedge Estuary, the Swan River, Western Australia. He claims that due to the increasing anthropogenic input from urban and agricultural activities, the density of phytoplankton bloom and anoxia increases and these problems have significantly increased management efforts to control phytoplankton bloom.

The general pattern observed from previous studies (Mallin, et al., 1999; Thompson, 1998; Sin, Wetzel and Anderson, 1999) is that there is spatial and temporal pattern of effects of nutrient loadings into estuaries. For example, Sin, Wetzel and Anderson (1999:263) claim that in their study area, phytoplankton production was high during summer and low during winter. In addition, they state that the station at the mouth of the estuary shows a spring peak and relatively high production during summer. This pattern underscores the importance of spatial and temporal components in understanding the problems in estuaries. Understanding the pattern of effects is likely to assist in a Cumulative Effects Assessment (CEA) study in estuaries.

4.3 Basis of the Theoretical Framework

This theoretical framework is based on the following assumptions:

(1) Scoping has been conducted properly so that the most important Valued Environmental Component(s)/VEC(s) have been selected. In this case, water quality is the most important VEC(s) selected from scoping stage (see Chapter V).

(2) There exist cumulative effects locally from one time to the other. There is also the interaction of effects from one location to the other locations. Every part of the estuary has experienced the accumulation of effects due to both direct effects from the activity close to this location and the effects of other activities.

(3) Cumulative effects can occur in every location (part) of estuary and this can spill over to adjacent areas.

(4) The system is assumed to be highly dynamic and the density of activities included in CEA is changing along the continuum.

(5) The issues of impact aggregation and impact interaction must relate to the smallest particular spatial unit (particular location) so that the presence of local cumulative effects can be identified. This will then be used to identify regional cumulative effects. It is assumed that, within a particular location, there have been effects due to the presence of activity(s) in that location. Using this concept, analysis of cumulative effect can be conducted hierarchically by mainly using the pre-determined smallest spatial unit towards the larger spatial unit. Therefore, cumulative effects can be local and regional. The local pattern will determine the regional pattern.

(6) Despite the complexity of the estuarine environment, there are spatial and temporal patterns of effects that can direct a CEA in estuary.

Figure 4.1 illustrates the basis of this theoretical framework. As can be seen, the basic spatial unit for the analysis is parts (segments) of estuary, and this can be the artificial division of an estuary. The arrow indicates that there is the movement (flow) of material from one location to the other. Flows, as the results of the activities of tides and wind must exist which can potentially distribute the effects from one location to the others. Within each location, there are other inputs and outputs of substances, such as nutrient loadings, which may flow into or out of other locations. Internal and external processes (see Section 4.3) do exist in every location, which determine the processes of accumulation or dispersion of effects. Considering this, the cumulative effects can potentially occur at very localised areas or due to the processes and interacting mechanism occurring in an estuary, this can reach to widespread area of an estuary.

Because of the existence of flows, effects can interact to each other in additive, interactive and synergistic manner. Figure 4.2 is from the study by Peterson, et al. (1983:2). As can be seen in this figure, there are two pathways of cumulative effects to occur, the first of which stems from the persistent addition from one process and the second from the compounding effects involving two or more processes. Each of these pathways can be divided into two groups, namely additive and interactive. In the summary of their paper, they conclude that particular types of cumulative effects relate to the pathways as described above. As they claim, pathways 1 and 3 relate to the time crowding perturbations, pathways 1 and 3 also relate to space crowding perturbations, synergism relates to pathways 4. From this figure, either persistent addition or the compounding effects can lead to the occurrence of cumulative effects. In each pathways, different interaction is likely to occur.

LaGory, Stull and Vinikour (1993:408) use "spatial overlap" for determining the impact interaction. In terms of analysis, this starts with the determination of impact zone for each activity included in CEA, then the impact overlap can be determined based on each impact zone. This approach may only be appropriate if the distribution of effects is known with certainty in terms of their directions. In a very dynamic environment, such as an estuary, this approach can potentially be applied, although the determination of the extent of effects is uncertain, due to the absence of a fixed boundary. As a result, it may be difficult to obtain accurate information on the "zone of influence" or "impact zone" and the accompanying "zone of impact overlaps". "Impact zone" is important in cumulative effects assessment in estuarine, confined environment. The identification of "impact zone" in estuarine environment relates to the processes occurring in estuaries.

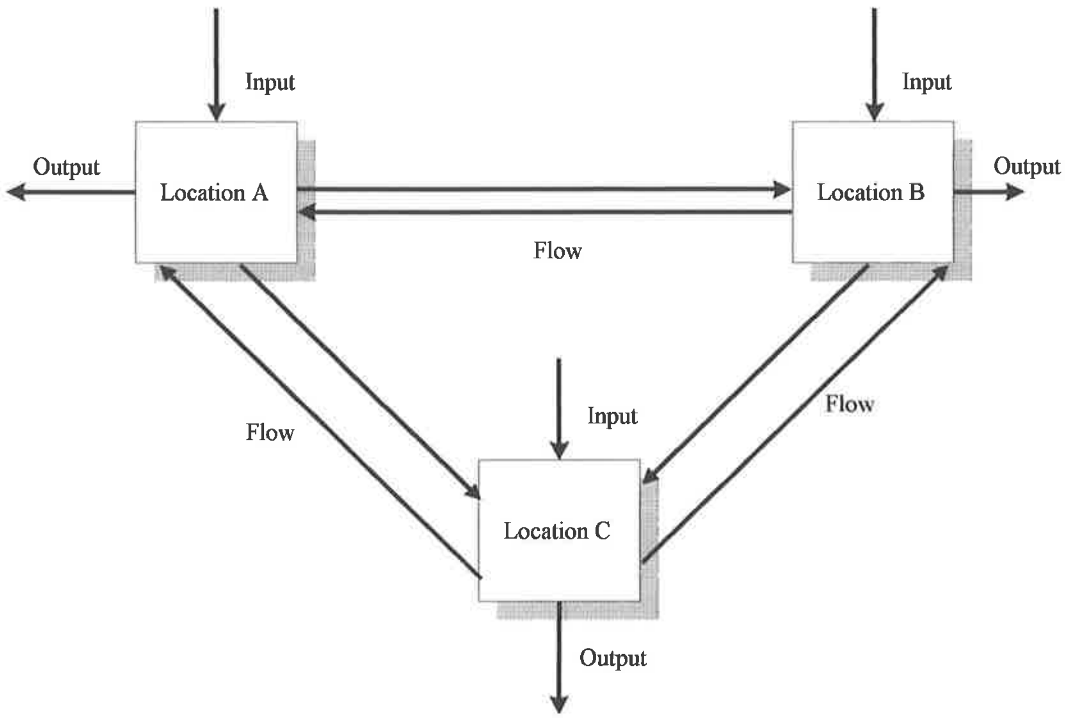


Figure 4.1 The Basis for the Theoretical Framework for CEA in an Estuary

The understanding of the processes occurring in estuaries is most likely to assist in the determination of which pathway of accumulation may be in evidence. For some parts of estuaries, there may be a repeated addition of nutrients which result in the tendency of the concentration of particular water quality parameters to rise from one time to the other so that temporal accumulation of effects is most likely to occur (pathway 1 or pathway 3 from this figure). Other parts of estuaries may show widespread significant

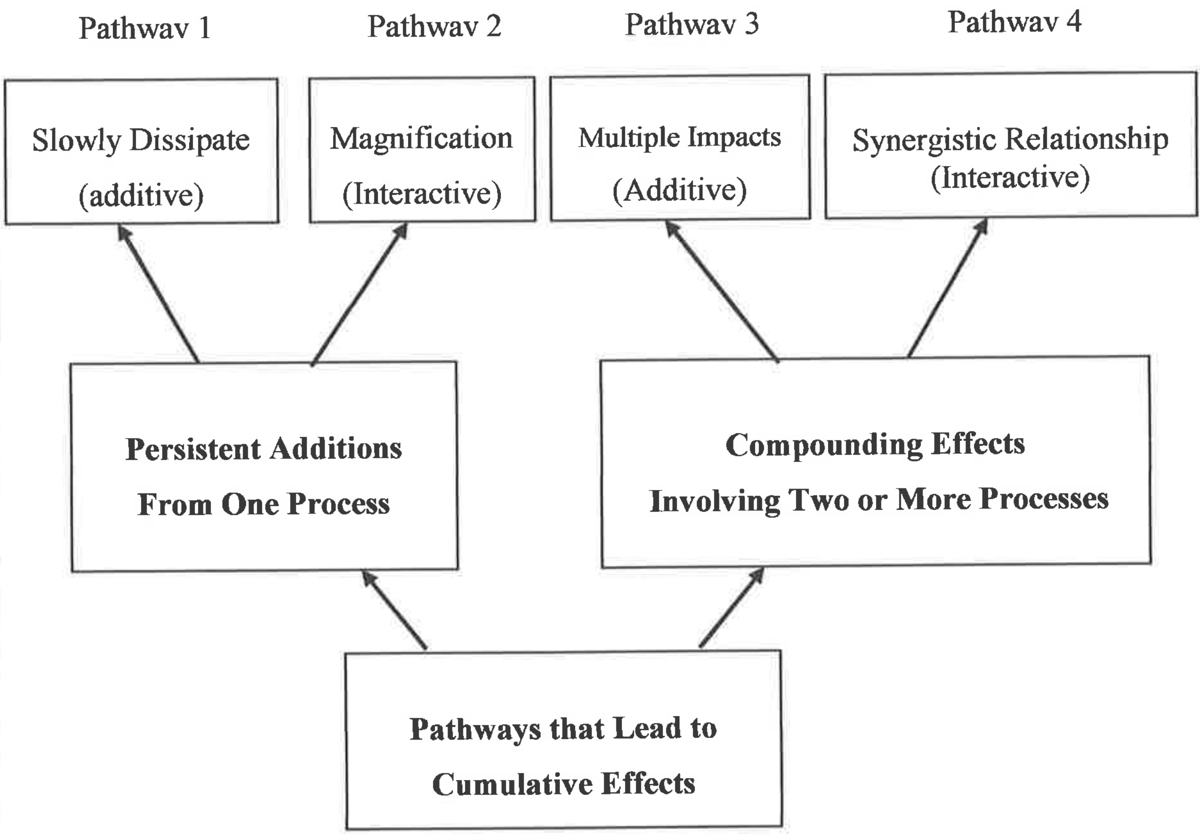


Figure 4.2 Basic Functional Pathways that Contribute to Cumulative Effects
(Source: Peterson, et al., 1983:5)

effects from time to time so that spatial accumulation of effects is most likely to happen (pathway 1 or pathway 3). There may also be the case that due to intensive tidal flushing, no accumulation occurs (Sin, Wetzel and Anderson, 1999:263). Therefore, in estuaries a set of complex interaction exist which determine the particular pathway and the pattern impact zone. Pathways and impact zone can then be used to identify the accumulation or the dispersion of effects. Therefore, the crucial components in the study of cumulative effects in an estuary are the spatial and temporal dimensions of activities, effects, processes and their interactions. Therefore, a framework must exist which can cover these components. The most appropriate framework for CEA in estuarine environment is likely to be types of cumulative effects.

The rationale for using types of cumulative effect for CEA in this study can be explained as follows. In an estuarine environment, environmental responses and effects are dynamic spatially and temporally. Larger spatial and temporal dynamics of environmental responses and effects can be expected than land-based dynamics. This will enhance the complexity of assessing cumulative effects in an estuarine environments. Because of the fact that different parts of an estuary have their own physical, biological and chemical characteristics, this implies that in the long term, this variation determines the pattern of the occurrence of type of cumulative effects in either localised areas or the overall area. Depending on the interaction of activities and the environmental condition of estuaries, each type of cumulative effect can potentially occur in any part of an estuary. For this reason, using types of cumulative effects will assist in the study of cumulative effects in estuaries. The explanation above provides the rationale for using types of cumulative effects as the bases of the theoretical framework for assessing cumulative effects in estuaries. Each type of cumulative effects has different attributes. For example, space crowding types of effects emphasis the spatial component, while temporal crowding types of effects highlight the temporal component.

The example of the rationale for using types of cumulative effects is as follows. Effects do not occur in the similar intensities for overall parts of estuaries. Due to the differences in environmental responses, the effects are likely also to vary for different parts of an estuary. The key driving factors, such as depth, tide, nutrient loadings and wind, vary for each part of an estuary. For example, from Figure 4.1, the location A may show additional nutrients continually from one time to the other, it is deep and experiences high wind speed; location B may be shallow and experience low wind speed. On the other hand, location C may provide characteristics, which are different to the other, because of freshwater input. This varying natural condition of estuarine environment and their associated activities will determine the pattern of the accumulation of effects. Some possible conditions may exist. These possible conditions are:

(1) Effects may accumulate in large areas of estuaries.
(2) Effects may accumulate in localised areas.
(3) Effects may be insignificant, but due to the presence of particular activities in the future, the effects becomes cumulative effects and significant.
(4) Effects may accumulate temporally.
(5) Effects may accumulate permanently.

Therefore, there are spatial and temporal components of effects on estuarine environments. For this reason, these components need to be included in analysing cumulative effects in estuaries. This can probabilistically assist in the identification and prediction of cumulative effects. Types of cumulative effects are considered as the most appropriate framework for analysing cumulative effects in an estuary. Types of cumulative effects and their definitions are explained below.

Chapter II (Literature Review) has provided definitions of types of cumulative effects, only four of them are the main concern in this study. The reason for choosing these four types is that these four types of cumulative effects are those that most likely to occur in the study area. The definitions of these four types are adapted from Spaling and Smit (1995:106-107) as follow:

1. Space crowding is portrayed by a high spatial density of environmental change that can alter a region's spatial pattern or its spatial processes.
2. Compounding can occur when two or more environmental changes interact to contribute to another environmental change.
3. Triggers and thresholds indicate disruptions to environmental components or processes that fundamentally alter system structure or functions.
4. Temporal crowding occurs when the interval between one perturbation and succeeding perturbations is too small for an environmental system, or system component or process, to assimilate or recover from the perturbations.

The importance of these types of effects for CEA in estuaries can be explained by relating them to the most fundamental component in any environmental impact assessment, that is significance.

Canter and Canty (1993:291) claim that "therefore, significance is sometimes based on professional judgement, executive authority, the importance of project/issue, sensitivity of project/issue and context; or by controversy raised". Duinker and Beanlands (1986:7) propose a slightly different view of assessing the significance of environmental effects. They claim that

> Any exercise in judging the significance of environmental impact should thoroughly consider (a) the importance of the environmental attribute in question to project decision makers, (b) the distribution of change in space and time, (c) the magnitude of change, and (d) the reliability with which change has been predicted or measured.

It is apparent that the objective measures and subjective judgment must be used in assessing the significance of effects. Section 2.4.6 in Chapter II (Review of Existing

Literature) explains that there are many factors that can affect the interpretation of significance in assessing cumulative effects. The following are five of them, which can be the reasons for relating the component of variability and types of cumulative to significance of cumulative effects.

(1) Exceedance of a threshold. Significance may increase if a threshold is exceeded (The Canadian Environmental Assessment Agency in http://www.ceaa.gc.ca/0011 /0001 /0004/guide_e.htm). If the threshold used is the standard of water quality, the different part of an estuary may have different concentration for one time to another. In other words, some parts of estuaries may have experienced the concentration exceeding thresholds, while the other have not or they never reach the thresholds. Therefore, by using threshold type of cumulative effects as framework for analysing cumulative effects, parts of estuaries, which experience the effects exceeding threshold, can be determined. The concept of threshold relates to the "set value" proposed by Andrews et al. (1977) in Duinker and Beanlands (1986:8), who claim that "set value" has direct application to the determination of impact significance. This implies that if the values of effects exceeding "set values" then, the effects become significance.

(2) Relative contribution of effects of other actions. Significance may decrease as the relative contribution of effects of an action decreases (The Canadian Environmental Assessment Agency in http://www.ceaa.gc.ca/ 0011/0001/0004/ guide_e.htm). The contribution of effects of other actions can relate to the synergistic type of cumulative effects because this type of cumulative effects considers the contribution of activities. For example, Vlachos (1985:63) claims that the most fundamental component of synergism is "the whole is more than the sum". Considering this, therefore, the concept of synergistic effects can be used as reference to study the effects of one activity to those in combination. This implies that synergistic effects can be used to analyse the contribution of each activity and the combination of activities included in CEA. By using the synergistic type of cumulative effects as framework for analysing cumulative effects, the relative contribution of each activity to the total cumulative effects can be identified.

(3) Significance of local effects. Significance may decrease as the significance of local effects decrease (The Canadian Environmental Assessment Agency in http://www.ceaa.gc.ca /0011/0001/0004/guide_e.htm). This statement recognises the importance of local effects in CEA. From this statement, it implies that CEA is the aggregation of local effects. If every part of an estuary has significant local effects from one time to the others, this means that the cumulative effects on overall estuarine environment are also significance. Space and temporal crowding effects, are types of cumulative effects that consider spatial and temporal distribution of effects. These types of effects consider local and regional distribution of effects and short term and long-term effects. Therefore, by considering space and time, the significance of local effects will not be overlooked, while that of regional effects will not be underestimated.

(4) Magnitude of change relative to natural background variability (The Canadian Environmental Assessment Agency in http://www.ceaa.gc.ca/0011/0001/0004/guide_e.htm). This is the most difficult part of assessing the significance of cumulative effects. The reason for this is that obtaining information about natural variability is not straightforward. This may need long records of data to possibly interpret the natural background. If there were long-term data, the concept of temporal crowding type of cumulative effects would assist in the interpretation of significance of cumulative effects.

(5) Incremental contribution of effects from action under review (The Canadian Environmental Assessment Agency in http://www.ceaa.gc.ca/0011/0001/0004/guide_e.htm). This may be the essence of cumulative effects assessment. Analysing the contribution of effects from an action requires firstly, the consideration of single activity, then the combination of activities. This kind of analysis can be conducted if the synergistic types of cumulative effects are considered.

From this explanation, it is clear that types of cumulative effects have relationship with the components which determine the significance of cumulative effects. The most fundamental factor which relate to these components is the spatial and temporal variability of activities and their associated effects.

4.4 Processes which Determine the Accumulation of Effects in Estuarine Environments

Water and sediments are the main agents for the distribution of effects in estuaries. For example, Morin and Morse (1999:108) estimate that the movement of 318,00 m^3 sediment is likely to release 5.3×10^8 l of NH_4^+ when sediments are dredged or relocated. From this estimate it is clear that sediment can be the source of pollutants for overlying waters. Because of the fact that sediments and the overlying waters do interact each other, the changes in the physical, chemical and biological condition in sediments are likely to affect overlying waters (Emerson, Jankie and Heggie, 1984; Lijkema, 1980; Mortiner, et al., 1998). The movement of water and the entrapment of pollutants in the sediments are the main pathways that determine cumulative effects in estuaries, although other chemical, physical and biological processes could also contribute to the accumulation and dispersal of effects. The movement of waters in a watershed is most likely to be downstream, whereas the movement of waters in the estuary is difficult to predict with certainty. Abbott, Dawson and Oppenheimer (1971:62), for example, state that "....these masses of water are continually in motion in all directions, fusing, mixing and separating".

This statement indicates that understanding the processes in estuaries is not straightforward. Identifying the areas where the dispersion and accumulation of effects occuring in an estuary is, therefore, fairly complicated, although some patterns can potentially guide the identification and prediction of processes. For the purpose of CEA, simplification is necessary, as shown in the section 4.2. The simplification should be regarded as the way of organising space and processes rather than the precise identification and prediction of patterns. Other natural and human-induced processes occuring in estuarine environments, which can also affect the behaviours of pollutants can be seen in Table 4.1. Understanding these processes and their associated roles in the spread and dissipation of effects are very important for CEA.

Table 4.2 Summary of Processes Occurred in the Estuary (Orians, 1988; Harbison, 1986a, 1986b; Sklar and Browder, 1998; Abbott and Dawson, 1971; Morin and Morse, 1999; Cadedacas, Mogueira and Brogueira, 1999; Braga, et al., 2000; de Jonge, 2000)

Natural Agents/ Processes	Human-Induced Processes
(1) Tidal flushing	(1) Loading of materials (suspended solids and nutrients) leading to eutrophication and the attenuation of light
(2) Wind	(2) Changes in the morphology of estuary due to dredging and other disturbances
(3) Waves, tides and currents	(3) Scouring due to the discharges
(4) Topography	(4) Leachate
(5) Adding of freshwater	(5) Stormwater discharge
(6) Erosion and deposition	(6) Shipping
(7) Stratification waters due to	(7) Marinas
(8) Temperature differences	
(9) Seasonal affected processes	
(10) Storm	
(11) Sedimentation	
(12) Salinity	

Within particular parts of an estuary, the intensity and frequency of the processes can be different to the other parts. There are two main categories of processes in the estuary. The first category occurs in an overall estuary and are mainly determined by the activities of the tides and waves. The second category is local activities. For example, Harbison (1986a, 1986b) suggests that the local oxidising and reducing conditions have effects on the release of metals from sediments into waters in the estuary. Cabecadas, Noguira and Brogueira (1999) provide evidence on how the morphometry, drainage basin characteristics (land use, soil composition, population and industry), river discharges and climate (temperature and incident irradiance) can affect the distribution of chlorophyll a and nutrients, such as nitrate, ammonium and phosphate. Precise identification of processes responsible for the accumulation and dispersion of effects is difficult, although these processes can be estimated by experienced people (experts).

The movement of materials controls processes occurring in an estuarine environment. Understanding impact accumulation in an estuary must relate to the movement of materials. Water is considered to be the main agent for movement of pollutants and chemicals. As a result, there may be a shift in the locations of accumulation of effects. For example, the area directly adjacent to the activity(s) may not show patterns of accumulation, whereas those further away may show the accumulation of effects. There may also be the case that the accumulation of effects would only occur in a much-localised area, either surrounding the activity(s) or far away from the activity(s). Processes occurring in estuaries in conjunction with their potential roles in accumulating and dispersing effects are described below.

Orians (1988) states that the addition and the removal of materials such as chemicals and species of living organism can be used as the indicator of whether effects are accumulated or dispersed. In addition, Orians (1988) also suggests that understanding of the type of processes, the relative strengths, the rates of processes and their interactions can lead to better analysis of potential cumulative effects.

Identification of cumulative effects in spatially unconstrained areas, like estuaries, is complicated, because there is no definite boundary as that in spatially constrained areas, although artificial boundaries (as shown in Figure 4.1) can be used to simplify the complex relationships in estuaries. However, there are patterns of processes and effects in estuaries, which potentially guide CEA in estuarine environment, as demonstrated by previous studies (Hubertz and Kahoon, 1999; Thompson, 1998; Mallin, et al., 1999). These studies show that there are some factors that could affect the phytoplankton bloom and nutrient status in estuaries: temperature, rainfall, salinity, and discharges from river and nutrient loadings. In relation to nutrient loading, Capuzzon and Ketser (1987) in Braga, et al. (2000: 165) claim that ocean dumping of sludge can raise some fundamental environmental problems: biomagnification, bioaccumulation of pathogenic organism, chemical contaminants, physical disturbance of marine ecosystem and resuspension of sludge solids causing unacceptable turbidity, localised eutrophication, nutrient enrichment and oxygen depletion. The ocean dumping of sludge is also observed in the area used in this study. Thompson (1998) shows that there is spatial and temporal pattern of variability of chlorophyll a concentration. Although these previous studies were not specifically cumulative effects, the results of these studies can potentially guide CEA in estuaries. This kind of pattern will at least direct the identification of cumulative effects in estuarine environment. For example, if the upper parts of estuaries show higher concentration than that of lower part from one time to the others, then this upper part of estuary is more likely to accumulate effects than the lower parts of estuaries.

4.5 Data Availability and Cumulative Effects on Estuarine Water Quality

The difficulty in assessing cumulative effects of activities to water quality in estuaries has been underscored by Eyre (1997:178) who claims that :

> One of the major problems with interpreting the effects that changes in coastal land use pattern over the last 30 years may be having on estuarine water quality, is the lack of long-term data.

Limited amount of data will not capable of identifying the presence of cumulative effects. The results of Eyre's study indicate that in the event following the runoff, phosphate and nitrate concentrations were 2.5 and 3.0 times higher than 50 years ago. The concentration of these two water quality parameters obviously indicates the presence of cumulative effects in the estuary. This may show that water quality of the estuary takes longer time for significant changes to occur.

Eyre's study (1997) implies that time frames for analysing cumulative effects are very crucial. This also underscores the importance of considering past, present and future activities and effects in CEA in estuaries. Considering this, the most complicated process may relate to the determination of past and future activities and their associated data. Past data is often lacking as well as planning documents. The presence of planning documents in the forms of zoning, for example is an important component in selecting future activities that must be included in CEA.

4.6 Cumulative Effects on Estuary

Table 4.2 illustrates possible types of cumulative effects occurring in estuaries. As can be seen, there are four possible types of cumulative effect, which can potentially occur in estuaries with the nutrient loading as the main perturbation, that is space crowding, temporal crowding, threshold and synergistic types of cumulative effects. Other types might also exist in the study area, but the main concern is only on the four types above. There are some reasons for selecting these four types of cumulative effects:

Table 4.3 Possible Types of Cumulative Effects in an Estuary with Nutrient Loading as the Main Attribute

Cumulative Effect	**Environmental Change**	**Description**
Space Crowding	Changes in water quality; Change in the sediment quality	Changes in the water quality due to similar kind of discharges into the estuary from many adjacent activities.
Temporal Crowding	Change in water quality and Change in sediment quality	Continuing discharge of effluent in particular section of the estuary which is rich in nutrients.
Compounding /Synergistic	Change in the areas of seagrass and mangroves	Significant effects of the combination of nutrient loadings on water quality compared to the single nutrient loadings.
Triggers and thresholds	Thresholds are exceeded	Continual addition of nutrients would trigger the bloom of algae. Continual addition of nutrients would result in the concentration exceeding the pre-determined standard.

(1) There are some activities surrounding the estuary in the study area as can be seen in Figure 3.2, and these activities are not on the same parts of the estuarine areas, instead, they are distributed over the areas surrounding the estuary. For example, Bolivar Sewage Treatment Works and Port Adelaide Sewage Treatment Works are located in the different parts of the estuary. Some other activities, such as landfill and marina also occur in the different part of the estuary. These perturbations are crowded so that this can potentially lead to the occurrence of "space-crowded" type of cumulative effects. This is the reason for selecting "space-crowded" type of cumulative effects in this study.

(2) The history of the activities surrounding the estuary in the study area has been explained in Chapter III. Long-term discharge of nutrients into the estuary can potentially lead to the accumulation of effects and subsequently lead to the temporal crowding type of cumulative effects.

(3) The occurrence of "algae bloom" in the study area in spring and summer indicates that threshold of water quality has been exceeded. Because of the fact that there is a regular occurrence of "algal bloom", this indicates the presence of "threshold" type of cumulative effects.

(4) The interaction of effects can result in the synergistic type of cumulative effects and this type of cumulative effects can potentially occur in the study area. For example, the loss of mangroves is more likely to relate to the combination pollutants than a single pollutant. The combination and interaction of pollutants from different sources (marina, Port Adelaide Sewage Treatment Works and Bolivar Sewage Treatment Works) may also contribute to the occurrence of synergistic type of cumulative effects.

The description of types of cumulative effects as listed in Table 4.2 can provide the basis for analysing types of cumulative effects and the procedures for determining them. However, determining each type of cumulative effects in practices is still the main issue in the area of cumulative effects. Some methods and techniques in EIA and CEA may have merits in the determination of types of cumulative effects, however, there is a limited evidence of this, while there is a wide concern on the possible merits provided by types of cumulative effects in CEA. Types of cumulative effects can provide the basis for solving problems embedded in CEA because of the fact that every type considers either spatial or temporal aspects or the combination of both.

In estuarine environment, one type may occur with other types, or one type may interact with each other to result in particular type of cumulative effects. Complex interaction may occur which determine a particular type of cumulative effect. However, the distribution of each type of cumulative effect can be different, with the result that the occurrence of types of cumulative effects may also different for different parts of estuaries. Continuous loading of nutrients in combination with longer residence time may be responsible for space crowding effects, temporal crowding effects and threshold effects.

Thompson and Godfrey (1985) in Davies and Kalish (1994:127), for example, demonstrate that due to wind and tidally driven mechanisms, a marked increase in mixing and vertical motion can be observed in the upper and lower parts of the estuary they studied. If this kind of pattern occurs for long period of time, cumulative effects will occur. In such a situation, the space crowding type of cumulative effects may not in evidence. If the sources of pollutants are in the upper part of the estuary, this may be the evidence of cross-boundary flow due to its movement from the upper part to the lower part of the estuary.

4.7 Implementation of Theoretical Framework

This theoretical framework has obvious implications for CEA of activities surrounding estuary on water quality. These are:

(1) CEA must be viewed as a dynamic process consisting of repeating stages: scoping, the determination of VEC(s), the prediction of cumulative effects, and the synthesis of cumulative effects.

(2) Planning documents must exist to guide the selection of future activities included in CEA. Long term monitoring at pre-determined locations of samples and continuing assessment of effects on both single activity and the combination of many activities must be conducted.

(3) The use of water quality modelling is likely to assist in CEA on estuarine environment. The main reasons are: (a) processes occurred in estuary could be incorporated; (b) spatial and temporal variability can be included in water quality modelling and (c) the interactions of different components will be covered in water quality modelling. The results obtained form water quality modelling can provide not only the quantitative information that the waste loads must be reduced, but also the amount of reduction required for maintaining the estuary to assimilate the pollutants. Moreover, the combination of mathematical models and spatial analysis tools (e.g.

Geographical Information Systems/GIS) would significantly provide information on not only numerical values, but also locations. These methods are crucial for the management of the estuary water quality.

4.8 Conclusion

Conclusions drawn from this theoretical framework are:

(1) Different approaches are needed for dealing with the complexities embedded in CEA for estuaries.

(2) The consideration of the smallest spatial unit, the determination of VEC(s) and understanding processes would be appropriate for the study of CEA in estuaries.

(3) Modelling is the most appropriate approach for conducting study on CEA, such as an estuary, especially when water quality is selected as the most fundamental Values environmental Component (VEC). A method that can conduct spatial analysis, such as Geographical Information Systems (GIS) is also necessary for the analysis of CEA in estuarine environment, due to spatial variability of activities, environmental conditions and their responses and environmental effects.

V. SCOPING

5.1 Introduction

The role of scoping for cumulative effects has been recognised by Council on Environmental Quality (1997:12) stating that:

> In broad sense, all the impacts on affected resources are probably cumulative, however, the role of the analyst is to narrow down the focus of the cumulative effects analysis to important issues of national, regional and local significance.

As a part of formal assessment, scoping must provide general as well as specific information about the components included in CEA. The Council on Environmental Quality (1997:11) states that significant cumulative effects issues, geographic scope, time frames, and other actions affecting resource, ecosystems and human communities, must be covered by scoping. For this reason, scoping should be conducted in a structured way. In other words, scoping for CEA must have a defined methodology.

5.2 Methodology for Scoping

The procedures for scoping used in this study can be seen in Figure 5.1. The main aim of scoping in this study was to determine the Valued Environmental Components or VEC(s) that have been, or are being affected past and present and will be affected by possibly future activities, the most significant cumulative effect issues, cause and effect relationships, spatial and temporal boundaries and more importantly to determine indicators for further analysis. There are four fundamental sources of background information for scoping in this study:

(1) Expert opinions.

(2) Existing studies which relate to resources, effects and activities in the study area.

(3) Information obtained from people in environmental groups, EPA (Environmental Protection Authority), industries and three local councils: Port Adelaide and Enfield, Salisbury and Munoppara.

(4) Planning documents. In this study planning documents are the Development Plans.

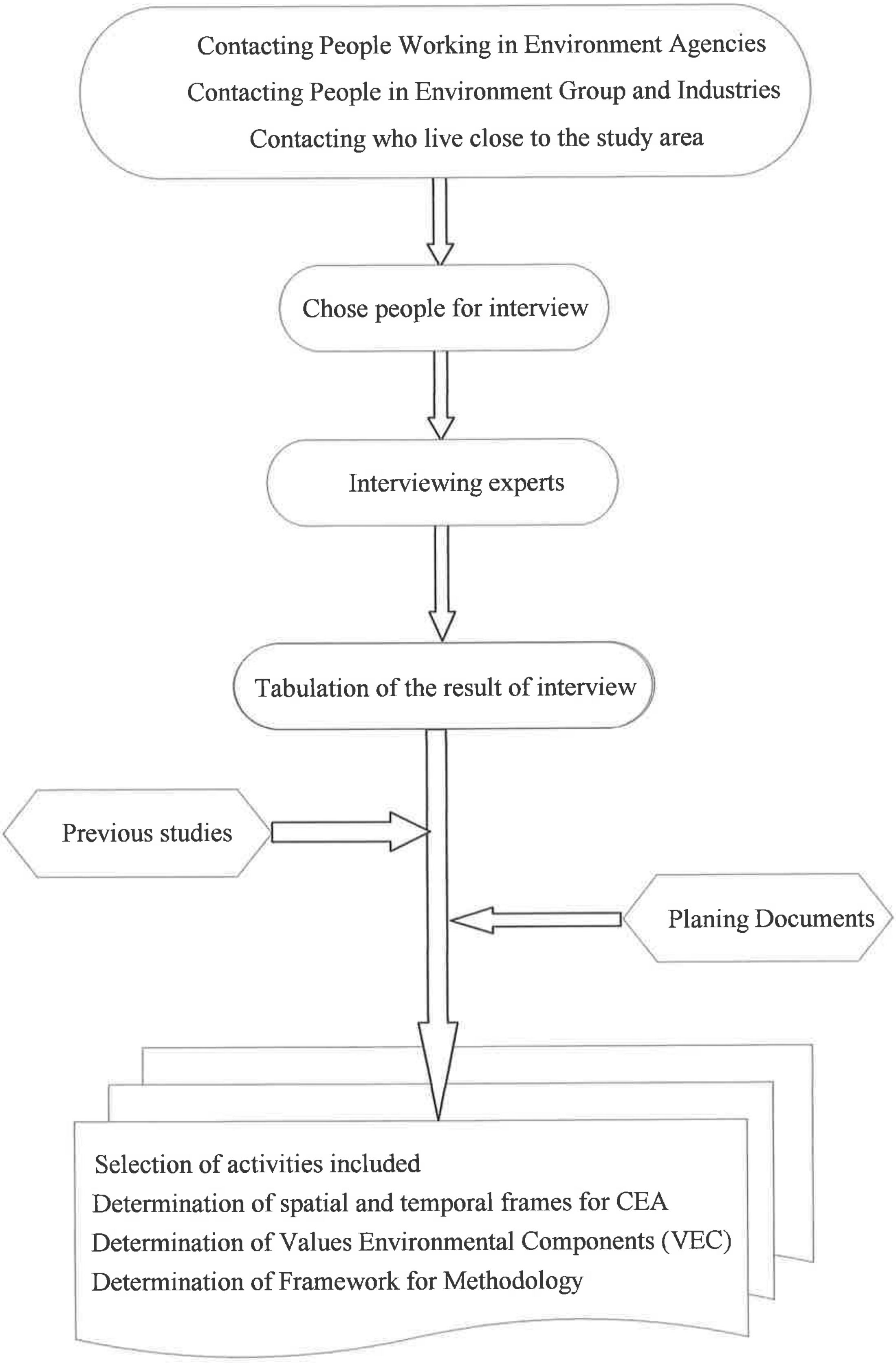


Figure 5.1 Stage Used in the Methodology for Scoping

There are three information generating methods for CEA which are considered suitable for both social and environmental effects, especially in the process of scoping: interviews, questions and panels (Council on Environmental Quality, 1997: A-3). In this study, structured interviews were the main technique used. Familiarity with the biophysical condition in the study area, their experiences and their studies were used as basis for selecting experts and other representative people. A selected number of experts and representatives of people were interviewed, with each interviewee being given the opportunity to identify some key environmental issues and explain past, present and likely future environmental impacts, resources of concern affected, the possible activity(s) affecting resource(s) and a rough estimate of the significance of impacts. Different experts may have different opinions and this is indeed, a characteristic of the interview process, and this was expected.

Ten (10) people were chosen for the purpose of interview, each of them represent a group of society they represent. For example, Tony Bazeley and Stephen Darley (see Table 5.1) represent the people surrounding the estuary because they are the key peoples in "Environmental Groups". Some other people, such as John Cugly and Dough Fotheringham are from Department of Environment Housing and Aboriginal Affairs. Some other people from some local councils were also selected as the interviewees, such as Berity Sanders and Harmar (both of them are from Port Adelaide and Enfield local councils). There are two people form industries, that is Oleszyk and Manning. It is no doubt that the selection of people for the purpose of interview has considered a quite large number of components which relate to the management of estuarine environment in the study area.

Interviews are subjective (Stull et al., 1987 in Council on Environmental Quality, 1997:A-3). Despite this, subjectivity is necessary at this stage for obtaining similarity in the opinion of experts and other people. The reason for this is that cumulative effects are very broad, determining key components in the assessment and the process of narrowing down may be best conducted using subjective judgment. Moskert (1996:195) claims that:

> Some activities in Environmental Impact Assessment are subjective in nature, that is determination of need (whether EIA is required or not), determination of the study area (in CEA, this can be the determination of spatial boundary), selection of alternatives, selection of mitigation measures, selection and detail of treatment of effects, choice of methods, and comparison of alternatives.

For CEA, the subjectivity becomes much higher for several reasons:

(1) A number of activities can potentially be selected. Therefore, the selection of activities that must be included in CEA is subjective.

(2) In relation to point (1), the determination of past, present and future effects that must be included also poses subjectivity.

(3) The selection of the most significant Valued Environmental Components for further analysis will be another subjective aspect in CEA.

(4) The selection of spatial and temporal boundaries may also be affected by the difference in the interests, data and activities. This may also need subjective judgment.

(5) The determination of the most appropriate methods and techniques for the prediction in CEA is also subjective judgment.

Although subjectivity is an undeniable component in environmental assessment, this is crucial in CEA. If this is handled well, subjectivity will not result in problems (Moskert, 1996:191).

Existing studies regarding the study area are other important sources of information for guiding the selection of resources, impacts and activities to be included in the assessment of cumulative impact. Scientific documents in the form of reports, studies and investigations can provide useful information for CEA. Scientific documents are also expected to provide some degree of objectivity. Therefore, they are expected to complement the subjective results obtained from interviews. The use of more objective information is also expected to reduce the uncertainty in the selection of the activities, the impacts and the Valued Environmental Components obtained from the interviews. Available reports and investigations on the study areas provide information about the trend of resources, the activities impacting the resources and possibly guide the selection of pathways that must be pursued in the assessment of cumulative impacts. As seen in Figure 5.1, the interviews and the other sources of information were intended to complement each other.

5.3 Results of Scoping

Table 5.1 provides information about the results of interviews conducted for scoping. The following is the discussion on the results achieved from scoping.

5.3.1 The Sources of Environmental Changes

The sources of environmental change in the study area were considered to be the combination of many activities. Interviewees claim that there are a number of activities contributing to environmental changes. All interviewees believed that the long history of industrial uses has been responsible for the degradation of the environment in the study area, particularly water quality. Most of them claim that the interaction of activities is more likely to be the main factor, which has changed the environmental condition, especially the condition of water quality and the study of cumulative impact assessment in the study area is worth undertaking.

5.3.2 Activities Which Have Been Significantly Affecting the Environment

As can be seen in Table 5.1, three main activities have been identified as affecting the environment in the study area. These activities are: The Port Adelaide Sewage Treatment Works, The Bolivar Sewage Treatment Works and The Penrice Soda Products. Most interviewees agree that these three activities have been affecting the nutrient status of the estuary. Most also strongly believed that these activities have been responsible for the regular bloom of algae (red tides and blue green algaes). The opinions of these interviewees were generally in agreement with the findings of some previous studies regarding the excessive nutrient loads from these three major activities and their effects on water quality and other environmental components (Canon, 1996).

Table 5.1 The Results of Scoping

Items \Interviewees	Stephen Darley	Berity Sanders	Tony Bazeley	Doug Fotheringham	John Cugly	Pat Harbinson	Oleszyk	Steffensen	Harmar	Manning
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
Activities (Single or Combination) which result in environmental change	• combination	• combination	• combination	• combination	• combination	• combination	• combination	• combination	• combination	• combination
Activities which significantly have been affecting the environment	• Port Adelaide Sewage Treatment Works (I) • Penrice Soda Products (I)	• Penrice Soda Product (I) • Port Adelaide Sewage Treatment (I) • Bolivar Sewage Treatment Works (II) • Stormwater	• Penrice Soda Product (I) • Port Adelaide Sewage Treatment Works (I) • Bolivar Sewage Treatment Works (I) • potentially, stormwater in the future (II)	• Bolivar (I) • Power Station(II) • Port Adelaide Sewage Treatment Works (III) • Penrice Soda Products (III) • Stormwater	• Penrice Soda Products • Bolivar Sewage Treatment Works • Port Adelaide Sewage Treatment Works • stormwater	• Port Adelaide Sewage Treatment Works • Bolivar Sewage Treatment Works • Penrice Soda Product • stormwater (not in the future)	• Port Adelaide Sewage Treatment Works • Bolivar Sewage Treatment Works • Penrice Soda Product • Stormwater	• Port Adelaide Sewage Treatment Works • Bolivar Sewage treatment Works • Penrice Soda Product • Stormwater	• Port Adelaide Sewage Treatment Works • Bolivar Sewage treatment Works • Penrice Soda Product • Stormwater	• Port Adelaide Sewage Treatment Works • Bolivar Sewage treatment Works • Penrice Soda Product • Stormwat
Activities which have no significant effects environment	• Marinas/boating • shipping	• Torrens Island Power Station • Marina/boating	• marina/boating • shipping	• shipping (introducing marine pests) • marina • salt field	• saltfield • boating • shipping	• shipping • boating	• shipping • landfill	• salt field	• marinas • salt field	• marinas • salt field
Significant Issue(s)	• water pollution (I) • air pollution (II) • soil pollution (III)	• water pollution (I) • air pollution (II)	• water pollution • land pollution	• water quality • land shinking	• water quality • seagrass	• water quality • algae blooms	• water quality	• water quality	• water quality	• water quality

Note : I indicates the most important activities and the most significant issues
II indicates less important activities and less significant issues
III indicates not important activities and much less significant issues

Table 5.1 (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Activities in the future	• Pelican Point Power Station; • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Pelican Point Power Station	• Pelican Point Power Station • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Pelican Point Power Station • Gross Pollutant Trap Installation	• Pelican Point Power Station • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development	• Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development	• improvement of Port Adelaide and Bolivar Sewage Treatment Works • wetland development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development	• improvement of Port Adelaide and Bolivar Sewage Treatment Works • Pelican Point Power Station • Wetlands development	• Dredging • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Industrial Development • Pelican Power Point Station • Wetland	• Dredging • Land-based disposal of Penrice Soda Product materials; • Pipelines for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Industrial Development • Pelican Point Power Station • Wetland	• Pelican Point Power Station; • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Gross Pollutant Traps Installation	• Pelican Point Power Station • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Gross Pollutant Traps Installation
Activities in the future	• Pelican Point Power Station; • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Pelican Point Power Station	• Pelican Point Power Station • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Pelican Point Power Station • Gross Pollutant Trap Installation	• Pelican Point Power Station • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development	• Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar Sewage Treatment Works to Virginia • Industrial development	• improvement of Port Adelaide and Bolivar Sewage Treatment Works • wetland development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development	• improvement of Port Adelaide and Bolivar Sewage Treatment Works • Pelican Point Power Station • Wetlands development	• Dredging • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial Development • Pelican Power Point Station • Wetland	• Dredging • Land-based disposal of Penrice Soda Product materials; • Pipelines for discharging wastes from Bolivar to Virginia • Industrial Development • Pelican Point Power Station • Wetland •	• Pelican Point Power Station; • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Gross Pollutant Traps Installation	• Pelican Point Power Station • wetland • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Industrial development • Land-based disposal of Penrice Soda Product materials • Pipeline for discharging wastes from Bolivar to Virginia • Gross Pollutant Traps Installation

Note : I indicates the most important activities and significant issues
II indicates less important activities and less significant issues
III indicates not important activities and much less significant issue

Connolly, 1986; Walker and McComb, 1992; Neverauskas, 1988; Neverauskas, 1987). Continuous nutrient loadings from Bolivar Sewage Treatment Works and Port Adelaide Sewage Treatment Works are believed to have been continually stressing the wetland ecosystem (Banham, 1992). Two other activities were also recognised as affecting the environment: stormwater and Torrens Island Power Station. According to the Environmental Protection Authority Report (1997), stormwater is a nutrient loading mechanism that is most likely to result in poor water quality in terms of heavy metal and nutrients content. Some interviewees also claim that due to the development of artificial wetlands, stormwater will not be the serious threat to estuary water quality in the future. There were some activities most interviewees considered insignificant in terms of their impacts on the environment. These were: marina/boating, landfill, shipping and salt-fields. For this reason, these activities will not be included in CEA in this study.

From the discussion above, it is clear that there are three main activities which are thought to be those which have been affecting the quality of the environment (water quality) in the study area: Port Adelaide Sewage Treatment Works, Bolivar Sewage Treatment Works, and Penrice Soda Products. Stormwater discharge is an additional activity that will be included for further analysis. The reason for this is that although stormwater discharge into the estuary may not affect water quality condition in the future due to the ongoing construction of artificial wetland (Harbisson, pers.comm., 1999), this activity has been evidently affecting the environmental condition to date. To summarise, activities included in CEA can be selected using interview.

5.3.3 Significant Issues

There were significant environmental issues recognised by interviewees including soil condition, water quality and air pollution. Of these, water pollution or water quality was the most significant issue. As can be seen in Table 5.1, this is the most fundamental environmental issue interviewees identified. There were also other related water quality issues recognised by interviewees, such as algae blooms, dinoflagellate and *Ulva*, loss of seagrass and the loss of mangroves. This relationhisp has been explained in Chapter III (Study Area).

Previous studies also recognise that water quality is one of the most significant issues in the study area. For example, Schrale, et al. (1991:98) in Banham (1992:51) states that approximately 950 Ha of seagrass beds in the 7 km of shallow coastal waters between St. Kilda and Port Gawler have been degraded over 40 years due to the decline in water quality. Edyvane (1991) in Banham (1992:51) also claims that the death of mangrove seedling can be due to the growth of *Ulva*, which is also due to the excessive loadings of nutrients which have resulted in poor water quality conditions.

5.3.4. Activities in the future

5.3.4.1 The Importance of Future Activities

As one component in CEA, selected future activities in combination with those representing past and present activities can determine the magnitude and significance of cumulative effects. Knowing future activities and their potential environmental impacts and in combination with past and present activities, therefore lead to reasonable prediction of cumulative effects.

The determination of future activities is complicated. Proposed activities may be cancelled, delayed or revised. The proposed activities may be very certain as there have been preliminary efforts to conduct this activity. Others may not be certain enough to be included in CEA. Other factors, such as economic, political and technical conditions can determine whether they will be pursued or not. The designs, the mitigation measures and the technologies used may not be known with any certainty.

5.3.4.2 Review of the Methodologies for the Determination of Future Activities

Chapter II (Literature Review) shows the studies which use time frames for CEA. As can be seen, there is variation in the use of time frames for CEA. The conclusion drawn from the literature review is that most CEA studies give little consideration to future activities and how any future activities could be identified. In addition, there is no stated reason for not including future activities. Rumrill and Canter (1997) and Council on Environmental Quality/CEQ (1997) may be the only sources of information regarding the methodology for the determination of future activities. Rumrill and

Canter's methodology provides the complete guideline for the selection of future activities, although this was considered appropriate only for areas in North America. Therefore, some changes are necessary for this methodology to be applicable to other areas. The methodology by Council on Environmental Quality (1997:17) states that the overlap of project impact zone and other documents, such as planning documents are main components for the determination of future activities. The implication of the uses of impact zones for the determination of future activities is that if the proposed or future activities are within the overlap of impact zones, they must be included in CEA together with selected past and present activities. In fact, CEQ's methodology (1997) for the determination of future activities is simpler than that in Rumrill and Canter (1997) in terms of basic information for generating future activities. Figure 5.2 illustrates the stages used in the methodology proposed by Rumrill and Canter (1997). In this figure, RFFAs stands for Reasonably Foreseeable Future Actions. According to their methodology, five aspects dictate the selection of future activities :

(1) Formal proposals.
(2) Connectedness.
(3) Resources invested.
(4) Planning documents.
(5) Significance.

There are some weaknesses in Rumrill and Canter's methodology (1997):

(1) Valued Environmental Component(s) are not the main emphasis. As explained, five aspects were used for determining future activities.
(2) Uncertainty is likely to accompany every aspect. Therefore, the determined future activities are likely to have much uncertainty.
(3) The process is fairly complicated.

As a result of these three weaknesses, the process for identifying and selecting future activities to be included in CEA could be cumbersome, which mainly due to the fact that this procedure has no consideration on the VEC.

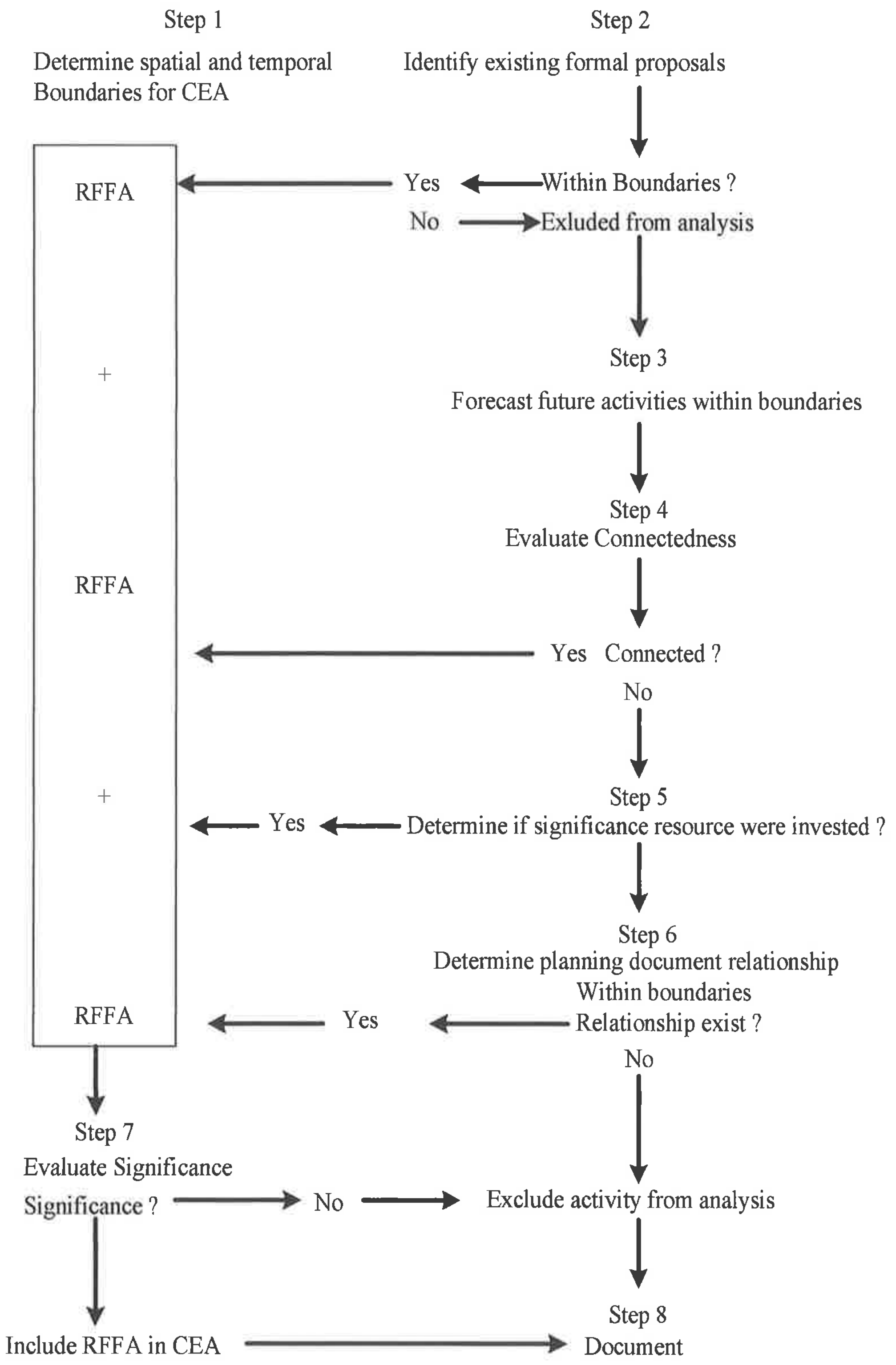


Figure 5.2 Eight_step method decision flowchart (Rumrill and Canter, 1997: 217)

In addition, the uncertainty accompanying this procedure is likely to be high due to the use of extensive uncertain documents, such as planning documents and the concept of significance and interconnectedness. Considering these reasons, a procedure for determining future activities is required, especially for CEA in an estuary. The main components that need to be considered will be:

(1) Using less uncertain data.

(2) Providing less uncertain information.

(3) Relate to the main Valued Environmental Components.

5.3.4.3 Proposed Methodology for the Determination of Future Activities in CEA

Figure 5.3 shows the proposed methodology for the determination of future activities. Assumptions used in the proposed methodology are :

(1) Determination of future activities is an integral part of scoping.

(2) Future activities must have effects on particular Valued Environmental Component(s) determined from scoping process.

(3) Spatial and temporal boundaries have been determined in scoping. The past, present and future activities located outside the spatial and temporal boundaries will not be included in the assessment.

(4) There are planning documents, such as Development Plans and other kinds of unpublished planning from different institutions. The future activities selected must be adjusted in accordance with the changes in Development Plans. The following Figures (Figure 5.4 to 5.8) show Development Plan of local councils surrounding the estuary of the study area. The importance of these figures was to show kinds of planned development for each council. These figures were also used as the sources of information for determining the spatial boundary for CEA.

Figure 5.3 illustrates stages used in the determination of future activities included in CEA. Interviews are considered as the most appropriate method for obtaining information about future activities. The results of the interviews were, then combined with the existing documents on planning or Development Plan. Some information necessary for the determination of future activities were:

(1) The institutions having responsibility for pursuing proposed or future activities. These institutions were, then contacted. Some institutions contacted were: Northern Adelaide and Barrosa Catchment and Water Management Board, Torrens Catchment and Water Management Boards, Ports Corporation, Local Councils (four local councils are contacted: Port Adelaide and Enfield, Elizabeth, Salisbury, Munop Para) and State Government. The questions asked were those related to the time of the beginning and the end of the activities, the stages that will be conducted for every activity.

(2) The effects of future activities on the key VEC(s). The information about the effects of future activities on VEC(s) was obtained from interviews. If interviewees consider that future activities will affect significantly the key VEC(s), then they will be included in CEA.

(3) The certainty of the future activities. The indicators used for determining the certainty of the proposed projects or activities were :

    (a) The existence of a formal proposal.

    (b) If the proposed activity related directly to the planning, then, this activity will be included in CEA.

    (c) A direct effect on VEC(s). If a particular activity is considered as the one that will affect VEC(s) directly in the short term and in the long term, then this activity will be included in CEA.

    (d) The evidence of on-going activity, although this has not finished.

    (e) The activities the interviewees considered them as certain.

(4) The spatial and temporal boundary.

(5) Unpublished plans. Obtaining the information about unpublished plan was obtained from interviews.

5.4 Results of Future Activities Determination and The Implications for making Scenarios for Cumulative Effect

The results of determining future activities for CEA are described below:

(1) Environmental Protection Authority for South Australia states that Environmental Improvement Programs (EIPs), reducing or eliminating discharges by 2001, are mandatory conditions of licences to industry.

This particularly relates to the discharge of effluents to the Port River Estuary and Barker Inlet.

(2) SA Water's Mandatory Environmental Improvement Programs for the Port Adelaide and Bolivar wastewater treatment plants(WWTP) includes the reduction of nitrogen and phosphorus to minimise impacts on the marine environment.

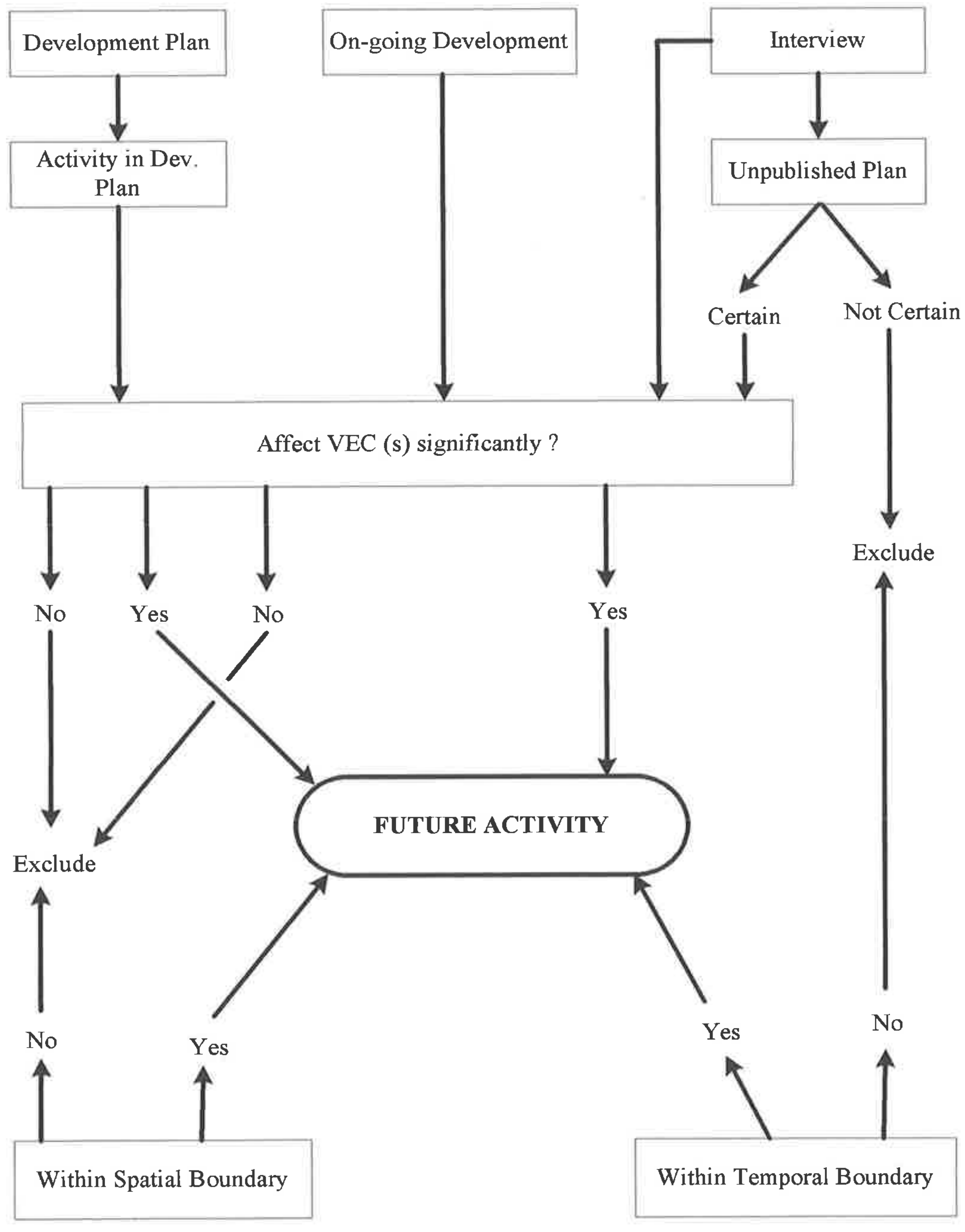


Figure 5.3 Procedures for Selecting Future Activities

(3) A new pipeline will take all summer effluent and some winter effluent from the Bolivar to Virginia Horticultural region, instead of discharging it to coastal water. This activity is considered certain because some preliminary stages of its development have been in progress.

(4) Despite the disagreement of some people, the development Pelican Power Station has been initiated. Because of this, this activity is considered certain in terms of CEA. The field check also confirmed that preliminary development of this activity has been conducted. However, according to the interviewees, this activity has no significant effects on the estuarine water quality, therefore this is nor included in CEA in this study.

(5) Gross Pollutant Entrapment has been built in Port River Estuary. This commences in September 2000, and this is expected to finish within the next two years and will only remove solid waste, but not the chemical (Harmer and Sanders, 2000, from Port Adelaide and Enfield Council, pers. comm.). The installation of propeller in the Port River aimed at avoiding stratification is also part of the efforts to make estuary healthier (Reynold, 1993).

(6) Industrial development is likely to occur in the study area, especially in the area close to the estuary. The results of interviews indicated that this is certain activity in the future, although interviewees do not know with certainty when these activities will commence.

(7) There has been a proposal to dredge the Port River (Pitcher from Port Corp., 2000, pers. comm.) from the year 2000. The process of dredging will start in the next two years. This activity is considered certain and this will cover large area of Port River. This activity will be aimed at the deepening Port River Estuary to allow access for ships.

The results of scoping indicate that the high level of nutrient input is the main problem occurring in the study area. The results of scoping also show that the main sources of nutrients discharged into the estuary are from Port Adelaide Sewage Treatment Work and Bolivar Sewage Works. In fact, there have been some plans for reducing the amount of nutrients discharged into the estuary from this activity. Some current plans for Port Adelaide Sewage Treatment Work are:

Figure 5.4 Councils Surrounding Estuary

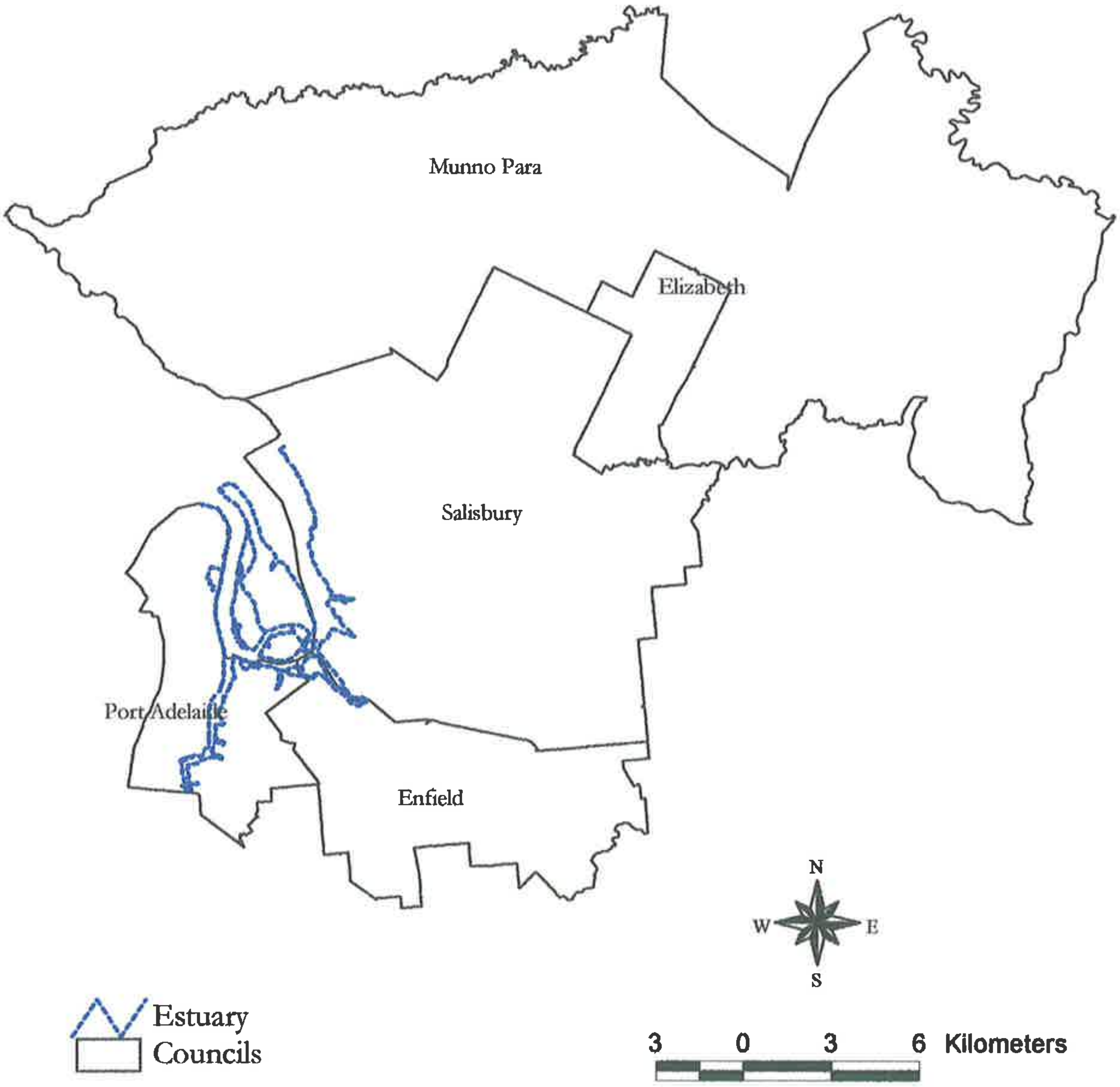
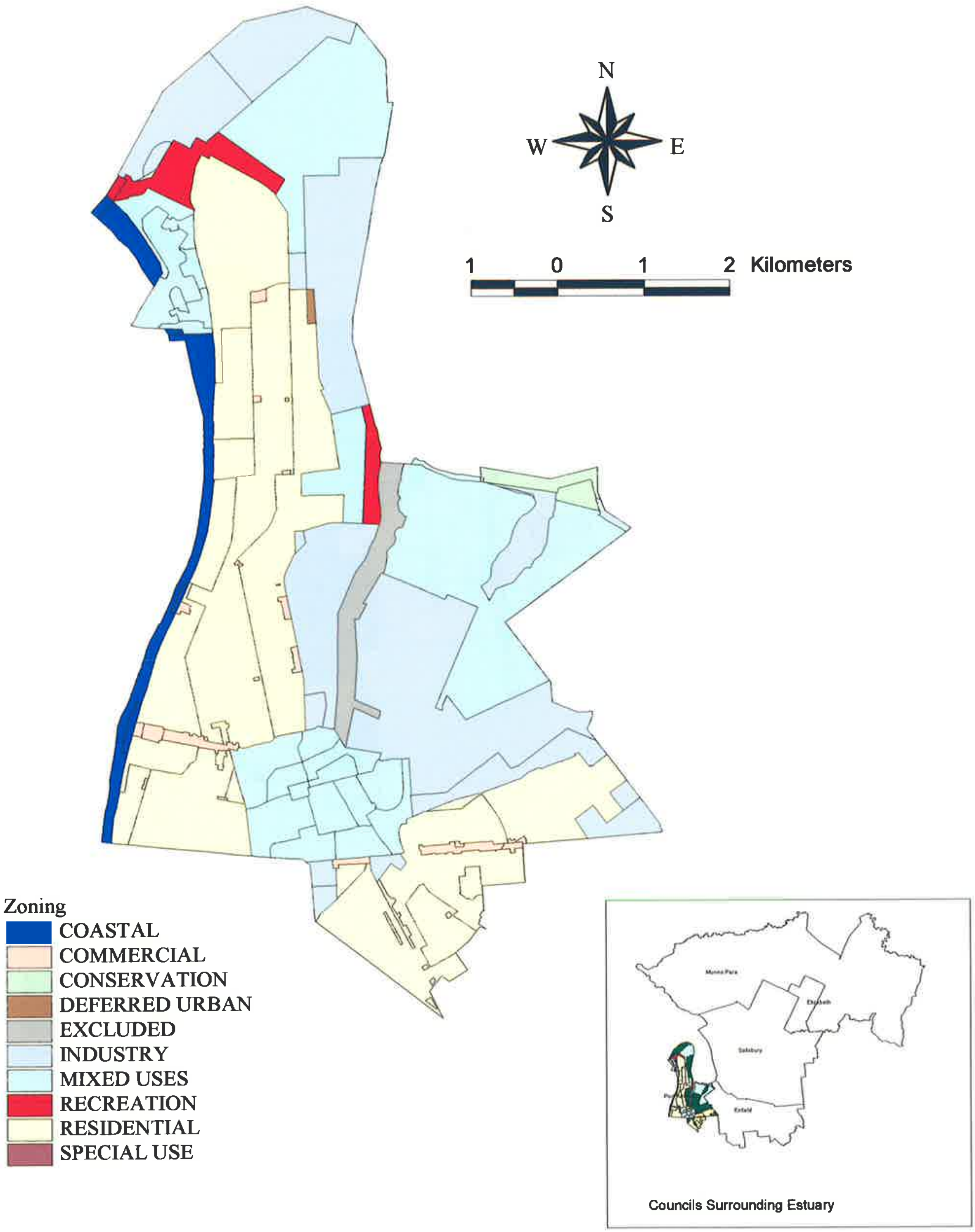
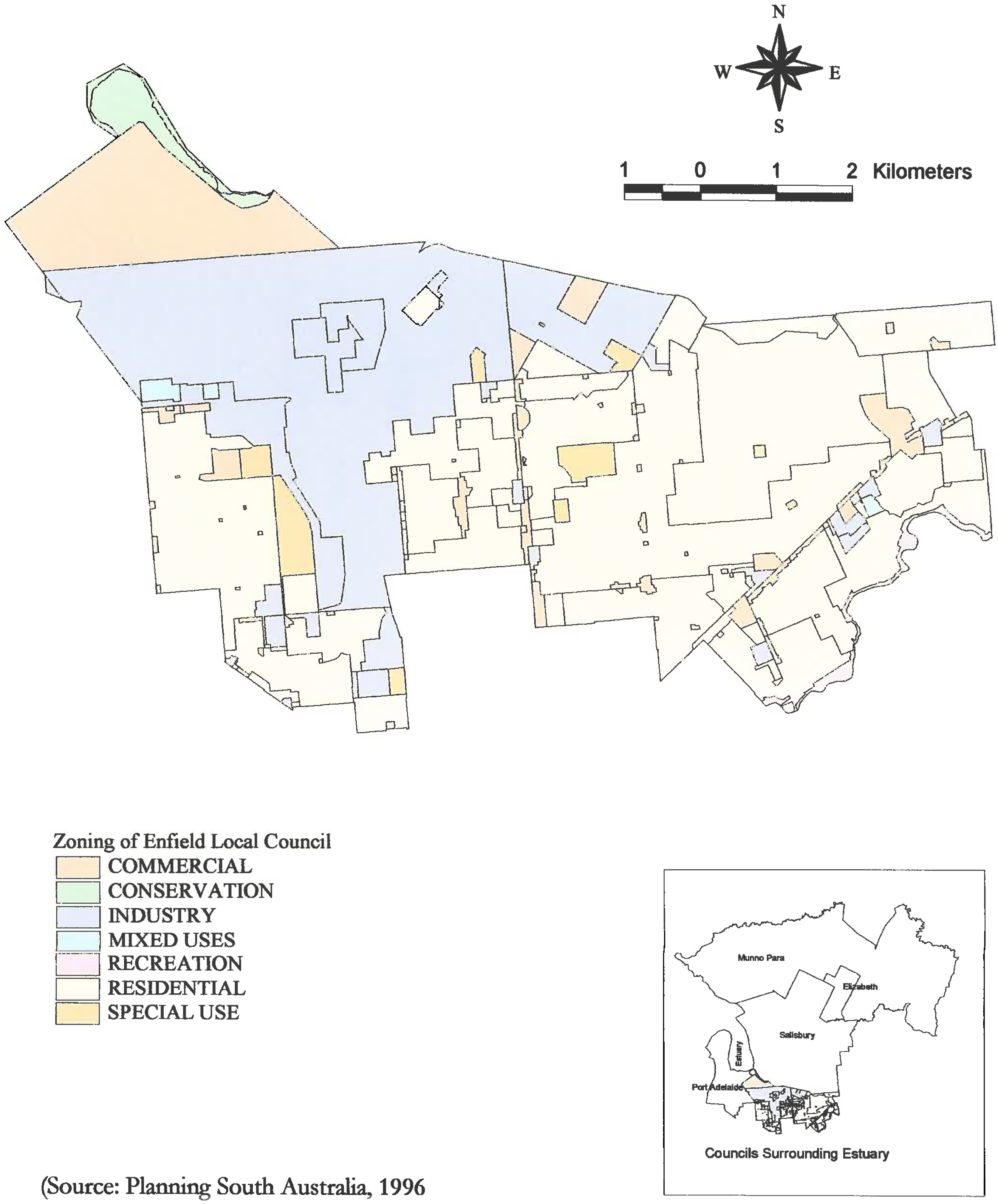


Figure 5.5 Zonings in Port Adelaide Local Council



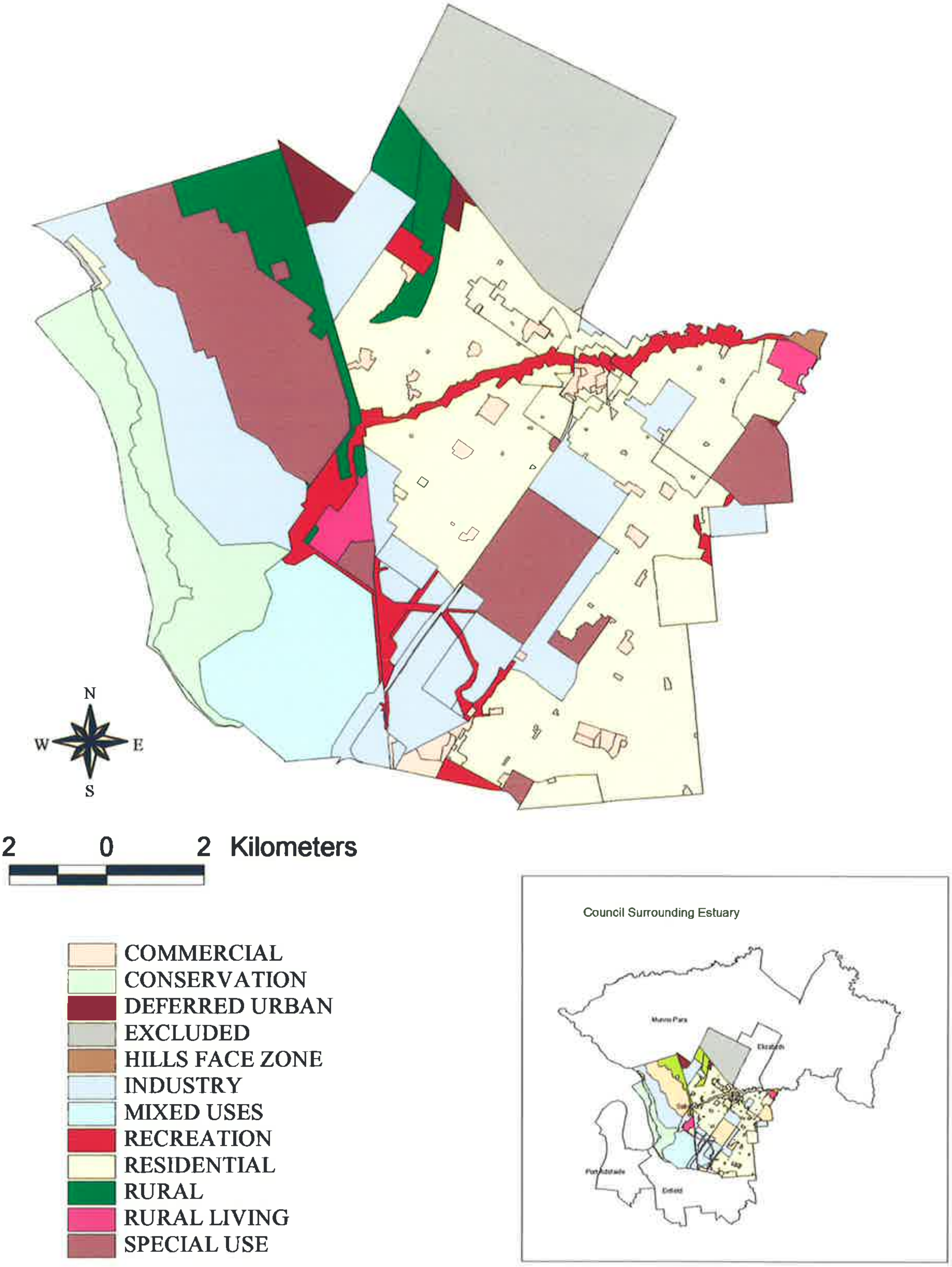
(Source: Planning South Australia, 1996)

Figure 5.6 Zonings in Enfield Local Council



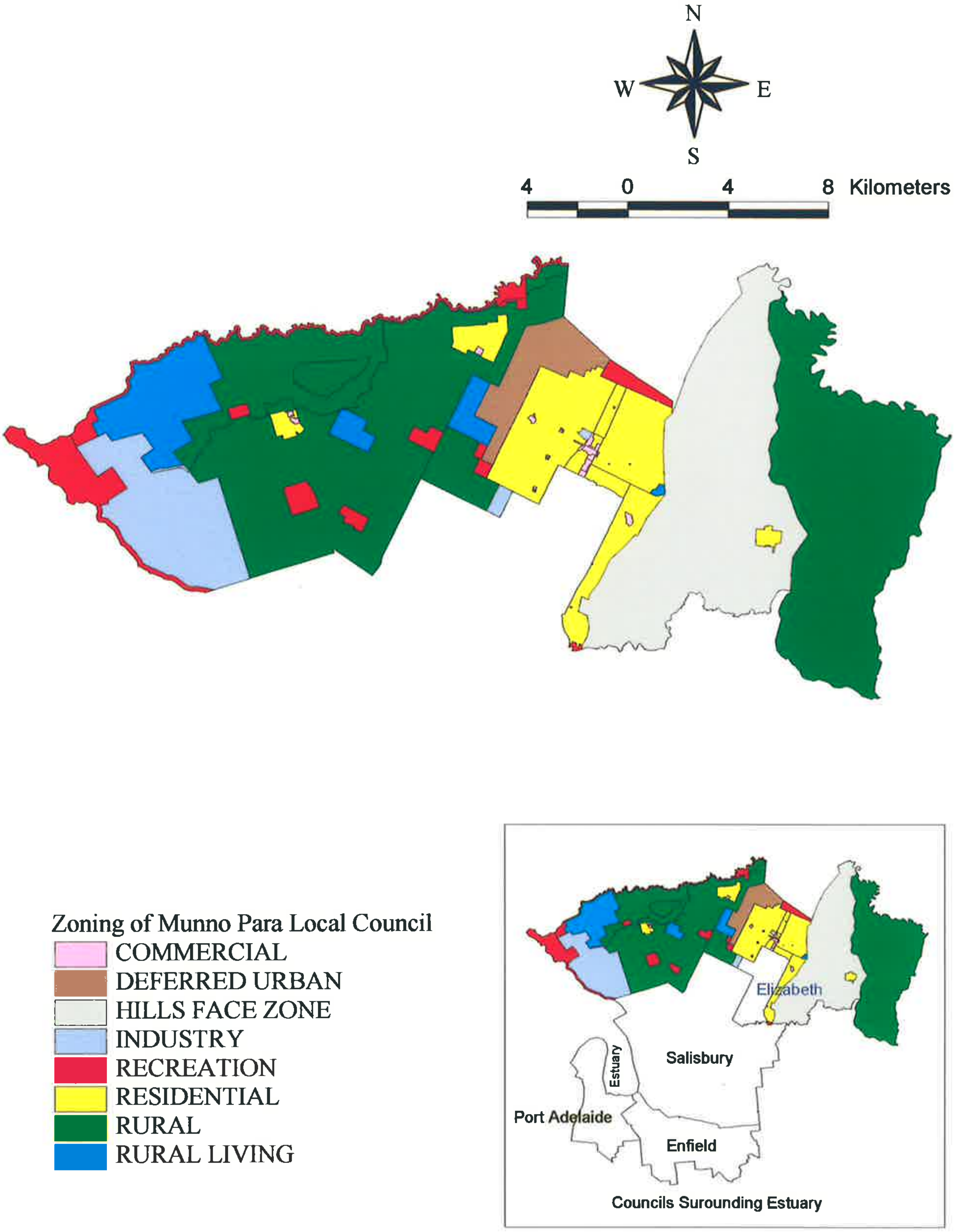
(Source: Planning South Australia, 1996

Figure 5.7 Zonings in Salisbury Local Council



(Source: Planning South Australia, 1996)

Figure 5.8 Zoning s in Munop Para Local Council



(1) Upgrading of the Port Adelaide works and continued discharge to the Port River.
(2) Upgrading of the Port Adelaide Works and discharge through a new outfall to the Gulf.
(3) Full Land Based Disposal.
(4) Partial land-based disposal with upgraded treatment and Gulf disposal for residual flow.
(5) Diversion of flow to Bolivar and Glenelg upgraded treatment for the Residual flow at Port River.
(6) Abandonment of the Port Adelaide works and the construction of a new treatment works at Glenelg.

The following table (Table 5.2) provides information about the plans of the Port Adelaide Sewage Treatment Works (SA Water, 1995:10). Of particular concern is dredging activity. Dredging in the Port River has raised the possibility of elevated nutrient concentrations (Sullivan in Portside Messenger, November 15, 2000). As Sullivan said, dredging is likely to increase the risk of algae proliferation. Industrial development, storm water and Pelican Power Point Station are other activities that affect the dolphins (Bossley in Portside Messenger, November 15, 2000). The expected reduction of the nutrient loading of nutrient into the estuary as shown in Table 5.2 in mainly for the Port River Estuary, because the location of the Port Adelaide Sewage Treatment Works is in Port River Estuary. For the Barker Inlet, there is a statement in the planning that in the outlet of Gulf of St. Vincent, 10% reduction of nutrients and silt must be achieved.

Due to the nature of the study area, which has been and will continue to be used for industrial purposes (as Development Plans stated), other scenarios for predicting effects of nutrient loadings into estuary are needed to cover this. For this reason, the assumed 3% increase in the nutrient loadings into the estuary will be used. This 3% increase was assumed to be due to the increase in industrial areas and the increase in the size of population.

Therefore, the future activities selected for further processes for CEA in this study are:

(1) Dredging Activity.

(2) The reduction of the amount of nutrient loadings which take into account the reduction of nutrient loadings due to the movement of wastes to Virginia.

(3) The increase of 3% after nutrient loadings to the estuary from Bolivar Sewage Treatment Works, Penrice Soda Products and Port Adelaide Sewage Treatment Works ceased.

(4) The combination of activities will also be analysed in terms of their effects on water quality conditions.

Table 5.2 Predicted Reductions of Flow and Nutrients due to Proposed Actions (Source: South Australian Water Corporation, 1995:10)

Option/Action	Percentage Reduction in Discharge to the Port Adelaide River		
	Flow	Nitrogen	Phosphorus
1. Continue discharge to Port River : 1.1 Moderate Level Upgrade 1.2 High Level Upgrade	 0% 0%	 73% 86%	 56% 81%
2. New Outfall at Grange 2.1 Moderate Level Upgrade 2.2 High Level Upgrade	 100% 100%	 100% 100%	 100% 100%
3. Full Land Based Disposal Aquifer Recharge Queensbury Reuse Pelican Pt Wetland	60 13 21	60% 13 11	60% 13% 11%
Total	94%	84%	84%
4. Partial Land Based Disposal Queensbury Reuse Pelican Pt Wetland High Level Upgrade and Outfall at Grange	 13 21 60	 13 11 60	 13 11 60
Total	94%	84%	84%
5. Partial Diversion of Flow Divert FG to Glenelg + Q to Bolivar High Level Upgrade Remaining Flow	62 0	62 33	62 31
Total	62%	95%	93%
6. Abandon Port Adelaide New WWTP (1) at Glenelg Combined New Outfall	100 0	100 0	100 0
Total	100%	100%	100%

To summarise, the ideal CEA requires a complete time frame (past, present and future). It is also apparent that to conduct a complete CEA, time frames for each activity should be available. However, none of this information is available in this study area. Therefore, in terms of cumulative effects, time frames were not used as the frames for analysing cumulative effects, rather the activity will be used. For example, the analysis will use the time of dredging, the time after dredging and et cetera, and not a definite year or time of the activity. This clearly increases the uncertainty of the prediction of cumulative effects. Despite the ease of determining possible future activities, no information is available regarding the stages for every future activity.

5.5 Environmental Indicator Used for CEA in this Study

Using the information from scoping, an appropriate indicator was determined. VECs selected from scoping determine the selection of indicator(s). Ross (1998:273) claims that the focus in CEA must be on the individual VEC. Besides, third principle of cumulative effects analysis (CEQ, 1997:8) requires that "Cumulative effects need to be analysed in terms of the specific resource, ecosystem and human community being affected". Considering the results of interviews and the references regarding the study area, the selected indicator was water quality. The reason for that is that:

(1) The main problem in the study area is the eutrophication due to continuing nutrient loadings.

(2) Quantitative monitoring data exist on water quality parameters so that this will make consistent and direct comparison of predicted and observed effects. Water quality is the indicator that is mostly used in studying environmental changes. Incorporation of new monitoring data of water quality can be conducted.

(3) Water quality does have effects on other Valued Environmental Components/VEC(s), for example the effects of water quality on seagrass and mangroves. This relationship makes it possible to determine the impacts on the other VEC(s).

(4) The uses of water quality parameters will provide the means for distinguishing stresses involved, the prediction of environmental thresholds and analysing the types for cumulative effects.

5.6 Spatial Boundary for CEA

Most previous methodologies recognise the importance of determining spatial boundaries for CEA with the result that the determination of spatial boundaries has been at the first stage in the methodologies for CEA. This approach, however, is only appropriate for spatially constrained areas, such as watershed due to the definite watershed boundary.

The procedure for determining spatial boundary for other environmental conditions, such as estuary and coastal environments has not been established. The generic methodology for determining the boundary must be established.

It can be argued that the determination of the spatial boundary should be based on the extent of VEC(s) and the activities affecting VEC(s). For this reason, the spatial distribution of VEC(S), which have been and would be affected by activities, must be identified. In this regard, the assumption used for boundary determination is that there is no exact spatial boundary for CEA. On the contrary, a fuzzy boundary of impacts exists so that the boundary for CEA must also flexible. The assumptions underlying this procedure is:

(1) Any boundaries determined from drawing the lines which are close to the limits of activities, VEC(s), their impacts and within the administrative boundary (the boundaries of local councils in this case) were acceptable. In this study, the boundaries of the details of planned activities in the Development Plans

documents as stated in Figure 5.4 to 5.8 was consulted in determining the spatial boundary for CEA.

(2) The extent of the spatial boundary can be derived from the distribution of VEC(s) and activities (if data do not exist).

(3) The boundary determined from the outer limits of activities in combination with those from Valued Environmental Components/VEC(s) affected and the boundary form Development Plans is considered to be the best estimate of the spatial boundary for CEA.

(4) The determination of the spatial boundary for CEA must not be regarded as both a very detailed process and fixed, but must be viewed as general and flexible, meaning that the established boundaries can possibly be refined, adjusting to new information.

Stages used for the determination of spatial boundaries for CEA are:

(1) Determine which VEC(s) are impacted by activities. This stage would determine all activities and VEC(s).

(2) Draw the spatial boundary based on the outer limits of the distribution of VEC(s) and past, present and possibly future activities.

(3) Determine past, present and future activities which are likely to have significant impacts. Possibly future activities must be included at this stage. Outer boundaries of every activity could be determined.

(4) Refine the boundary based on (2) and (3).

(5) Determine past, present and future VEC(s) which have been and would be significantly impacted by activities selected in stage (4).

(6) Refine the boundary.

(7) Final boundary is determined.

As can be seen, there are stages in the determination of spatial boundary for CEA. The selected activities and VEC(s) from scoping are the key components that dictate the spatial boundary. Because activities and VEC(s) have spatial characteristics, Geographical Information Systems (GIS) is the most appropriate method for this purpose. The above procedure shows the roles of GIS is determining spatial boundary.

Some available techniques such as buffering, overlay and polygon editing are basic techniques in GIS that will potentially assist in determining appropriate spatial boundaries for CEA. Moreover, as Johnson (1990:31-32) claims, there are some benefits GIS can provide for natural resource management and ecology:

1. Analyse temporal change.
2. Determine spatial coincidence of physical and biological features.
3. Determine spatial characteristics such as proximity, contiguity, and patch size and shape.
4. Analyse the direction and magnitude of fluxes of energy, organism or materials.
5. Produce graphic output.
6. Interface with simulation model to generate new spatial data.

Considering the stages used for spatial boundary determination, it is clear that GIS is an appropriate method for defining the spatial boundary for CEA. In fact, there has not been much evidence of the uses of GIS method for the determination the spatial boundary. Eedy (1995) in Canter and Sadler (1997:55) claims that GIS could potentially be used for:

1. Data management.
2. Data overlay and analysis relative to site impact prediction, wider area impact prediction, corridor analysis, cumulative effect analysis, and impact audits.
3. Trend analysis.
4. Integration into impact model such as climatic change model, and decision analysis using the Multi Attribute Tradeoff System.
5. Habitat analysis using Habitat Evaluation Procedure.
6. Aesthetic resources and impact analysis.
7. Public participation.

Considering the above, it is clear that for the purpose of analysing cumulative effects, GIS can be employed to determine the spatial boundary for CEA. However, this is likely to be one of other merits GIS can offer for CEA. The procedures for determining the spatial boundary may be more efficient than those based on natural boundaries, such as watersheds (catchments) because this will improve the efficiency and will provide the flexibility if changes are required. Because of the fact that spatial boundary can affect the significance of cumulative effects (CEQ, 1997), then GIS is fundamental method that can potentially be employed to assess the significance of cumulative effects in relation to the changes in spatial boundary. The result of determining the spatial boundary for CEA in this study can be seen in Figure 5.9.

5.7 Temporal Boundary for CEA

The determination of temporal frames (temporal boundary) for CEA in this study is considered very difficult. The reason for that is that historical data are rare, there is only a little data available on water quality changes in the past. For this reason, the time period for CEA in this study will be limited to the best available information in the past, present and future activities.

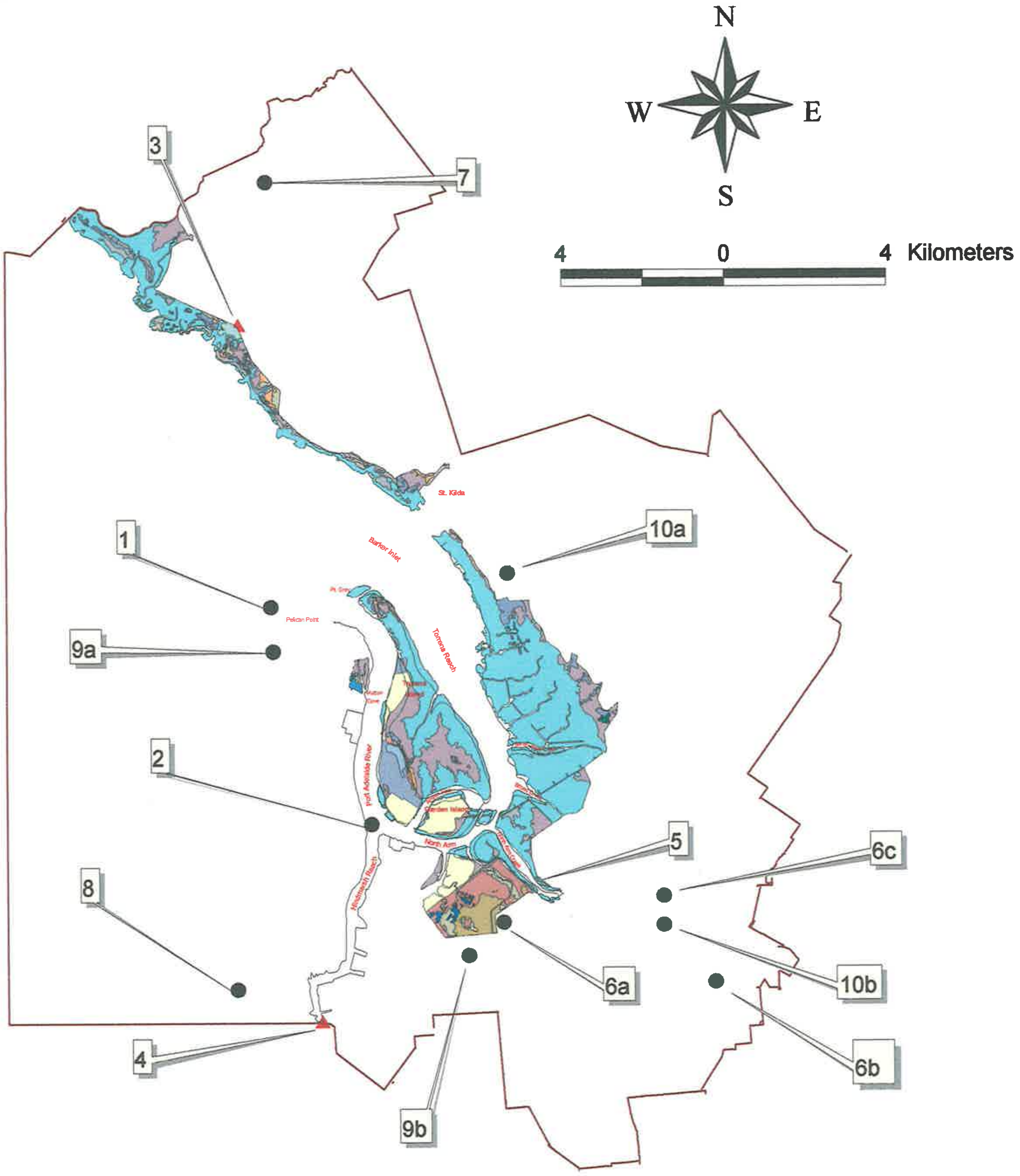
Uncertainty always accompanies the determination of future activities. Similar to the determination of spatial boundaries, temporal boundary determination must be considered as a dynamic process. The reason for this is that, this should adjust to the changes in what is going to happen in the future.

5.8 Methods for CEA

The most appropriate methods for analysing cumulative effect in this study are considered to be simulation modelling and Geographical Information Systems (GIS). Section 5.6 shows the merits provided by GIS in determining spatial boundary. In addition to GIS, simulation model was used in this study because:

1. Processes that determine the accumulations of impacts on water quality are various, such as nutrient loading, tides and other processes occurred in the estuary. Because all of these have spatial and temporal characteristics, mathematical models will provide the tools for combining all of these factors.

Figure 5.9 Spatial Boundary Used in Relation Past, Present and Future Activities and Resources



Legenda

╱╲╱ Spatial Boundary
╱╲╱ Estuary

■ Atriplex paludosa dwarf to open dwarf scrub
■ Avicennia marina dense low forest to low woodland
■ Bare Saline Flats
■ Bulboschoenus caldwellii dense tall sedges
■ Disphyma crassifolium dense mat plants
■ Dune low woodland, heath to open low scrub
■ Halosarcia halocnemioides/H. flabelliformis low heath to open dwarf scrub
■ Halosarcia halocnemioides/Sclerostegia arbuscula low heath
■ Halosarcia pergranulata low heath
■ Juncus acutus tall sedges
■ Lycium ferrocissum open low scrub
■ Maireana oppositifolia dense low heath to open dwarf scrub
■ Mangrove dieback
■ Outside study area
■ Phragmites australis dense tall sedges
■ Sarcocornia quinqueflora low heath
■ Sclerostegia arbuscula/Sarcocornia quinqueflora dense low heath
■ Suaeda australis dense low heath
▲ Locations of Sewage Outfalls

1 : Pelican Point Power Station

2 : Penrice Soda Product

3 : Bolivar Sewage Treatment Work Outfall

4 : Port Adelaide Sewage Treatment Work Outfall

5 : Stormwater

6a, 6b and 6c : Wetlands

7 : Middle Location of Bolivar Sewage Treatment Work

8 : Middle Location of PortAdelaibe Sewage Treatmeant Works

9 : Middle Location of PortAdelaide Sewage Treatment Works

9a,9b : Middle Location of Future Urban Development

10a, 10b : Middle Location of Salt Evaporation Pans

For example, nutrient loadings vary from one nutrient loading point to another, and the distribution of material will vary from time to time. Models are the most appropriate tools that can assess the impact of the spatial and temporal variability of nutrient loadings.

2. The results of interviewees indicate that nutrient loadings of three main selected activities, namely Bolivar Sewage Treatment Works, Port Adelaide Sewage Treatment Works and Penrice Soda Products and their combination have been greatly affecting the water quality characteristics in the estuary. The model will provide the ability to analyse not only the single nutrient loading, but also the combination of nutrient loadings.
3. Nutrient loading data are quantitative information and varying conditions of loads demands the methods that could analyse this variability. The method that is going to be used must also deal with the quantitative information and able to deal with variability. Mathematical modelling was considered to be one of appropriate methods for conducting this kind of analysis. Further temporal comparison of the result of analysis will assist in the comparison of the trend of water quality characteristics.

The reason for using Geographical Information Systems (GIS) for the analysis of cumulative effects in this study can be seen in Environmental Department The World Bank (1996:8) who claim that :

> The use of visual aids is strongly encouraged to help clarify locations of places or geographic features referred to in the text, the extent of environmental resources, locations of people or aspects of the natural environment affected by the project, and sampling locations. However, too many EA reports contain maps and other diagrams which are poorly prepared and cannot be reproduced easily and clearly.

João and Fonseca (1996:372) shows the importance of GIS for general use and claims that

> GIS can prepare the data for analysis more quickly and accurately that is normally possible by manual procedures. For example, changes of scale and projection, changes of weights of different variables, or conversion of the map data into a grid form can be carried out relatively easily. GIS can also cope with a higher level of detail and therefore increase the accuracy of the data handling process.

This statement provides information on the analytical capabilities of GIS in general. From this statement, there are three reasons worth noting for using GIS in this study. These three reasons are:

(1) The ability of GIS in handling changes of weight of different variable.

(2) The ability of GIS to conduct conversion of the map data into grid form.

(3) The ability of GIS to cope with a higher spatial detail.

These three reasons are considered extremely fundamental for Cumulative Effects Assessment and these are the reasons for using GIS in this study. Some other reasons for using GIS are:

(1) The response of the water in the estuary to stress is different from one location to others. Knowing the distribution of parameters determining the response of water quality in the estuary will be difficult without some further simplification. Geographical Information Systems (GIS) will provide the most appropriate method for this reason.

(2) Some data may not be available for input into water quality models. Techniques in GIS, such as interpolation are likely to be useful for deriving some information needed for input into a water quality model.

(3) Because results generated by mathematical models are not geo-referenced, the uses of GIS will likely to contribute to better sources of information for decision makers due to GIS's ability to portray the spatially referenced information.

(4) GIS can also provide techniques for aggregating and disaggregating impacts resulted from the analysis using models and possibly to combine quantitative and qualitative (weighting).

(5) Some display techniques provided by GIS will also assist in providing simplified information for decision makers.

Therefore, with regard to the methods used for CEA in this study, mathematical modeling is likely to provide the comprehensive coverage on the analysis of the variability of estuarine environment, whereas GIS can be very useful for deriving some data for input the model and for aggregating the qualitative and quantitative information.

5.9 Conclusion

To conclude, scoping is a very important process in CEA. As shown in this chapter, scoping has shown its main role in narrowing down the aspects for further processes in CEA. Interviews in conjunction with the results of previous studies were useful sources of information for this purpose.

Despite the subjectivity of interviews, its combination with published and unpublished governmental document and past studies are crucial conduct for gaining information pertinent for CEA.

Because of the fact that scoping has selected water quality as the VEC, further analysis of this VEC should be conducted. Spatial and temporal variability of water quality parameters, such as Ammonia, Dissolved Oxygen, Phosphate have been explained by some studies (Hubertz and Kahoon, 1999; Thompson, 1998; Mallin, Cahoon, McIver, Parsons, and Shank, 1999). The following chapter (Chapter VI) will discuss the analysis of water quality. This would include the analysis of spatial and temporal variability and modeling water quality.

VI. WATER QUALITY

6.1 Introduction

Chapter III and Chapter V show that water quality is the environmental component which has been significantly affected by the combination and interaction of activities. The importance of water quality relative to other environmental components (e.g. seagrass, mangroves, fish) has also been indicated in Chapter III.

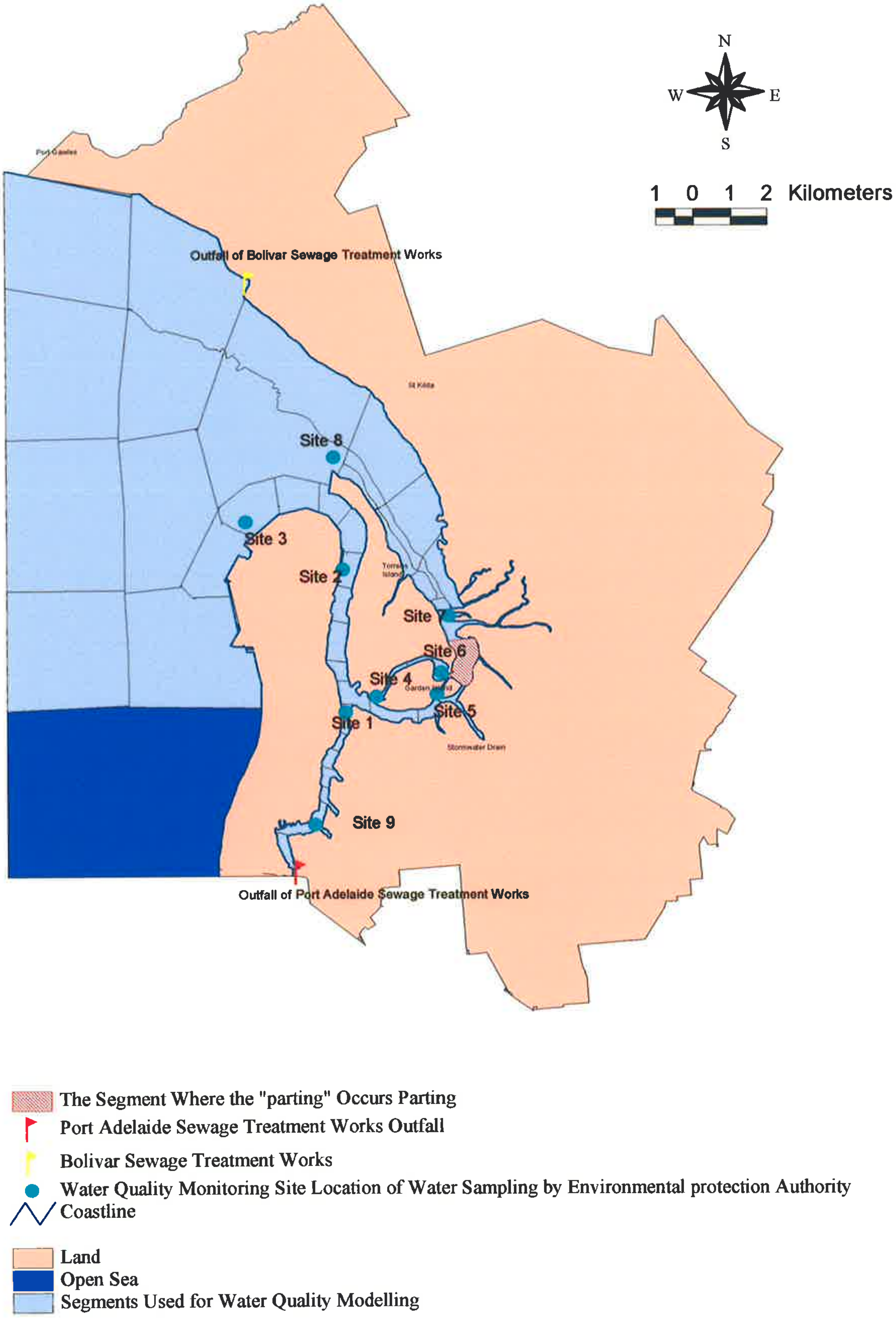
Nutrient enrichments in the coastal and estuarine environments have been an important environmental issue worldwide (Anon, 1990 in Gabric and Bell, 1993:262). The study area is an example of estuaries that has been experiencing nutrient enrichment from point and non-point sources pollution. If the enrichment of nutrient continues and exceeds the assimilative capacity of coastal and estuarine water resources, water quality will decline and have effects on other crucial environmental components.

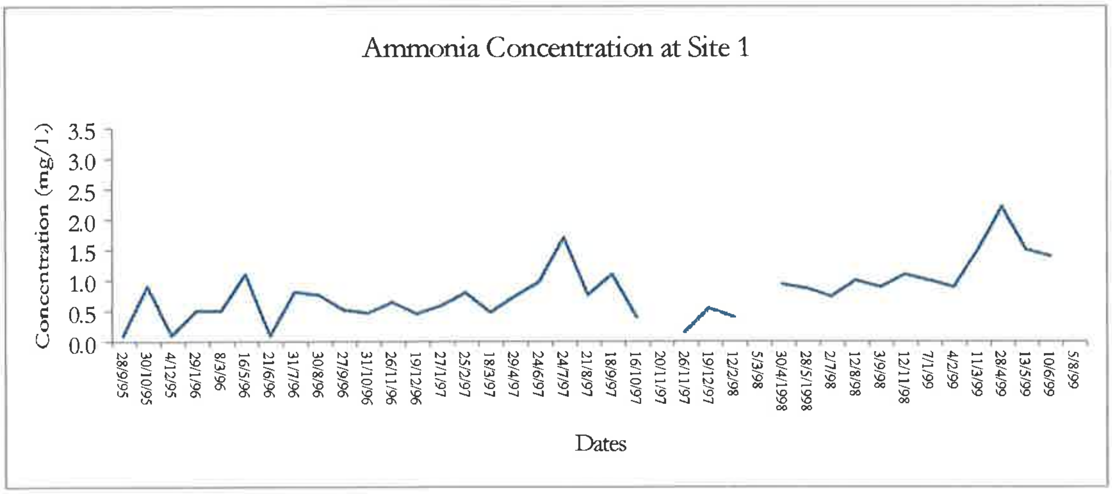
For the purpose of the management of water in coastal and estuarine environments, it is very important to understand the spatial and temporal variation of water quality parameters. This chapter will explore the spatial and temporal characteristics of water quality in the study area.

6.2 Spatial and Temporal Characteristics of Water Quality

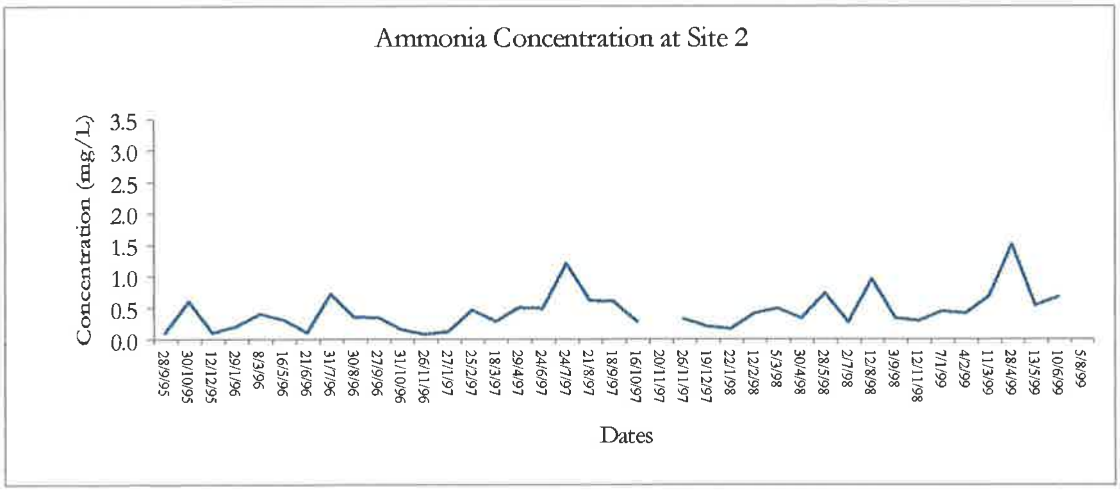
Figure 6.1 shows the locations of water quality sampling, the sewage effluents, rivers and "parting" in the study area. Figures 6.2 to 6.13 show the temporal variation of the water quality parameters i.e. ammonia, Total Kjeldal Nitrogen (TKN), phosphorus total and chlorophyll a for nine observation sites in the estuary of data recorded from September 1995 to August 1999 (Environmental Protection Authority, 1997). The broken lines in these figures indicate periods for which data were not available. These figures were obtained from organising and analysing the available data from DEHAA.

Figure 6.1 Locations of Important Phenomena Relation to Water Quality





(a)



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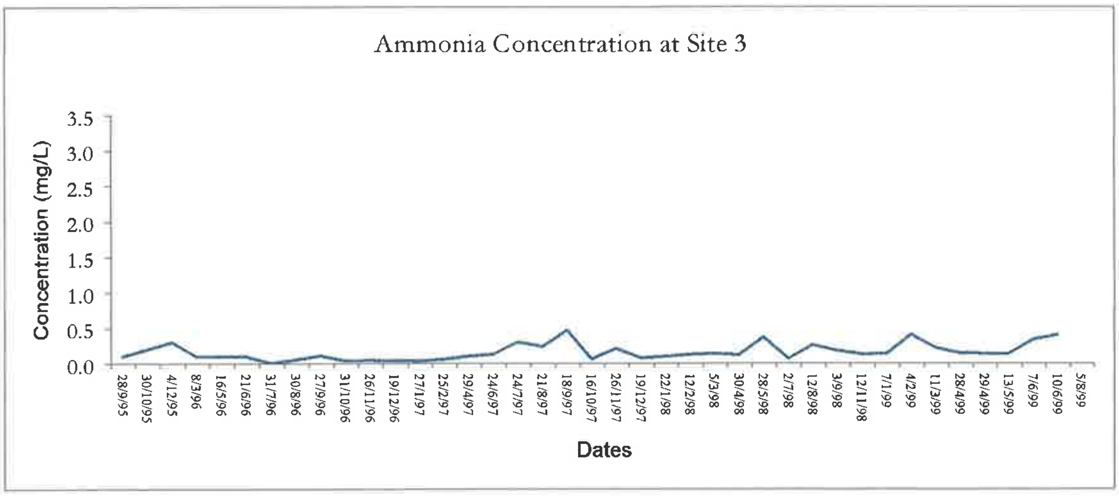
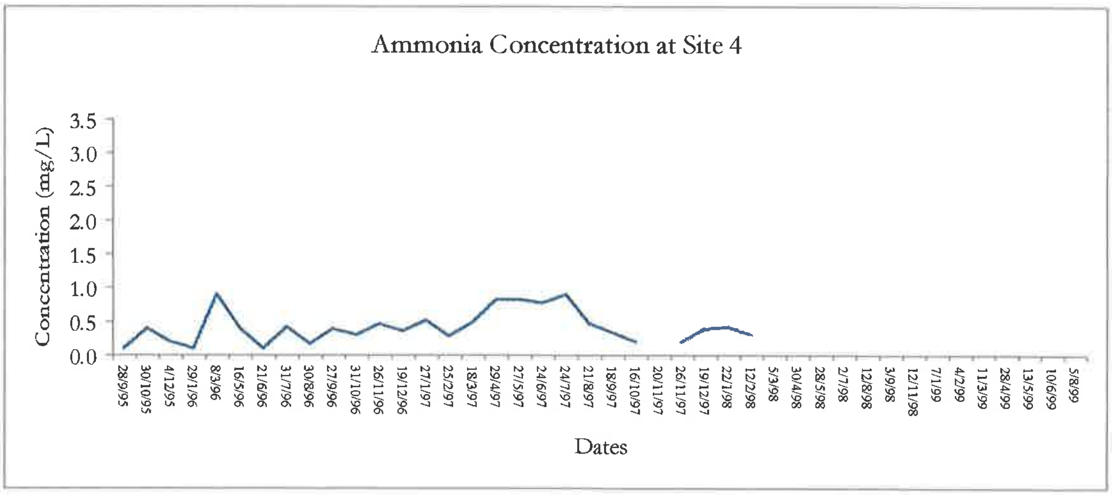


(c)

Figure 6.2 The Development of Ammonia Concentration at sites 1, 2 and 3 from 28/9/1995 to the beginning of 5/8/1999.



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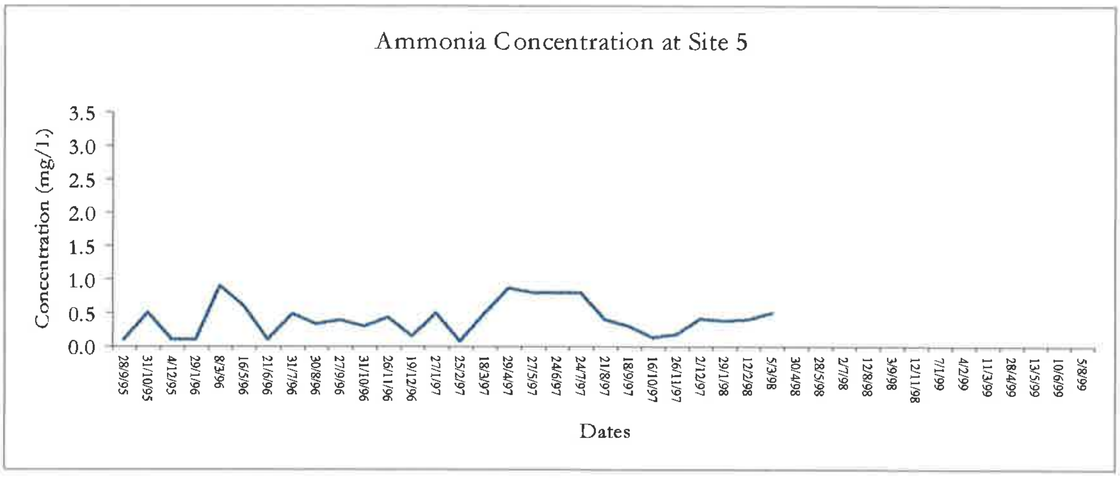

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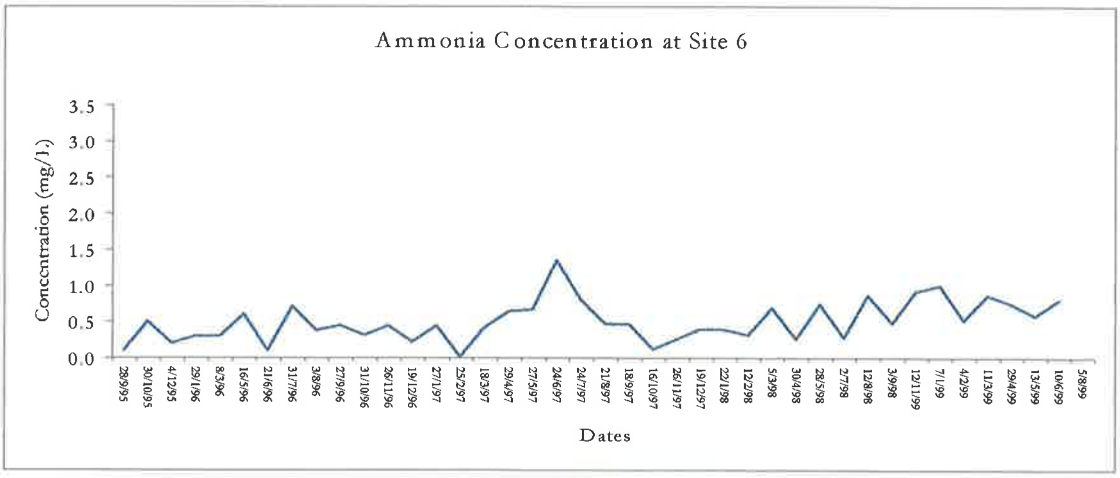
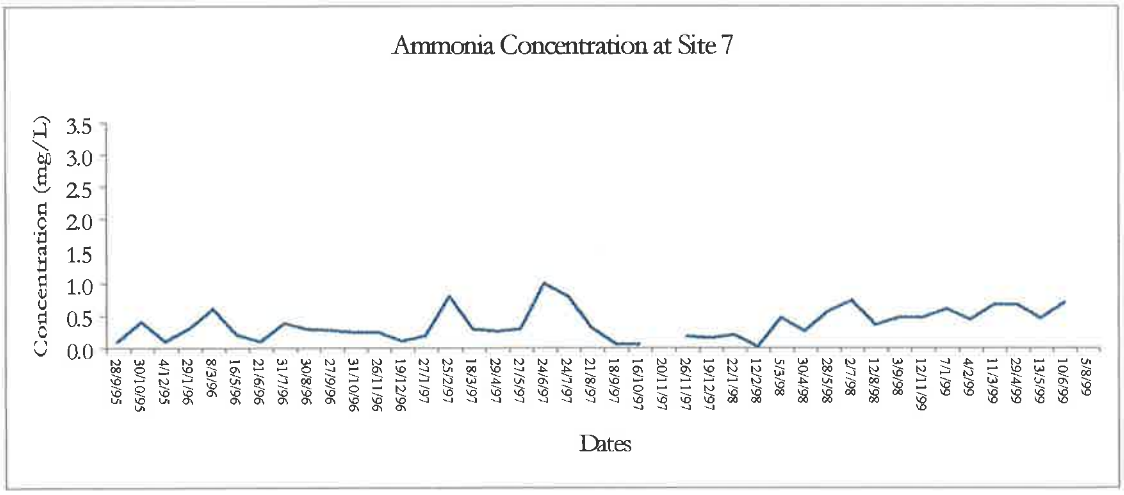
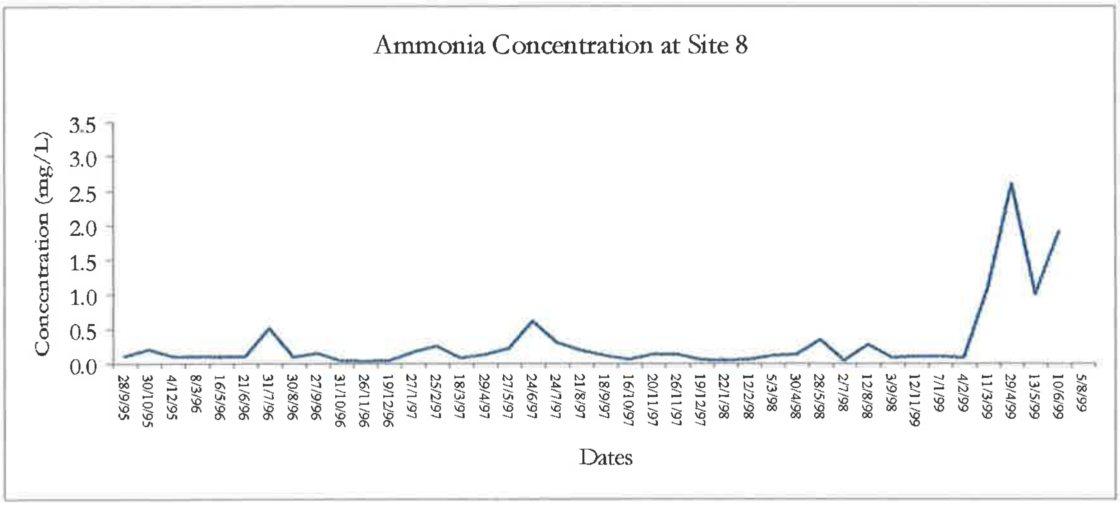


(f)

Figure 6.3 The Development of Ammonia Concentration at sites 4, 5 and 6 from 28/9/1995 to the beginning of 5/8/1999.



(g)



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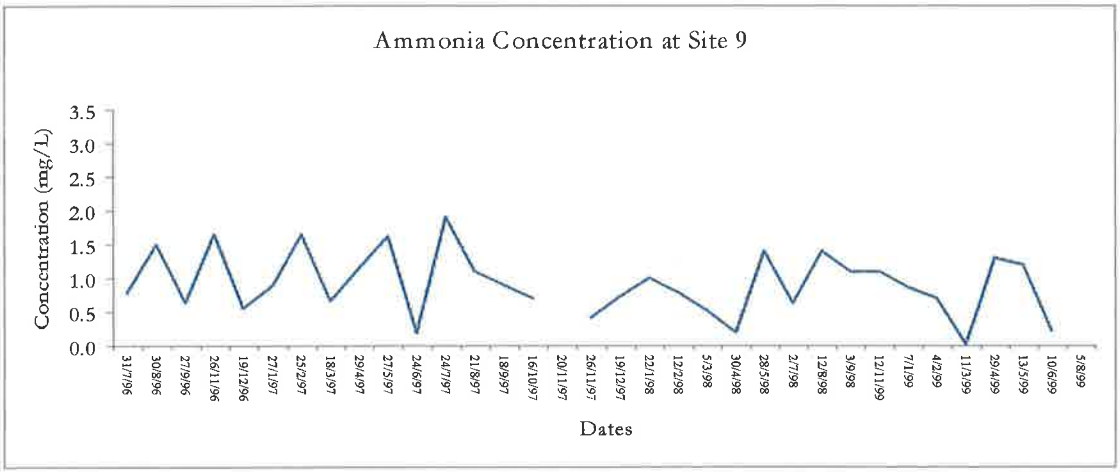
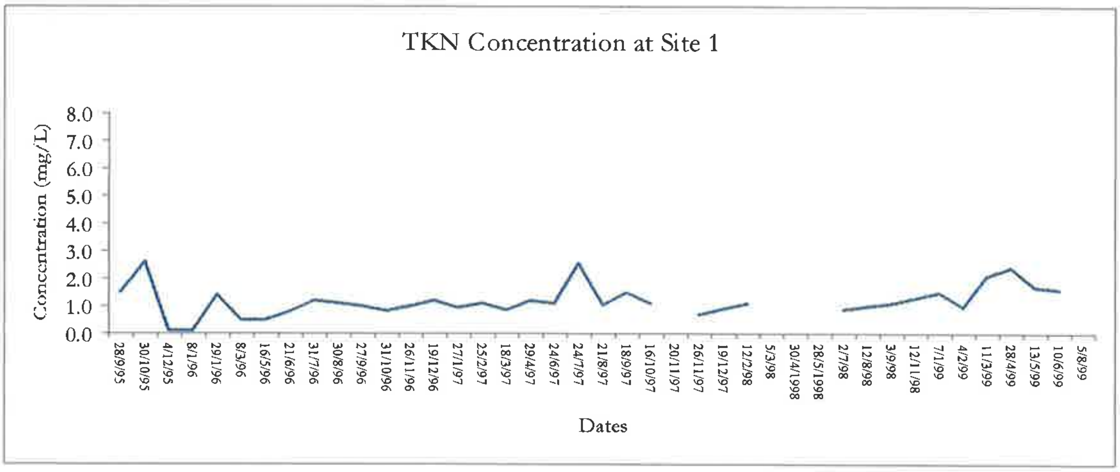


(i)

Figure 6.4 The Development of Ammonia Concentration at sites 7, 8 and 9 from 28/9/1995 to the beginning.



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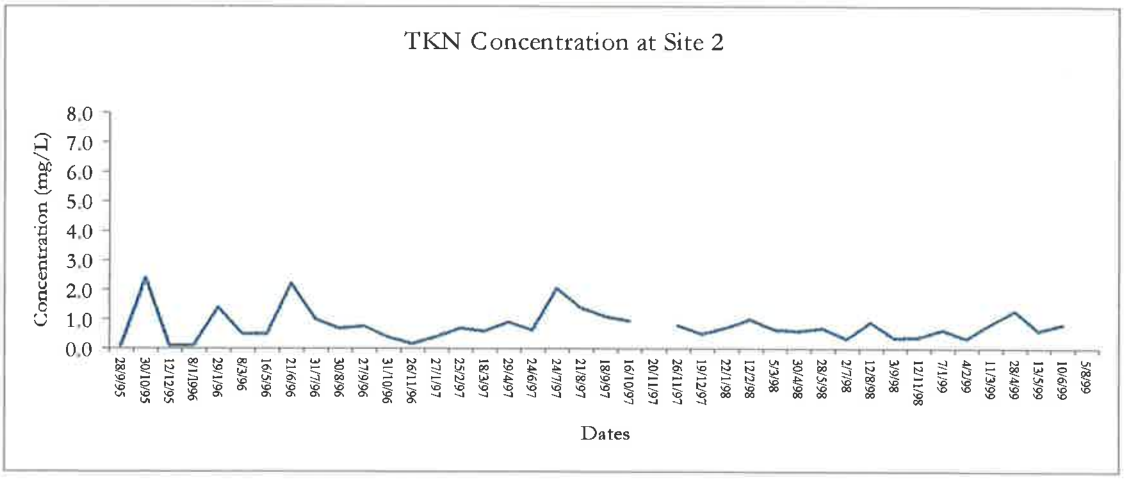

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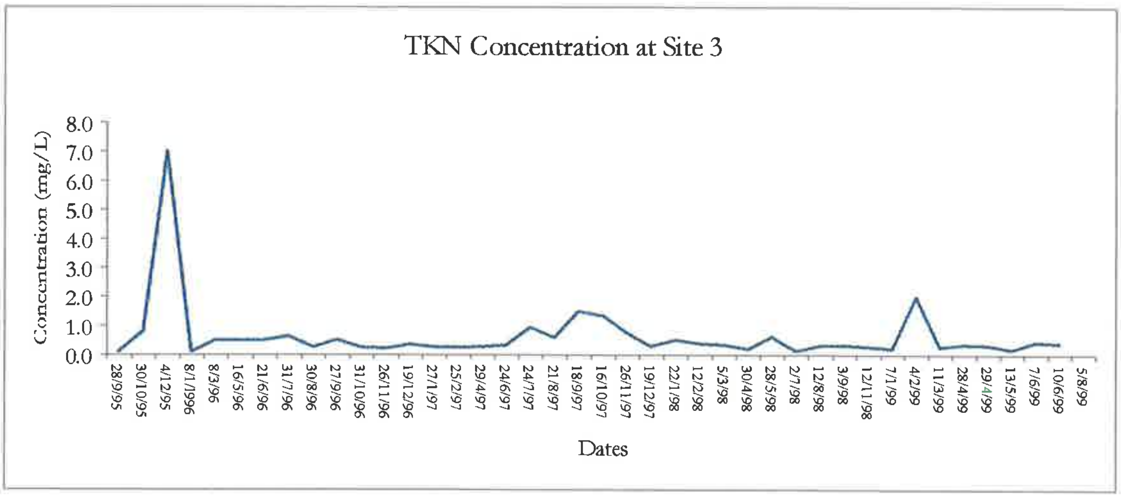
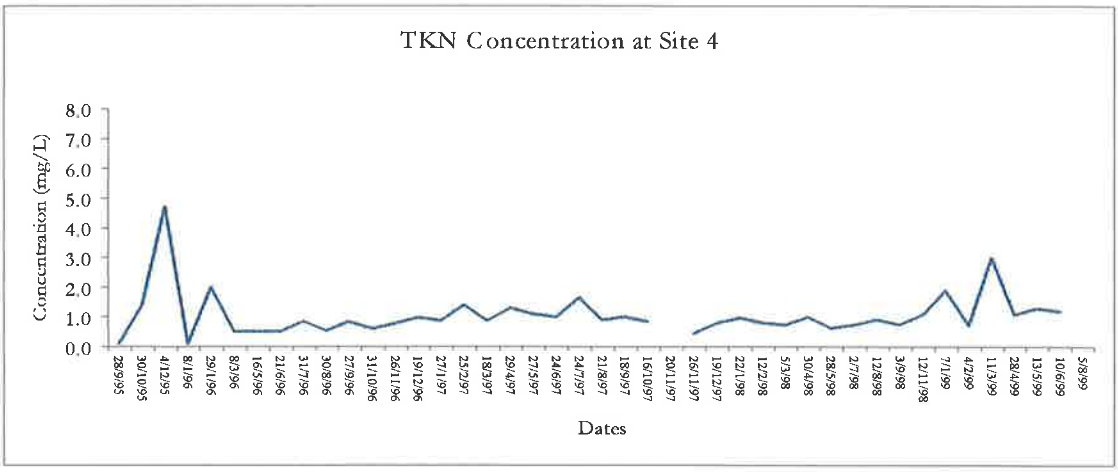


(c)

Figure 6.5 The Development of Total Kjedal Nitrogen (TKN) Concentration at sites 1, 2 and 3 from 28/9/1995 to the beginning of 5/8/1999.



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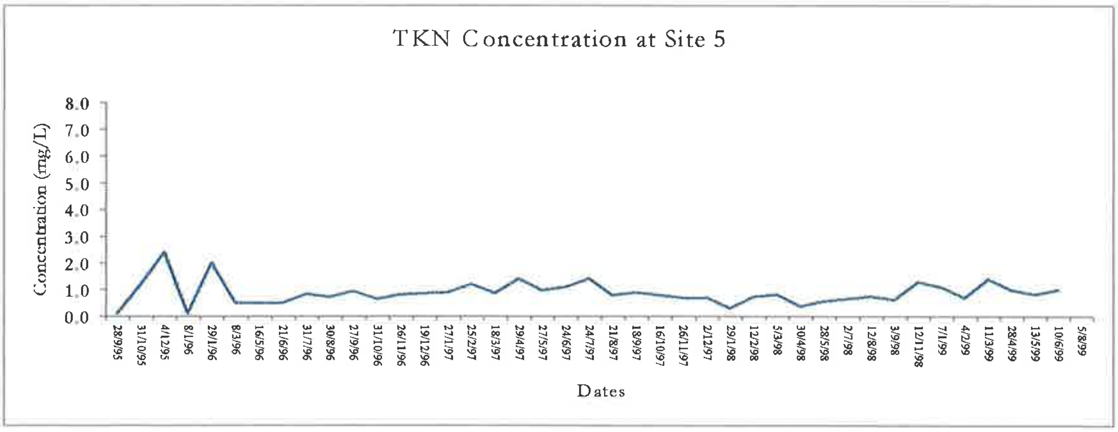

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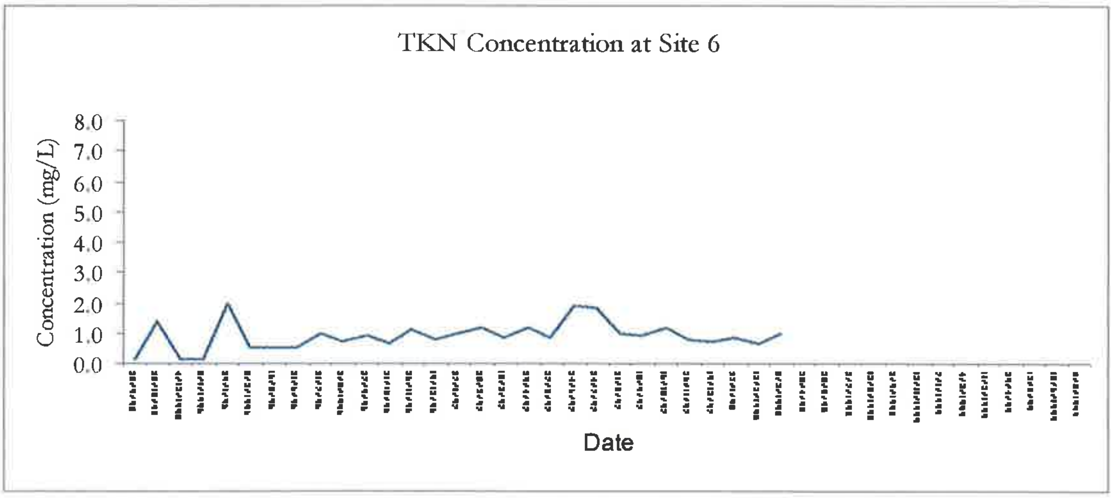

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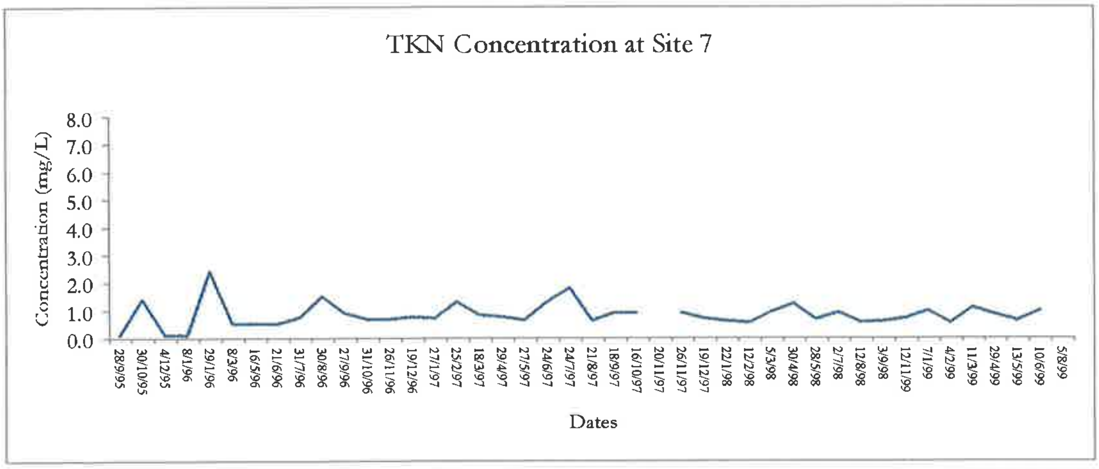
Figure 6.6 The Development of Total Kjedal Nitrogen (TKN) Concentration at sites 4, 5 and 6 from 28/9/1995 to the beginning of 5/8/1999.



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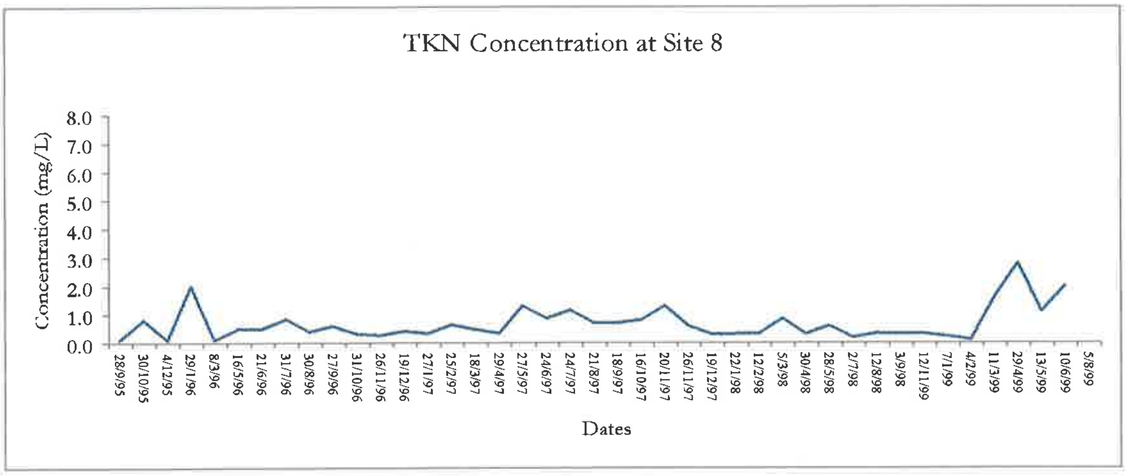

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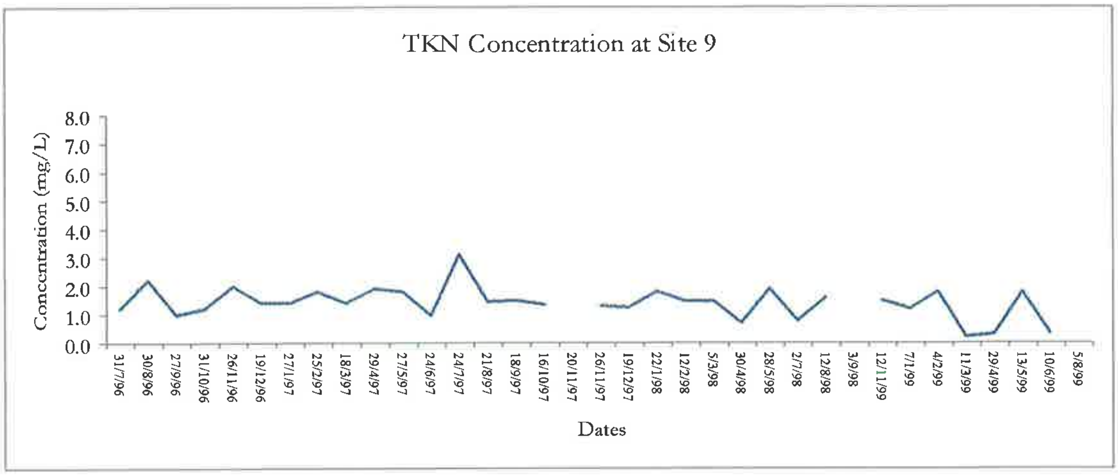
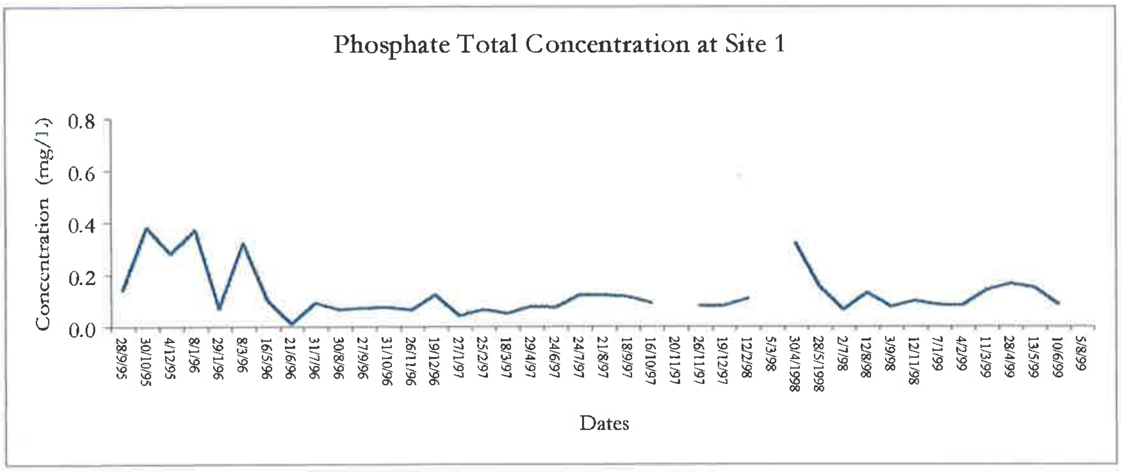
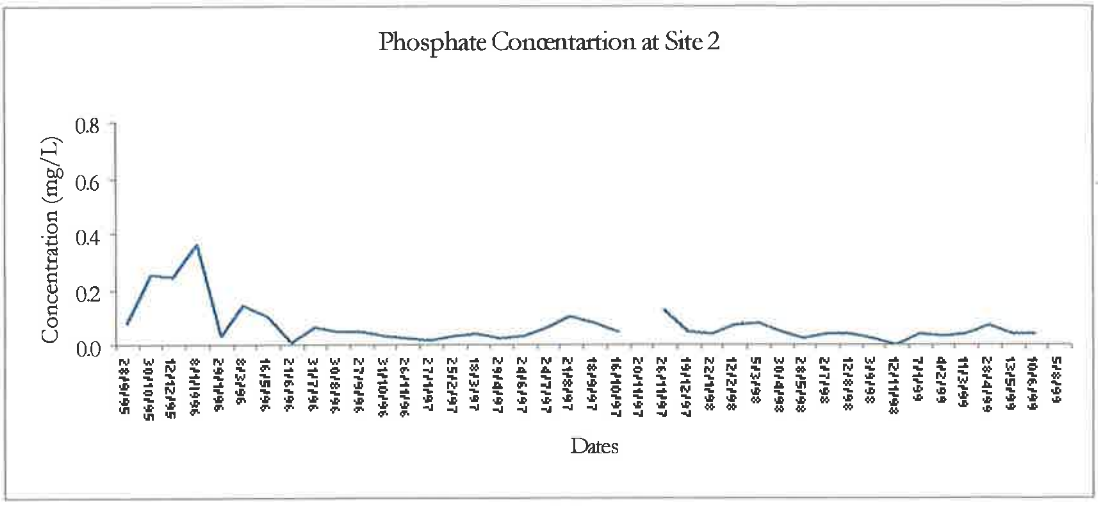


(i)

Figure 6.7 The Development of Total Kjedal Nitrogen (TKN) Concentration at sites 7, 8 and 9 from 28/9/1995 to the beginning of 5/8/1999.



(a)



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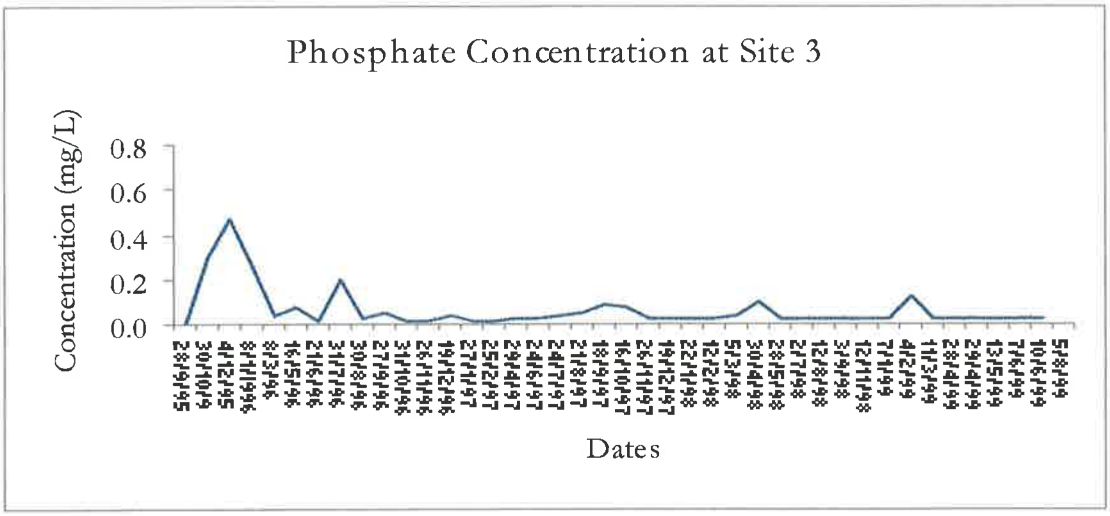
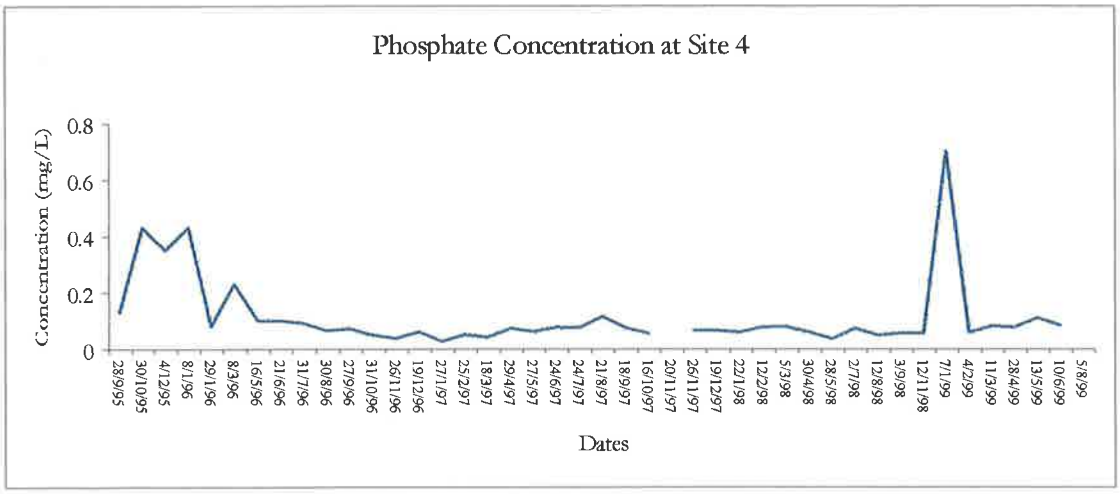


(c)

Figure 6.8 The Development of Total Phosphorus Concentration at sites 1,2, and 3 from 28/9/1995 to the beginning of 5/8/1999.



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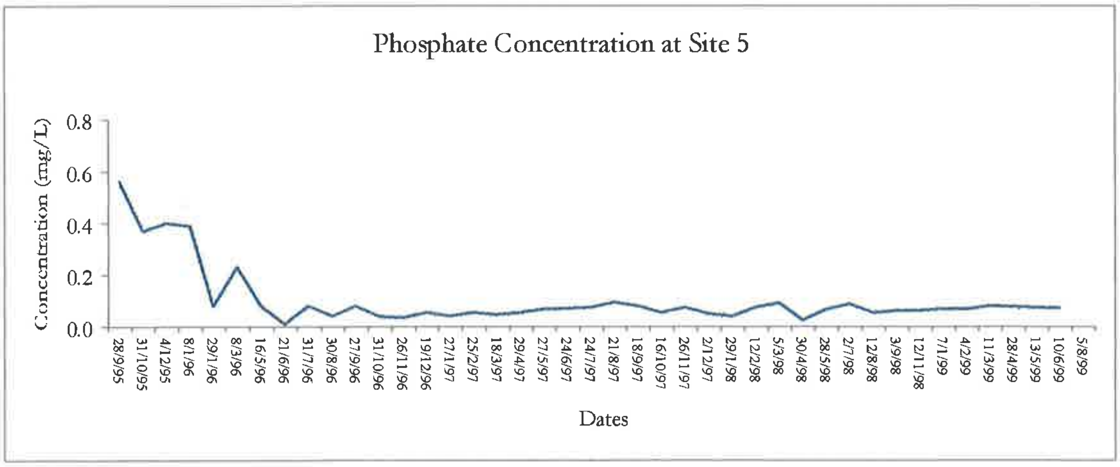

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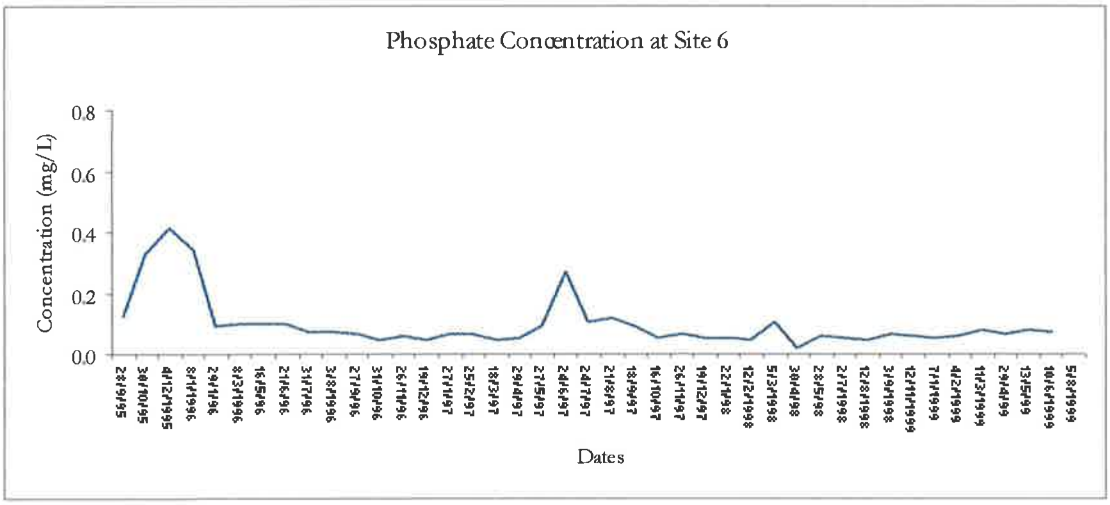

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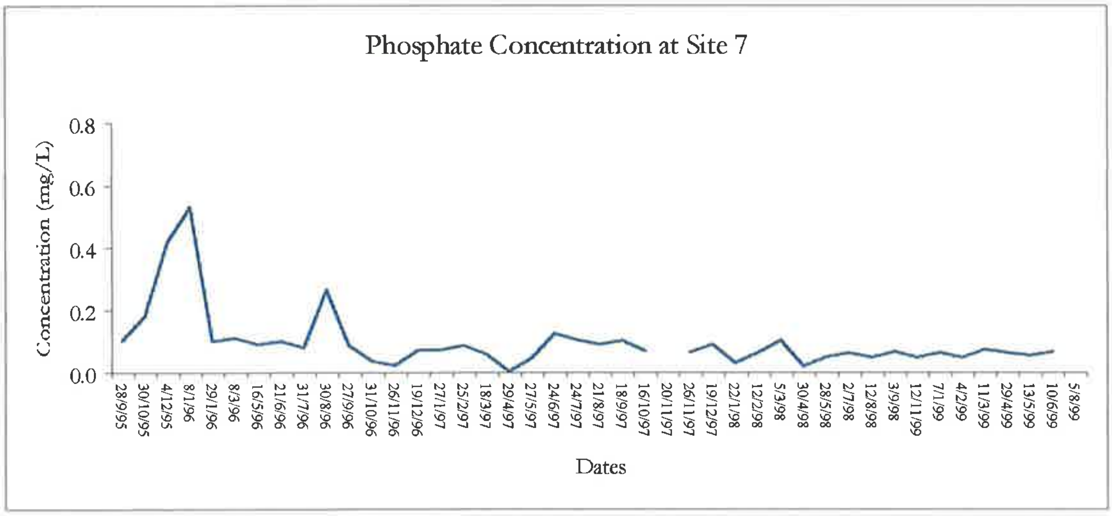
Figure 6.9 The Development of Total Phosphorus Concentration at sites 4, 5 and 6 from 28/9/1995 to the beginning of 5/8/1999.



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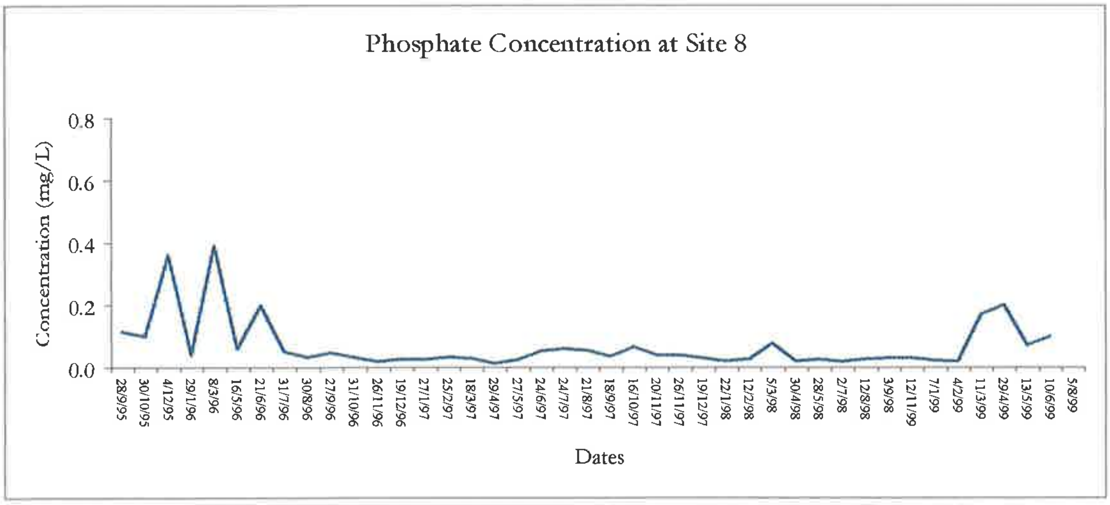

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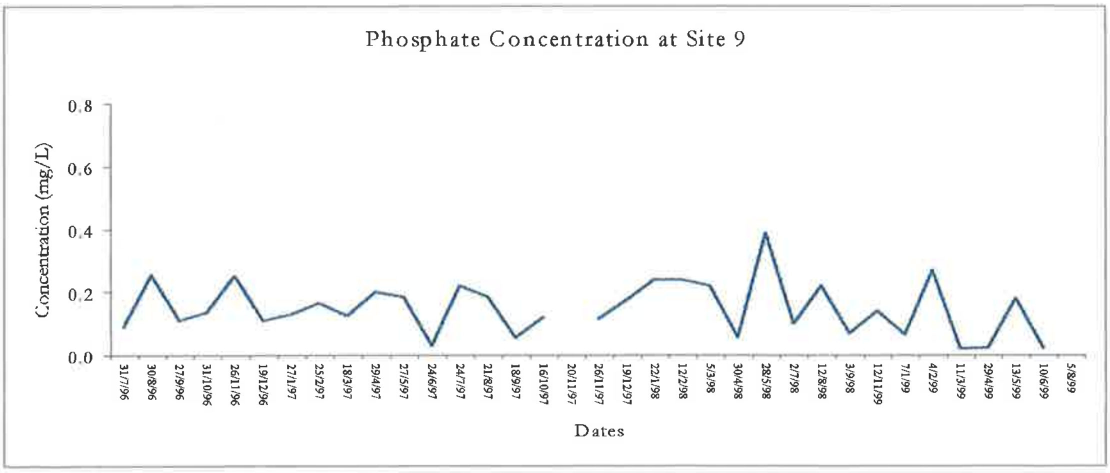
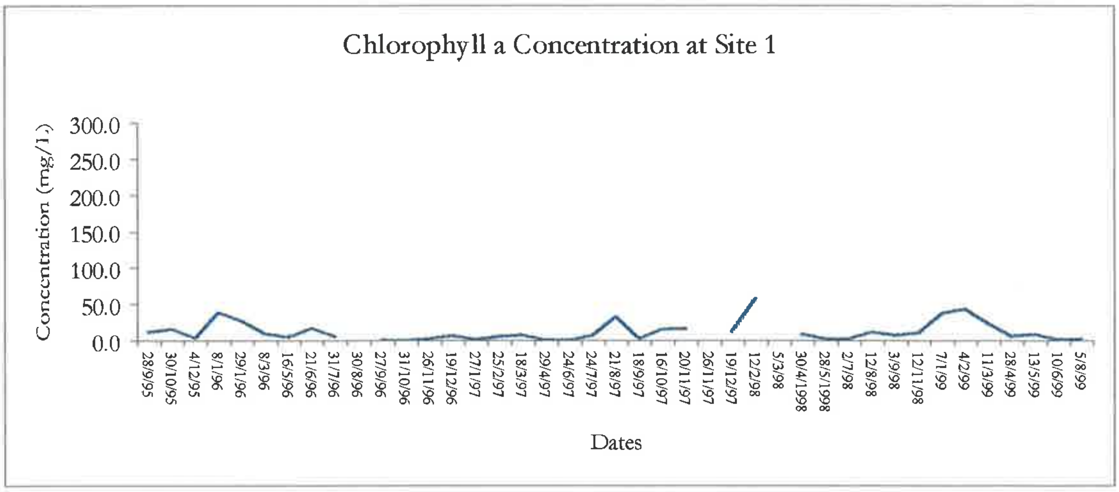
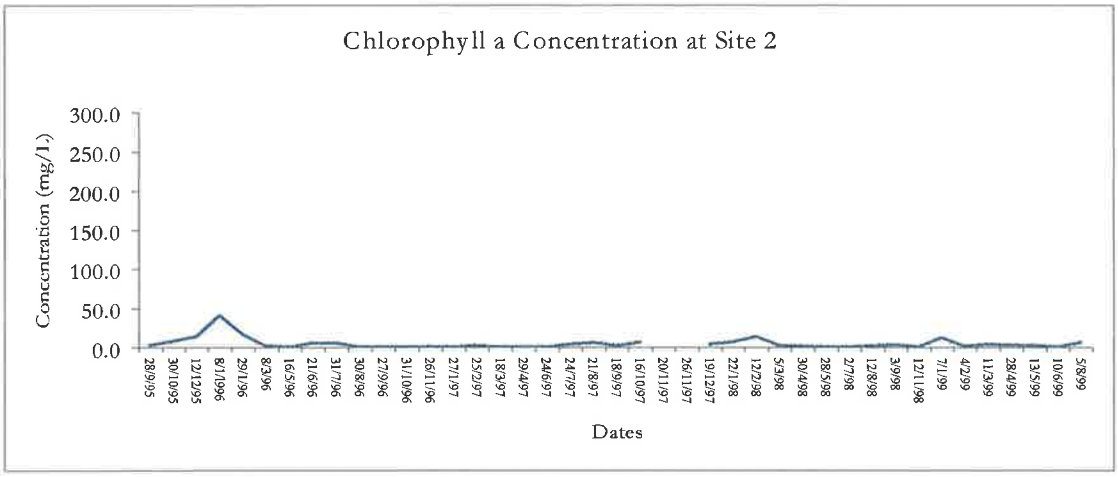


(i)

Figure 6.10 The Development of Total Phosphorus Concentration at sites 7, 8 and 9 from 28/9/1995 to the beginning of 5/8/1999.



(a)



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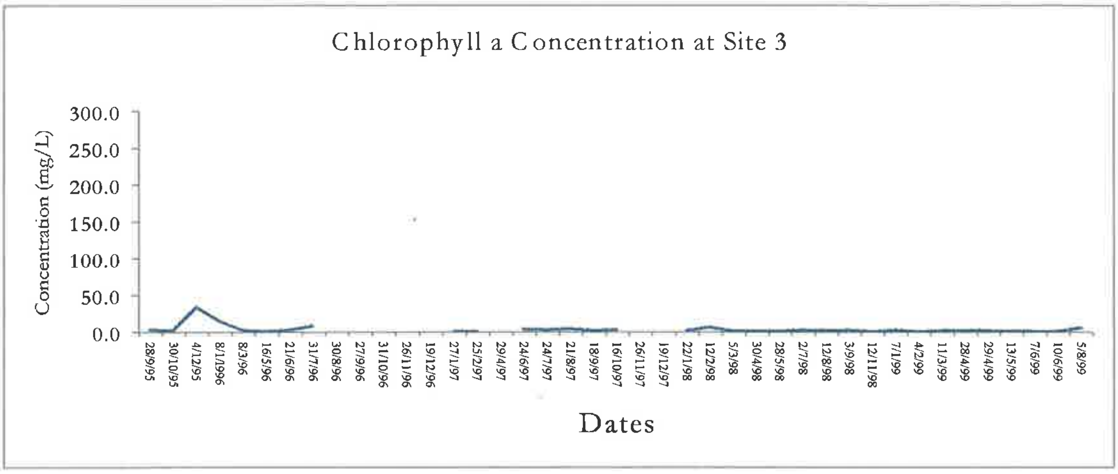
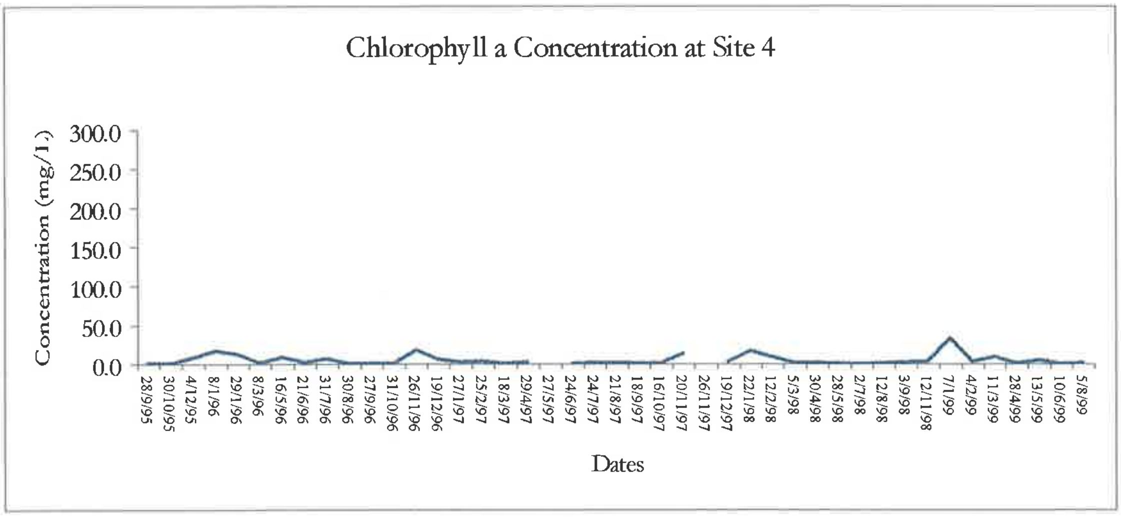


(c)

Figure 6.11 The Development of Chlorophyll a Concentration at sites 1, 2 and 3 from 28/9/1995 to the beginning of 5/8/1999.



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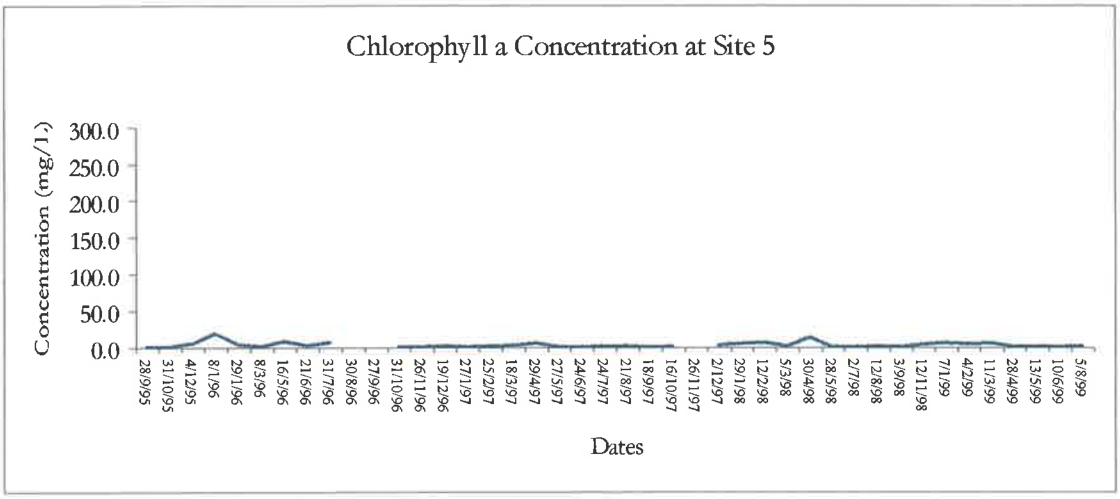

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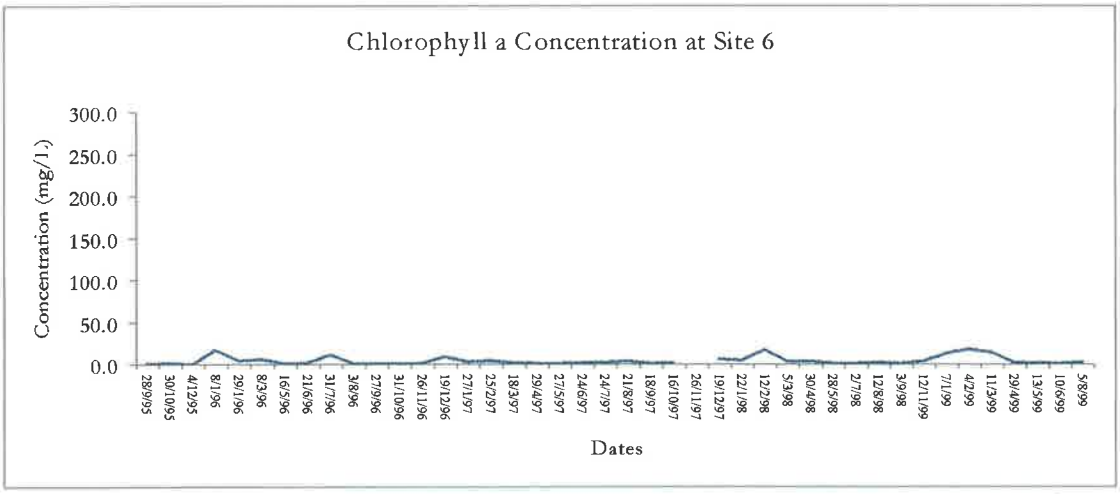
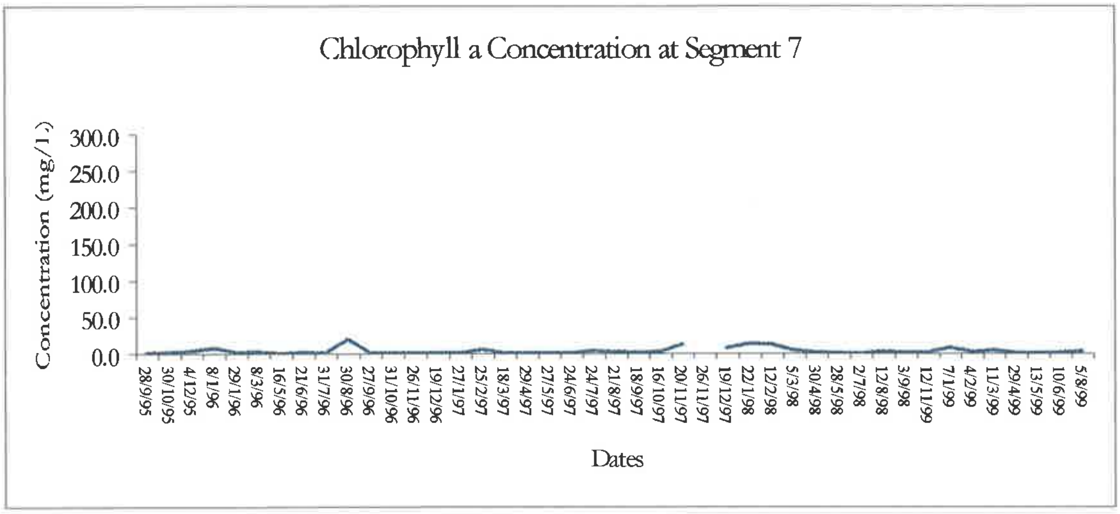
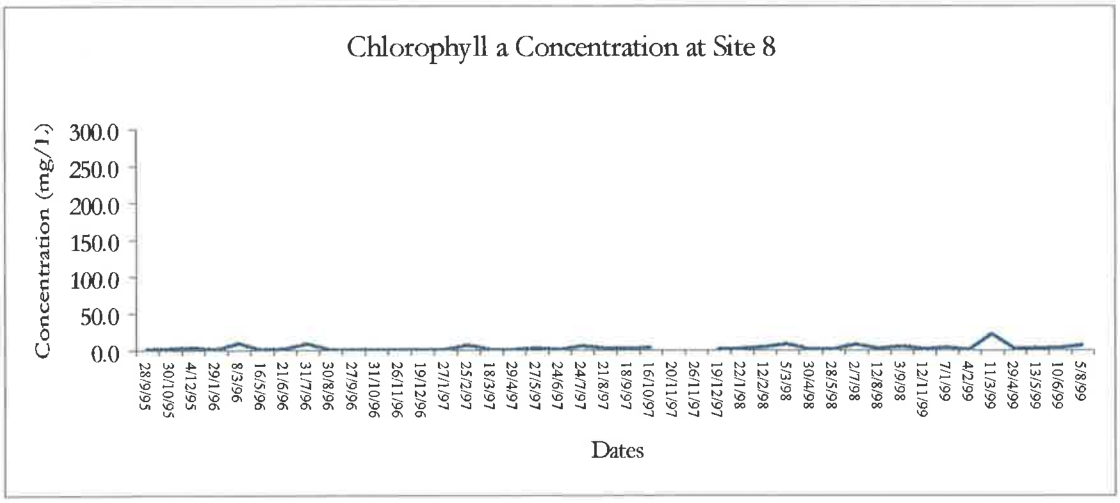


(f)

Figure 6.12 The Development of Chlorophyll a Concentration at sites 4, 5 and 6 from 28/9/1995 to the beginning of 5/8/1999.



(g)



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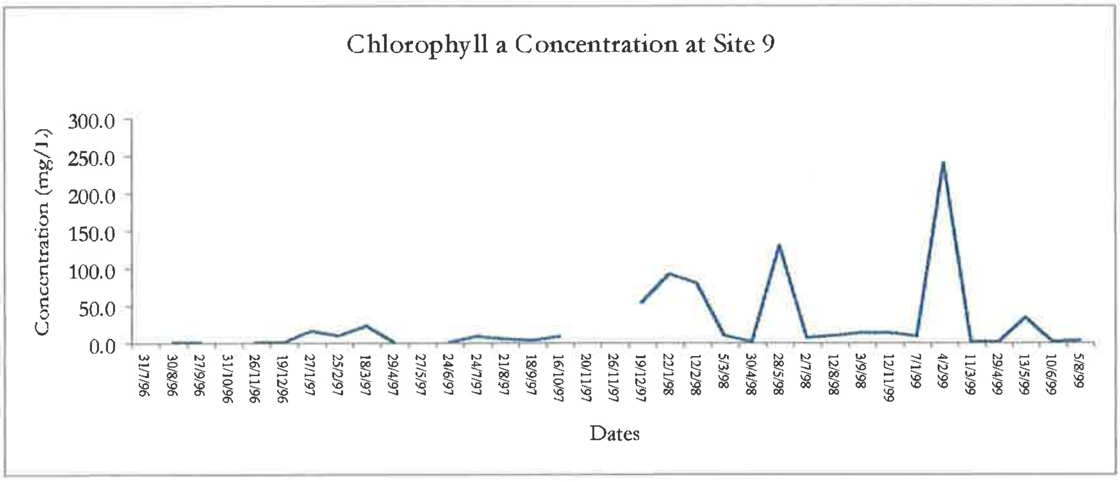


(i)

Figure 6.13 The Development of Chlorophyll a Concentration at sites 7, 8 and 9 from 28/9/1995 to the beginning of 5/8/1999.

As can be seen in figure 6.2 to 6.13, there are general pattern of water quality parameters in the study area. The following statements are a summary of general characteristics obtained from the analysis of available data:

(1) High concentration of Ammonia is often observed during the months of May to August for all nine observation sites, with the maximum concentrations in June and July. Low concentrations of Ammonia are usually observed in January. High concentration of Ammonia occurs in winter time. This may relate to higher winter loading of nutrients into the estuary;

(2) High concentration of Phosphate is generally observed during the months of December to January for all nine observation sites. Low concentration of Phosphate is observed in March and April. Summer and Autumn are two seasons having high concentration of Phosphate;

(3) High concentration of Total Kjeldal Nitrogen (TKN) is generally observed in July, August, November and December. Low concentration of TKN is generally observed in March to May. Therefore, high concentration of TKN occurs in the seasons of summer and winter;

(4) High concentration of Chlorophyll a is generally found in January, February and March or in summer times. Low concentrations are observed in July, August and September. This may indicate the importance of temperature for the growth of Chlorophyll a in summer. Comparing this pattern with that in Ammonia, it is clear that at the time when the concentration of Chlorophyll a is high, the concentration of Ammonia is low.

Considering the peaks of the concentration of water quality parameters, it is clear that:

(1) The concentration of Ammonia at two sites, that is, site 8 and site 9 is higher than the others. Bolivar Sewage Treatment Work (for site 8) and Port Adelaide Sewage Treatment Works are most likely to be the activities responsible for high concentration of Ammonia at these two sites;

(2) More peaks of Ammonia, Phosphate and TKN are observed for site 9 compared to other sites. Using visual comparison from these figures, water quality at site 9 is considered heavily polluted. Although little data are available for 1995 and 1996, higher concentration of Chlorophyll a could be expected to occur at this site. Port Adelaide Sewage Treatment Works is likely to be the main activity

responsible for this. Less frequent tidal flushing and high nutrient loading in site 9 may also affect this phenomena;

(3) Site 7 is of particular concern. The reason for this is that although this site is quite far from Bolivar Sewage Treatment Works outfall, it has a quite number of peaks of Ammonia, TKN and Chlorophyll a. There could be a number of reasons for this:
    (a) Tides may have affected the distribution of nutrients from Bolivar Sewage Treatment Work;
    (b) Little Para River and Dry Creeks may have contributed to nutrients into Barker Inlet;
    (c) The presence of the "parting" may have precluded water movement so that these sites (site 7 and site 8) could potentially have high concentration of nutrients. The mechanism of high nutrient status in site 9 may also apply to site 7.

The description of the characteristics of water quality parameters as shown above has clearly indicated that there are some factors that affect water quality conditions in the estuary. As explained, the seasons, the estuarine morphology, tides and varying loads can affect nutrient status spatially and temporally.

Figure 6.2 to 6.13 show the pattern of changes in water quality parameters. From these figures, it is possible to obtain some insights into the determination of possible sources of accumulation, of single or the combination of activities. For example, high concentration of Ammonia and Phosphate at site 9 suggests that the single activity responsible for this is the Port Adelaide Sewage Treatment Works.

Figure 6.2 to 6.13 show the use of trend analysis for analysing water quality parameters. Trend analysis, as one of methods for cumulative effect assessment, has proved to be useful for analysing water quality changes over time. Future projection could be conducted using this technique if there is a linear trend of impacts. This assumption, however, may be inappropriate considering the fact that the proposed activities may have different impacts to the environment. Changes in the estuary morphology because of dredging, for example may affect water quality. Another example will be that nutrient loading into the estuary from Bolivar Sewage Treatment Works, Port Adelaide Sewage Treatment Works and Penrice Soda Product and stormwater may not always be the same from one time to the other. As a result, using a linear projection of impacts may not be appropriate for estimating future impacts.

Prediction of future impacts due to the combination of present and future activities is the key component in the assessment of cumulative effects. Therefore, methods for the prediction of future impacts must be flexible meaning that the method should be capable of adjusting to changes in conditions. For example, if loading of nutrients to the estuary decreases or increases, the methods should be able to adjust to these changes. Trend analysis will not be capable of conducting this kind of analysis. Water quality modelling will be crucial in this regard. The following section will discuss the modelling of water quality.

6.3 Modelling Water Quality

6.3.1 Introduction

Chapter II has provided information about models of water quality. The model used in this study was WASP5 (Water Quality Analysis and Simulation Program version 5). The characteristic of this program is that this can be used for modelling water quality for a number of environment condition: ponds, streams, lakes, reservoirs, rivers, estuaries and coastal waters (Ambrose, Wool and Martin, 1993a). This software is designed for many areas of application and compared to other water quality models, the flexibility afforded by WASP5 is unique in that WASP allows modellers to conduct modelling in one, two and three dimension; allow the specification of time variable exchange coefficient, advective flows, waste loads and water quality boundary conditions and kinetic process (Ambrose, Wool and Martin, 1993a).

This software contains two stand-alone computer programs, DYNHYD5 and WASP5, which can be run in conjunction or these can be run separately. The movement of water is simulated using DYNHYD5, while the WASP 5 simulates the movement and interaction of pollutants within the water (Ambrose, Wool and Martin, 1993a: 2).

The following formula is the basic of WASP5 program. As can be seen, there are many components which are considered in WASP5: advection, diffusion, direct and diffuse loadings, boundary and the kinetics transformation.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z}) + S_L + S_B + S_K$$

(Source: Ambrose, Wool and Martin, 1993a: 4-5)

In which:

C = Concentration of Water Quality Constituents (mg/L)
t = Time, day
U_x, U_y, U_z = Longitudinal, lateral and vertical advective velocities (m/day)
E_x, E_y, E_z = Longitudinal, lateral and vertical advective velocities coefficients (m/day)
S_L = Direct and diffuse loading rates (g/m3-day)
S_B = Boundary Loading rate (including upstream, downstream, benthic and atmospheric)
S_K = Total Kinetic Transformation rate, positive in sources and negative in sinks

DYNHYD5 and WASP5 models were used for simulating eutrophication. Eutrophication in the study area will be modelled by considering the movement of the tides and this was modelled by using DYNHYD5. Water quality parameters were modelled by using EUTRO5, a subprogram of WASP5. There are three levels of complexity for analysing eutrophication using WASP5 (EUTRO5):

(1) simple eutrophication kinetics;
(2) intermediate eutrophication kinetics;
(3) intermediate eutrophication kinetics with benthos.

At the outset, simple eutrophication kinetics was employed because Dissolved Oxygen (DO) data were not available. The results, however were not showing the patterns of the observed data. For this reason, intermediate eutrophication kinetics with benthos without DO was employed with one additional benthic segment. Ambrose, Wool and Martin, (1993a: 111) state that simulating benthic interactions requires the addition of benthic segments to the model network.

For the purpose of modelling water quality using WASP5, segments and channels need to be defined. For this reason, the estuary was divided into a number of segments, and channels are then determined from the configuration of segments. Determining the most appropriate configuration of segments was based on the expected spatial variability of water quality concentrations, which can be inferred from the existing values of nine locations of water quality samples. Spatial distribution of depth, the locations of water quality samples, the locations of effluents and the morphology of the estuary are other components that were used for the determination of segments and channels. Segment and channel determination was also conducted in part by trial and error. This means that after having the configuration of segments and channels, all data were input, and then DYNHYD5 and EUTRO5 were run. If the results were not in agreement with the observed data, then changes to the configuration of segments and channels were made. Significant effort went into the construction of segments and channels, which would produce the most reasonable results of predicted water quality parameters. However, a balance must be achieved between the configuration of the segments and channels and the time taken to run the model.

6.3.2 Data for Hydrodynamic and Water Quality Modelling

There are significant amounts of input data required for DYNHYD5 and WASP5. Because of the fact that the data were not always available, some of the input data required for this model were derived from interpolating the values in nine sites sampling locations by using Geographical Information Systems (GIS), while others were derived from existing literature on water quality studies and some estimated data were obtained from interviews.

The following figures (Figure 6.14 to Figure 6.18) are the characteristic of water quality, e.g. NH3 as Nitrogen, oxidized Nitrogen, Total Phosphorus and TKN, in Port River Estuary. These figures were drawn from survey data by Steffensen and Walter

(1980) for Port River only, as there were no similar data for Barker Inlet. The location of samples in their study in comparison with those from Environmental Protection Agency (1997) can be seen in Figure 6.19.

These figures (Figures 6.14 to 6.18) are considered important for additional information in the selection of the level of the complexity of the models and can be the source of information guiding the modelling efforts. These figures were from site 2 only from the study by Steffensen and Walter (1980), although another two sites were available for comparison. The main reason for this was to show whether there existed different concentrations according to depths.

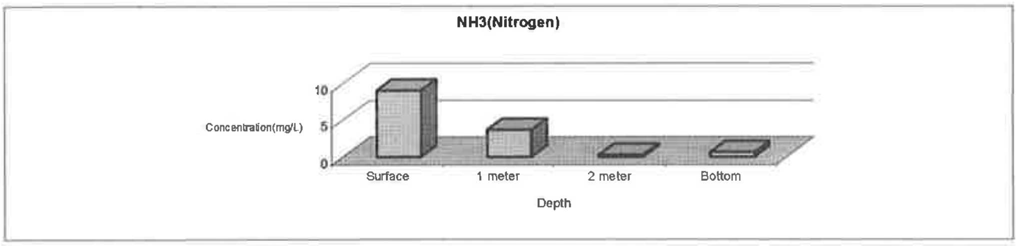


Figure 6.14 Concentration of NH3 as N with depth from site 2 in Port River (Sources of data: Steffensen and Walters, 1980).

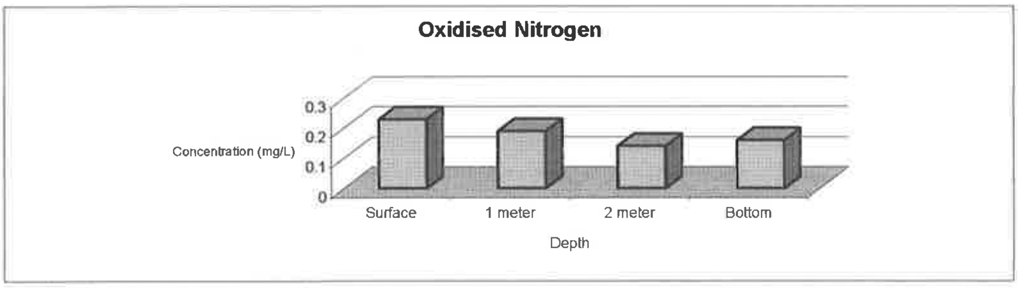


Figure 6.15 Concentration of oxidized Nitrogen with depth from site 2 in Port River (Sources of data: Steffensen and Walters, 1980).

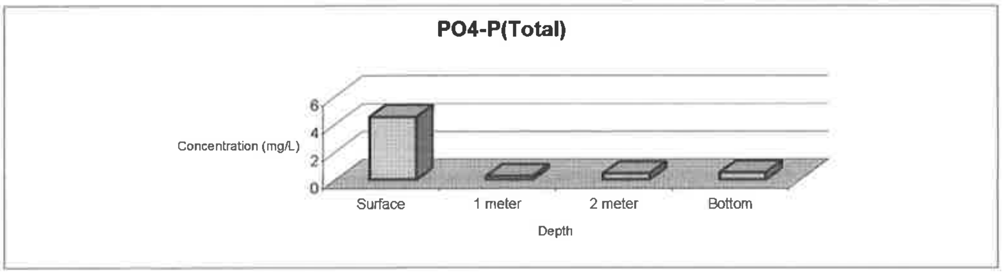


Figure 6.16 Concentration of PO4-P(total) with depth from site 2 in Port River (Sources of data: Steffensen and Walters, 1980).

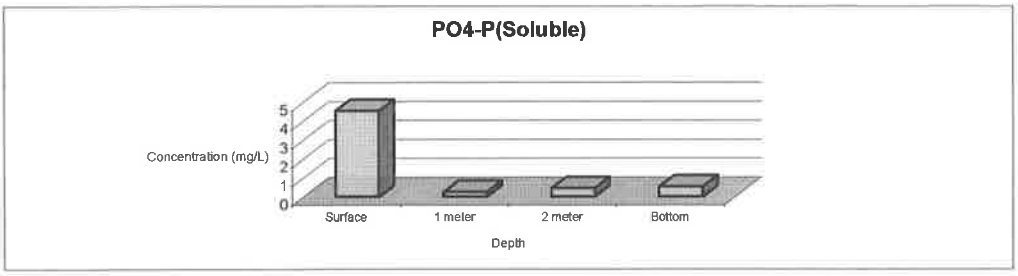


Figure 6.17 Concentration of PO4-P(soluble) with depth from site 2 in Port River (Sources of data: Steffensen and Walters, 1980).

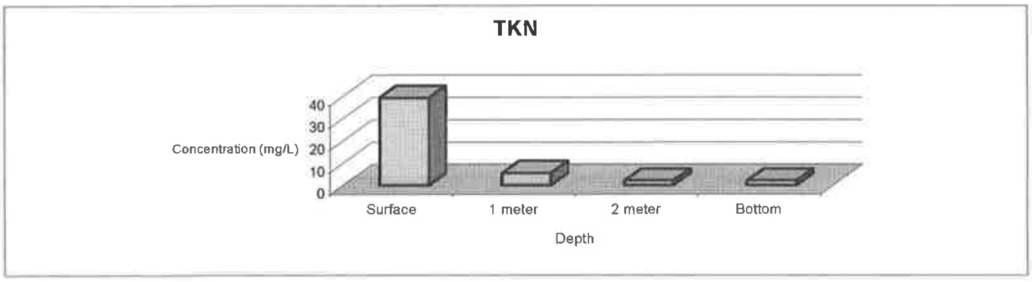
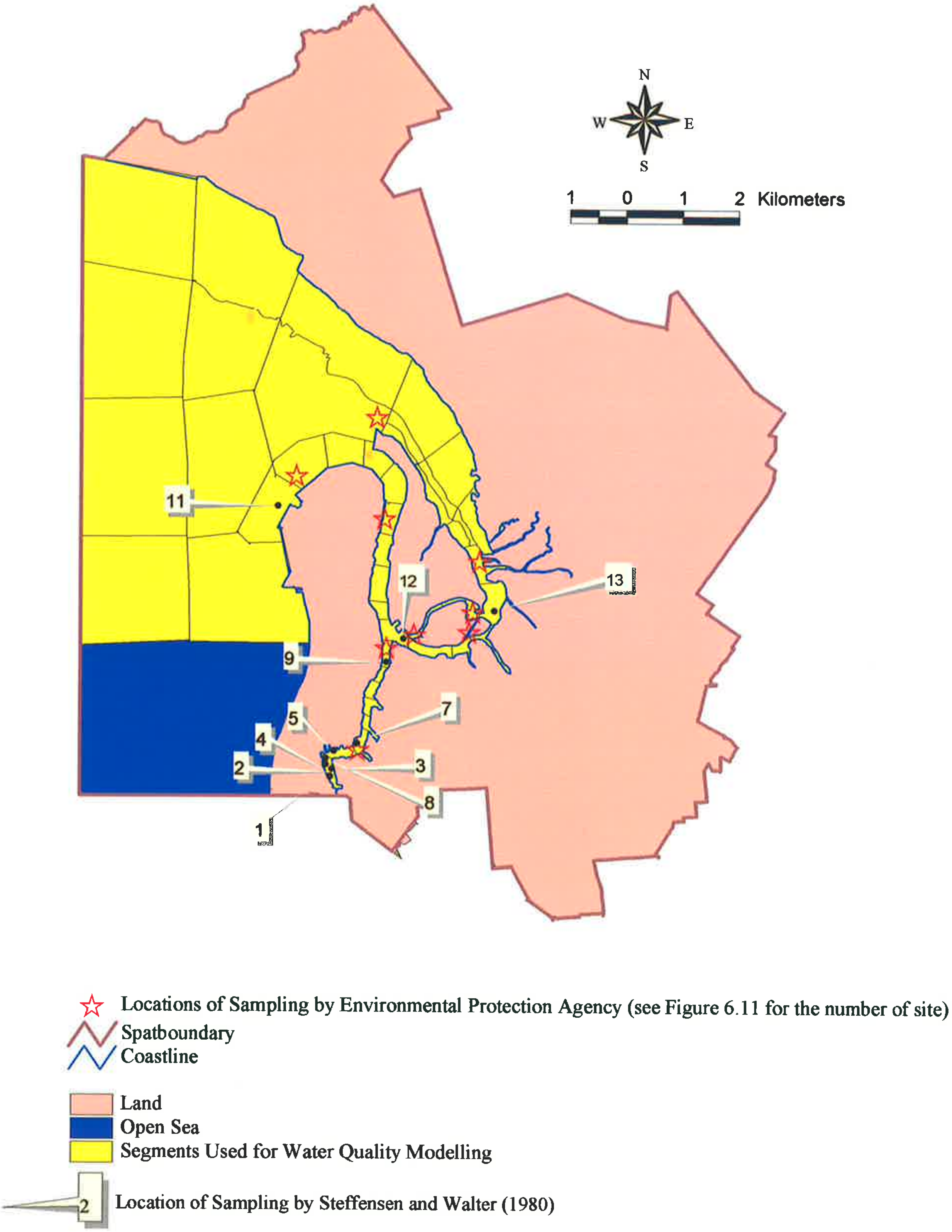


Figure 6.18 Concentration of TKN with depth from site 2 in Port River (Sources of data: Steffensen and Walters, 1980).

Considering these figures, it is clear that there are concentration differences among depths. These figures were also used as the sources of information for initial conditions for benthic sediment segments. As shown, there is a different concentration of Ammonia, TKN, Phosphate and oxidised Nitrogen in accordance with the depth in the Port River Estuary.

The following explanation relates to the processes of obtaining and analysing data used for DYNHYD5 andWASP5. Ambrose, Wool and Martin (1993b) list the data required for DYNHYD5 and EUTRO5 which is summarised in Table 6.1 below. All of the data listed in Table 6.1 must relate to segments and channels. Ideally, every segment and channel should have available data on physical parameters and water quality data, but the existing data are considered incomplete to be input into segments. For this reason, the existing data must undergo pre-processing before they are input into the model. In this regards, Geographical Information Systems (GIS) is a useful tool.

Figure 6.19 The Locations of Samples from the Study by Steffensen and Walters and those Environmental Protection Agency



Arc/INFO version 8.1 and Arcview version 3.2 are the two GIS software programs used in this research. These were used interchangeably depending on the analysis conducted. Table 6.1 shows data for input into DYNHYD5 and WASP5 models. As can be seen, there are 12 groups data for DYNHYD5, while 10 for WASP5. A detailed description of these data groups can be seen in Ambrose, Wool and Martin (1993b,c).

Table 6.1 Data Input for DYNHYD5 and EUTRO5
(Source: Summary from Ambrose, Wool and Martin, 1993a, b,c)

Data Group for DYNHYD5	Name of Data Group	Data Group for EUTRO5	Name of Data Group
A	Simulation Control	A	Model Identification and Simulation Control
B	Printout Control	B	Exchange Coefficient
C	Hydraulic Summary	C	Volumes
D	Junction Data	D	Flows
E	Channel Data	E	Boundary Concentration
F	Inflow Data	F	Waste Loads
G	Seaward Boundary Data	G	Parameters
H	Wind Data	H	Constants
I	Precipitation/Evaporation Data	I	Kinetic Time Functions
J	Variable Junction Geometry Data	J	Initial condition
K	Variable Channel Geometry Data		
L	WASP5 Junction to Segment Map		

Each data required for DYNHYD5 and the processes to obtain them can be explained as follow.

(1) Aerial Photographs (APs) were obtained from Mapland at the scale of 1: 10000. 1997 APs were used to derive segments (junctions) and channels. Intepretation of these APs was mainly aimed at establishing the segments for the modelling. The channels were then determined based on the segments. Ambrose, Wool and Martin (1993c) provide guidelines for producing segments and channels. The channels were drawn by connecting two adjacent junctions (segments). The segments used in this study can be seen in Figure 6.20.

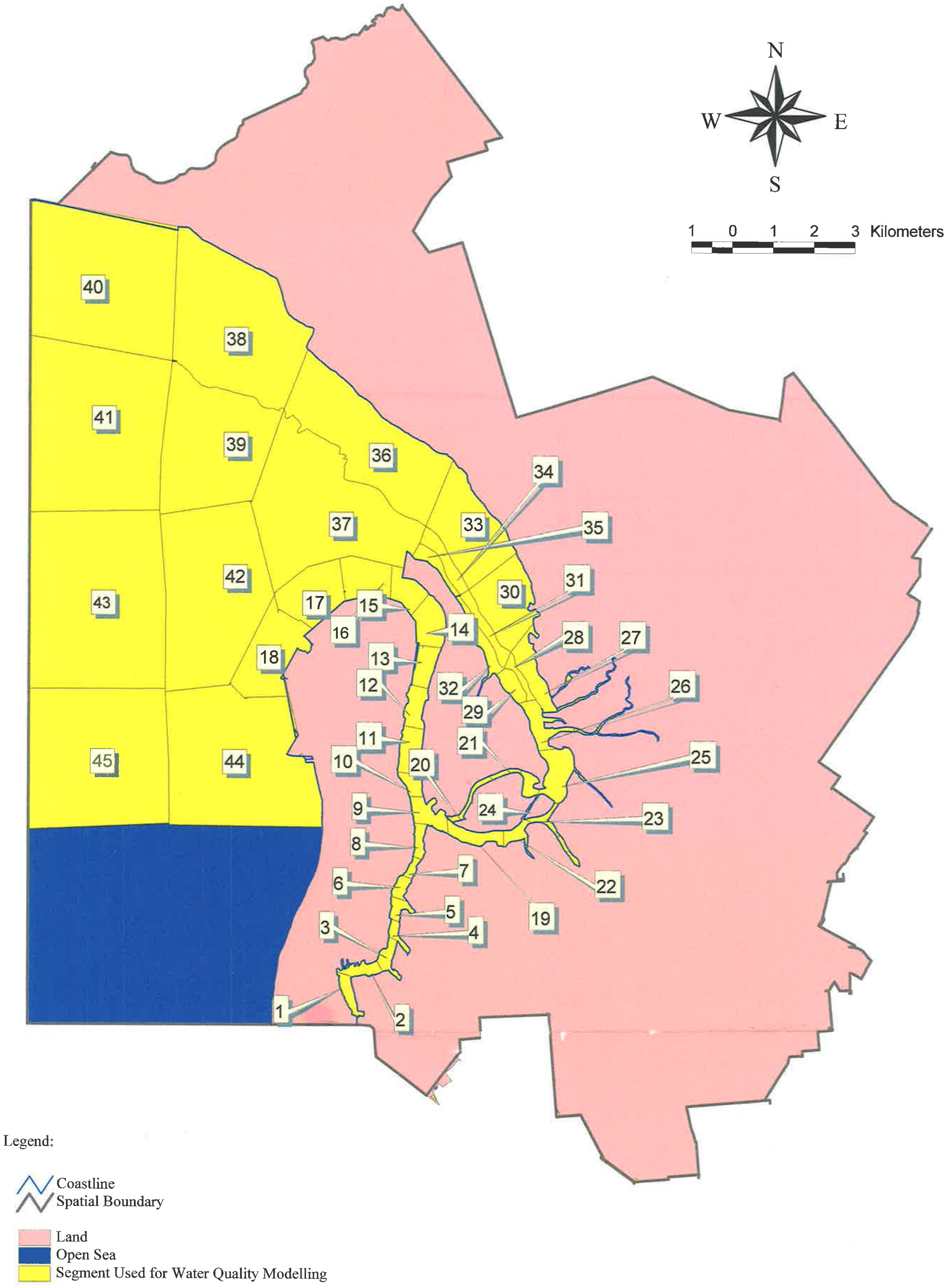
(2) Data Groups A, B and C in DYNHYD5 are mainly for input control data, and will not be described in detail. The time step for running DYNHYD5 was 30 seconds.

(3) Data Group D in DYNHYD5 is that for inputting segment (junction) related data. Geographical Information Systems (GIS) were used to derive some data related to segments and channels, such as junction number, initial head, surface area and bottom elevation. Data Group E is that for inputting channel related data, such as: length, width, direction, depth of channels. Some of these were also derived from GIS. For Data Group E, the velocity of channels is an important component. Data on velocity of channels for DYNHYD5 input were obtained from a study conducted by KINHILL (1989). In their report, there is a map (as shown in Figures 3.4 and 3.5 in Chapter III) which portrays the velocity of tide entering and leaving Port River Estuary and Barker Inlet. The velocity of tides leaving the estuary is about the same as that entering the estuary (Bennet, pers. Comm., 2000). In addition, the report by D. A Lord and Associates Pty. Ltd. (1996) also provided information about tide velocities for Barker Inlet and Port River Estuary. They claim that the flow in the Port Adelaide River is generally parallel to the shore, and current velocities vary from 0.05-0.1 m/s in the upper reach to 0.25-0.3 m/s in the lower reach. On the other hand, current velocities in Barker Inlet can be up to 0.8m/s. In fact, this report provided similar information to that study by KINHILL (1989). Therefore, the assumption used was that any velocity values entered into DYNHYD5 model is valid from any data within this range. Velocity data were input into DYNHYD5 model (Data Group E, as part of channel data);

(4) Inflow data (Data Group F) were obtained from the study conducted by D. A Lord and Associates Pty. Ltd. (1996);

(5) Seaward Boundary Data (Data Group G) consists of some components, such as number of seaward boundaries, number of data points and a scale factor. Tide data were obtained from Tide Tables. These provide times and heights for tides. Discussion with people in the National Tide Facility (NTF) was also conducted. There is only one tide observation in the study area, that is the Port River estuary;

Figure 6.20 Segment (Junctions) Used for Water Quality Modelling



(Source: Analysis in GIS)

(6) There were no data entered into Variable Junction Geometry Data (Data Group J) and Variable Channel Geometry Data (Data Group K);

(7) The guidelines given by Ambrose, Wool and Martin (1993c) were used for inputting Data Group L (WASP5 Junction to Segment Map).

The data required for WASP5 (see Table 6.1) and the processes for obtaining these data are explained below.

(1) Data Group A is mainly the Model Identification and Simulation Control. The most important component of this data is time steps. Because DYNHYD5 and EUTRO5 were integrated, the time step was set automatically by WASP5 by considering the time step in DYNHYD5;

(2) Data Group B is the Exchange Coefficient. This coefficient is computed from input dispersion coefficient, cross sectional areas and characteristics lengths (Ambrose, Wool and Martin, 1993b);

(3) The calculation of volume (Data Group C) was obtained from the multiplication of surface area (in m^2) and the depth (m);

(4) The flow data (Data Group D) were obtained from the results of hydrodynamic modelling. The process of integrating the results of hydrodynamic modelling to EUTRO5 sub-model can be seen in Section 6.4.

(5) Sinking velocity of phytoplankton refers to Chapelle, Lazure and Menesguen (1994:534) who proposed sinking velocities of phytoplankton of 0.7 m/day;

(6) Boundary condition data (Data Group E) were obtained from the segments having observation sites. In this case, the values from observed data were input into the closer segments having no observation data. For the segments located farther from the sampling locations, the values resulted from interpolation were used;

(7) The most crucial data for water quality modelling is nutrient loading data (Data Group F in WASP5) because these data were used for running scenarios and due to the fact that the most significant issue in the study area is excessive nutrients. Loading data were obtained from estimated loads from the study conducted by MFP-Adelaide Management Board (see Figure 6.21) in Banham (1992) was also consulted. Load data from Penrice Soda Products (PSP) could not be obtained because of confidentiality, therefore, loads of PSP was estimated to be the same as that of Port Adelaide Sewage

Treatment Works, as the study by D.A Lord and Associates Pty. Ltd. (1996) suggested. The report by D.A Lord and Associates Pty. Ltd. (1996) was another source of information for loads entering the estuary from Penrice Soda Products, stormwater and rivers (see Appendix 1). No data were available for non-point sources;

(8) Environmental Parameters (Data Group G in WASP5) were obtained from Ambrose, Wool and Martin (1993b);

(9) The values of environmental constants (Data Group H in WASP5) were obtained from previous studies on water quality modelling. Table 6.2 provides the values and the literature from which the values are obtained. For the parameters which have a large range of values in the literature, experiments with the model were conducted so that the predicted values approach the observed ones. The name of constants and parameters and their selection were based on the complexity of eutrophication model selected (Ambrose, Wool and Martin. 1993a). Averaged values are input into WASP5 model;

(10) Wind parameters, such as velocity and direction were obtained from Bureau of Meteorology. Average values were entered in model for wind velocity. Wind parameters were not entered in DYHNHYD5, but were entered as part of WASP5 input data set (Data Group I). Averaged temperature were also input into this data group. GIS provides techniques to conduct spatial interpolation;

(11) The spatial interpolation techniques used in this research was kriging. The reason for using kriging is the fact that "it is optimal interpolator in the sense that the estimates are unbiased and have know minimum variance" (Oliver and Webster, 1990:317). This technique was very useful, particularly for obtaining data for segments with no observation sites from adjoining segments that do have observation sites for Data Group J in WASP5. There are only 9 locations of sampling, whereas the number of segments used was 45. The cell size used for interpolating water quality parameters and depths was 50 meters. Data on the location of water quality samples were obtained from Department of Environmental Heritage and Aboriginal Affairs

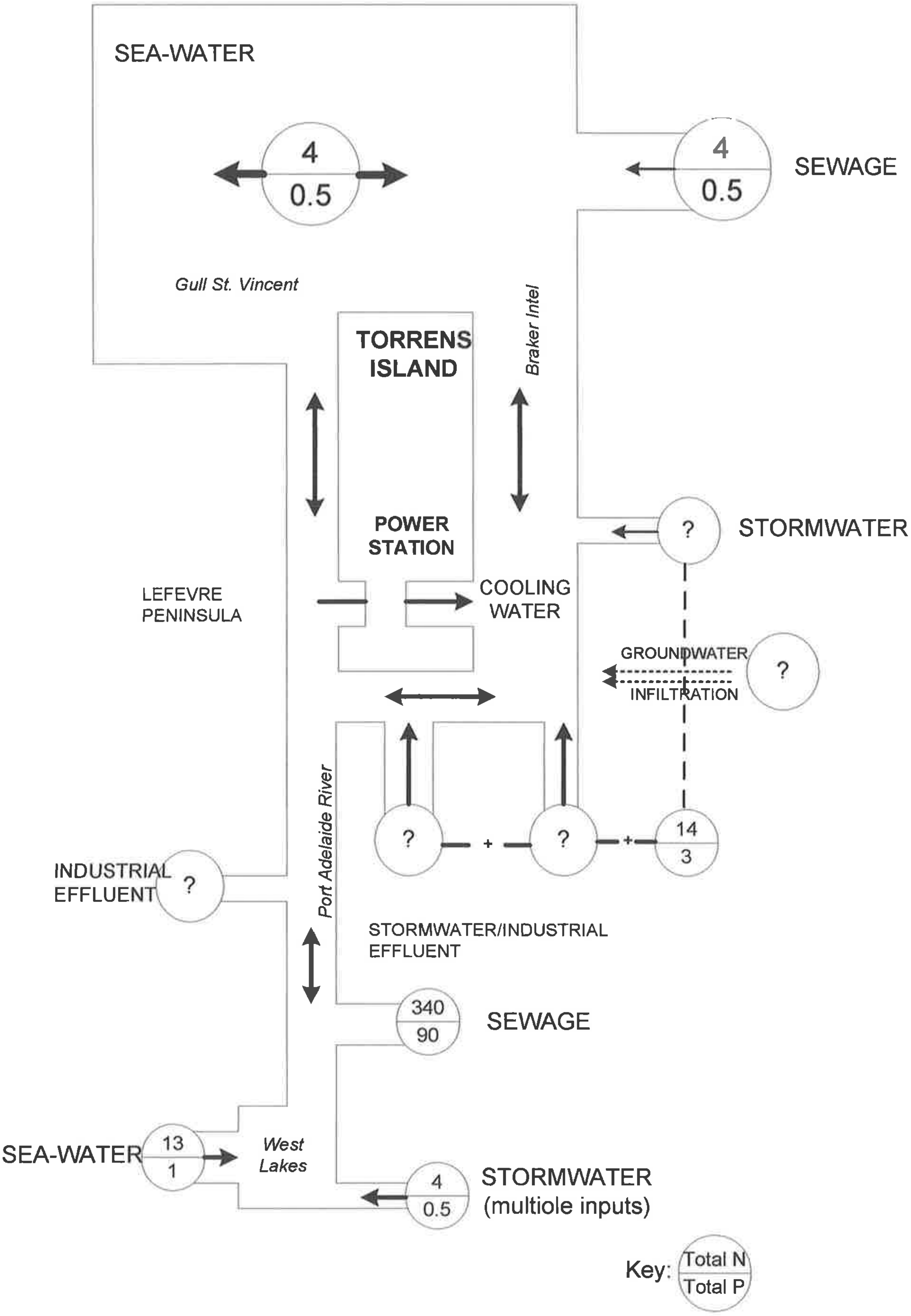


Figure 6.21 Estimated Nutrient Loading (Source: MFP-Adelaide Management Board, 1991 in Banham, 1992)

(DEHAA). The values of four water quality parameters used from 1995 to the beginning of 1999 can be seen in Appendix 2.

6.3.3 Validation of Models

The Manning Roughness Coefficient (n), as part of the input data in DYNHYD5 was used to tune the model so that the calculated values of velocity and tide height (m) approach the observed values. The water quality model, EUTRO5 was calibrated against the values of environmental constants.

Jansen and Heuberger (1995) proposed validation measures and these measures are: average error, normalized average error, fractional mean bias, relative mean bias, fractional variance, variance ratio, Kolmogorov-Smirnov, root mean square error, normalized RMSE, Index of agreement, alternative index of agreement, mean absolute error, maximal absolute errors, median absolute error, upper quartile absolute error, ratio of scatter, modelling efficiency and regression quantities.

This study used the "Index of Agreement (IoA)" as the measure to validate the models. The reason for using this index is that the main emphasis will be to find patterns. Bacsi and Zemankovics (1995:256) claim that the use of IoA has the following advantages compared to the regression analysis as follow:

> One of the advantage of using this index is that the result it gives is in good correspondence with the subjective opinion formed after simply looking at a plot of model results and observations. It also takes into account the magnitude of the observation through observation average in the equation, and greater allowance is made for variables which are supposed to have higher values.

The formula for IoA is below.

$$IoA = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} \left(\left| P_i^{'} \right| + \left| O_i^{i'} \right| \right)^2}$$

in which:

P_i = Predicted value;
O_i = Observed value;
$P_i' = P_i - \bar{O}$;
$O_i' = O_i - \bar{O}$;
$\bar{O}$ = the mean of observed value

(Sources: Jansen and Heuberger, 1995:63)

While IoA was used to calibrate the models, average error was employed to assess the model accuracy. Ambrose and Roesch (1982) in Martin and McCutheon (1999:81) used the following formula for average error. If $E_a > 0$, the model systematically over-simulates and if $E_a < 0$ the model systematically under-simulates the response of natural system.

$$E_a = \frac{1}{N}\sum_{i=1}^{N}(O_i - S_i)$$

In which,

O_i = observation
S_i = simulated values
N = total number of observation

The value of calculated IoA is within the range of 0 to 1. A zero value indicates that the observed and predicted value completely disagree each other, whereas the value of 1 (or close to 1) will suggest that there is agreement between the observed and predicted values. If there is a strong agreement between observed and predicted values, then the model was considered validated and can be used to predict of the impacts of future activities on water quality. The calculation of IoA was conducted for all predicted values that had observed values to be compared for all segments in the estuary.

Table 6.2 Environmental Constants Obtained from Previous Studies

No.	Constant Symbols	Description	Range of Values	References	Values Used
(1)	(2)	(3)	(4)	(5)	(6)
1	K1C	Saturated growth rate of phytoplankton	0 – 0.3	DiToro, et al. (1977);	0.3
2	NCRB	Nitrogen to Carbon Ratio in Phytoplankton	0.2 – 0.25	Yassuda, et al. (2000); Ambrose, Wool and Martin (1993b)	0.25
3	IS1	Saturated light intensity for phytoplankton	150 - 550	DiToro, et al.(1977); Ambrose, Wool and Martin (1993b); McEwan et al. (1998);	300
4	KMPHY	Light formulation switch	Default = 0.0	Ambrose, Wool and Martin (1993b)	0
5	K1T	Temperature Coefficient	0.98 - 1.08	Yassuda, et al. (2000); Tufford and McKellar (1999) Ambrose, Wool and Martin (1993b)	1.08
6	K1RC	Endogenous respiration rate of phytoplankton at 20°C	0.02 – 0.60 (most values are between 0.05 –0.20)	Tufford and McKellar (1999); Bowie, et al.(1985) in Ambrose, Wool and Martin (1993b)	0.02
7	K1RT	Temperature Coefficient for Phytoplankton Respiration	1.045 – 1.1	Tufford and McKellar (1999); Di Toro and Matysik (1980) in Ambrose, Wool and Martin (1993b)	1.045

(1)	(2)	(3)	(4)	(5)	(6)
8	KMPG1	Phosphorusus half-saturation constant for phytoplankton growth	1.0	Yassuda, et. al. (2000)	1.0
9	K1G	Grazing rate of phytoplankton	1.5 – 2.0	Kishi and Ikeda (1986);	0.001
10	PHMIX	Maximum yield constant	Default = 720	Tufford and McKellar (1999)	720
11	XKC	Chlorophyll extinction coefficient	0.016 - 5	Tufford and McKellar (1999); Kishi and Ikeda (1986); Yassuda, et al. (2000);	0.016
12	CCHL	Carbon to Chlorophyl ratio	0.01 – 250	Jin, Egashira and Chau (1998:233) Kishi and Ikeda (1986); Di Toro, et. al.(1978); Ambrose, Wool and Martin (1993b); Yassuda, et al. (2000); Lee, et al. (1990) in Jin, Egashira and Chau (1998).	29
13	KMNG1	Nitrogen half-saturation constant for Nitrogen for phytoplankton growth	0.015-0.025	Tufford and McKellar (1999);	Calibrated = 0.5
14	K1D	Non-predatory phytoplankton death rate	0.03	Yassuda, et al. (2000)	0.03
15	K12 T	Temperature coefficient for Nitrification	1.04	Yassuda, et al. (2000)	Calibrated = 2.0
16	K12C	Nitrification rate at 20°C	0.3	Yassuda, et al. (2000)	Calibrated = 0.2

(1)	(2)	(3)	(4)	(5)	(6)
17	KNIT	Half saturation constant for nitrification-oxygen limitation	2.00	Ambrose, et al, (1991) in Warwick, Cockrum and Horvath (1997)	2.0
18	K20C	Denitrification rate at 20°C	0.40	NDEP 208 Study in Warwick, Cockrum and Horvath (1997)	0.4
19	K20T	Temperature coefficient for denitrification rate	1.045	Ambrose, et al. (1991) in Warwick, Cockrum and Horvath (1997)	1.045
20	KNO3	Half-saturation constant for denitrification oxygen limitation	0.1	Yassuda, et al. (200)	0.1
21	K71C	Mineralisation rate of dissolved organic nitrogen	0.50	Warwick, Cockrum and Horvath (1997)	0.5
22	K71T	Temperature coefficient for K71C	1.080	Ambrose, et al (1991) in Warwick, Cockrum and Horvath (1997)	1.080
23	LGHTS	Light formulation switch: LGHTS =1, USE Di Tiro et al (1971) formulation; LGHTS = 2 USE Dick Smith's (USGS) formulation	1 and 2	Ambrose, Wool and Martin (1993b)	2
24	FON	Fraction of dead or respired phytoplankton nitrogen recycled to organic nitrogen	0.15	Warwick, Cockrum and Horvath (1997)	0.1
25	NUTLIM	Nutrient limitation	0 or 1 (Default)	Ambrose, Wool and Martin (1993b	1.0
26	KPZDC	Decomposition rate constant for phytoplankton in the sediment		Ambrose, Wool and Martin (1993b	0.12
27	KPZDT	Temperature coefficient for the decomposition o f phytoplankton in the sediment	1.0	Ambrose, Wool and Martin (1993b	1.0

(1)	(2)	(3)	(4)	(5)	(6)
28	K1G	Grazing rate on phytoplankton per unit zooplankton population	0.0 – 2.0	Kishi and Ikeda (1986); Yassuda, et al. (2000)	0.0
29	PCRB	Phosporus to Carbon ratio in phytoplankton	0.025	Caupp et al. (1991) in Warwick, Cockrum and Horvath (1997)	0.047
30	KOPDC	Decomposition rate of organic phosporus in the sediment at 20°C	0.1	Di Toro, et al (1977)	0.10
31	KOPDT	Temperature Coefficient for the decomposition of organic phosporus in the sediment	1.0	Ambrose, Wool and Martin (1993b	1.0

6.4. Integration of DYNHYD5 and WASP 5

The integration of the hydrodynamic model (DYNHYD5) and the water quality model (WASP5) is crucial in this research. The results of running the WASP5 model only show that they were not capable of reproducing the patterns on observed data. In combination with DYNHYD5, the pattern of seasonal changes of water quality parameters can be gained. The "pattern' here is meant as the fluctuation of water quality parameters modelled from time to time. This shows the significant roles of hydrodynamic conditions in the study area in determining the characteristics of water quality. Therefore, DYNHYD5 and WASP5 had to be integrated to obtain adequate results.

Martin and McCutcheon (1999:718-720) provide the methodology for integrating the hydrodynamic and water quality models:

(1) Direct linked;
(2) Indirect linked.

The following is their explanation of each approach.

(1) In the direct approach, the equation for the transport and kinetics of water quality constituents are imbedded within the flow model. The equation for conservation of momentum, conservation of water mass or continuity, and conservation of constituent mass are solved simultaneously by the same computer code. In addition, the intensity or concentration of certain constituents (e.g., temperature and salinity) are linked to the flow calculations through the equation of state, relating changes in water properties to changes in density (Martin and McCutcheon, 1999:718);

(2) In the indirect linkage approach, the results of the circulation model are processed, saved to files, and then used as input to models of water quality (Martin and McCutcheon, 1999:718)

The second approach, that is the indirect linkage of hydrodynamic and water quality model, was used in this research. The reason for this is that it was desirable to look at and evaluate the performance of DYNHYD5 before it was integrated into the WASP5 model. In other words, the accuracy of the results obtained by DYNHYD5 must be assessed before being input into WASP5 model.

Maskel (1992:110) claims that the capability of a model to simulate and predict water quality is dependent on its ability to simulate all the relevant hydrodynamic processes. Therefore, this study will integrate water quality model (EUTRO5 in WASP 5) and hydrodynamic model (DYNHYHD 5).

The time step used in these models was a major problem encountered during the integration of these two models. A significant amount of iterative processes were conducted in order to obtain the time steps required for WASP5. For this reason, models were repeatedly run so that the time steps of these models were matched.

6.5 Results of Hydrodynamic Modelling

Figure 6.22 shows the comparison of head/tide height (in metres). As can be seen, the DYNHYD5 model is capable of reproducing the pattern of the heights of tides. Visually, there is agreement between the observed and predicted values. The calculated value of the index of agreement was 0.992. The calculation of this index can be seen in Appendix 3. The results of hydrodynamic modelling were, therefore, considered in agreement with observed tide height and consequently, the results of the DYNHYD5 model could be input into WASP5 model. In this study, modeling of hydrodynamics was conducted for 24 hours time period. Short time modeling of hydrodynamic as conducted in this study will not be able to model the typical phenomenon in the study area, that is "dodge tide".

6.6 Results of Water Quality Modelling

The results of water quality modelling show that there is a quite good agreement between the predicted and observed values, despite a number of uncertainties in the data used for model input. The main sources of uncertainty are due to the limited amount of data for the determination of initial condition, boundary condition and parameters, although these uncertain components were kept minimum.

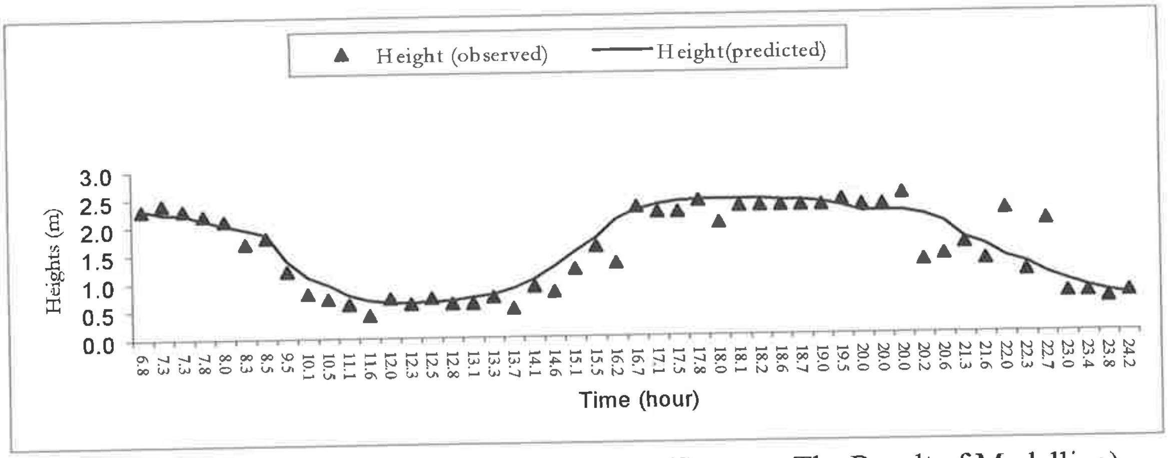


Figure 6.22 Predicted and Observed Tide Heights (Sources: The Result of Modelling)

There are four main water quality parameters modeled in this research. These four water quality parameters are: Total Kjeldal Nitrogen (TKN), Ammonia (NH_3), Total Phosphorus, and Chlorophyll a. Due to incomplete data on nitrate (NO_3), this water quality parameter was not modeled. In term of input data, TKN replaced the NO_3. The following discussion will start from the comparison of predicted and observed water quality parameters. This would then be followed by testing the model for different data sets. Subsequently, sensitivity analysis will follow.

6.6.1 Comparison of Observed and Predicted Water Quality Parameters

The calculation of IoA was conducted on data having both observed and predicted values. The following figures show the comparison of modeled and observed values of three water quality parameters for 1996 data for seven sites, that is site 1 (segment 8), site 2 (segment 14), site 3 (segment 17), site 4 (segment 19), site 5 (segment 23), site 6 (segment 25) and site 7 (segment 26). Site 8 and Site 9 in the 1996 data set have limited data to compare the results of modeling and the observations. For this reason, comparison of the predicted and observed values for these two sites was not conducted.

For the concentration of Chlorophyll a (as shown in 6.23 and 6.24), WASP5 model seems to be capable of reproducing the pattern, especially for some sites, i.e. sites 2, 3, 6 and 7. Segment 19 is of particular concern because it seems that the model is not capable of reproducing the peak values of chlorophyll a. The reason for that may be that this relates to the depth difference. Segment 19 or site 4 is the site having depth of about 2.35, which is close to segments 7 to 11 which have the depths of more than 8 meters. Overall, the results of the calculation of Index of Agreement (see Appendix 4) show that for sites 1 to 7, the value of this index is 0.873 for chlorophyll a for the overall estuary. Considering segments in Port River only, the value of IoA is 0.917 (see Appendix 5), and 0.723 for Barker Inlet only (see Appendix 6). This shows agreement between the observed and predicted values for Chlorophyll a concentration. The value of average error for 1996 Chlorophyll data was -1.75 (see Appendix 7), showing that the concentration of Chlorophyll a predicted by the model under-simulated the observed data, despite the agreement in pattern. These results indicate that Chlorophyll a concentrations are quite satisfactorily predicted by using WASP5.

Figures 6.25 and 6.26 show the comparison of predicted and observed values for Ammonia concentration (mg/L). Similar to Chlorophyll a concentration, it seems likely that the model is capable of reproducing the monthly pattern of Ammonia concentration, although some segments show overestimated pattern of prediction (segment 19, segment 23 and 25). Despite this condition, the calculation of IoA shows that there is a good agreement between predicted and observed Ammonia concentrations (mg/L). The calculated value of this index was 0.955 for overall estuary (see Appendix 8). Considering Port River only, the value of IoA was 0.75 (see Appendix 9), and 0.96 (see Appendix 10) for segments in Barker Inlet only. The value of average error of 0.113 (see Appendix 11) indicates that the model slightly over-simulated the observed data. Figure 6.27 and 6.28 show the comparison of predicted and observed values for TKN. From Figures 6.27 and 6.28, it would appear that model overestimated the observed concentrations, although patterns are generally reproduced. The value of the index of agreement for TKN is 0.406 (see Appendix 12). This value is lower than IoA for Chlorophyll a and Ammonia. The average error is also the highest, that is –0.3 (see Appendix 15). This may indicate the incapability of WASP5 in reproducing the pattern of observed values of TKN concentrations. By considering segments in Port River only, the result of IoA calculation is 0.537 (see Appendix 13), compared to 0.221 for Barker Inlet only (see Appendix 14). This shows that the prediction of TKN in Port River Estuary is considered quite satisfactory compared to the prediction in the Barker Inlet. Appendix15 shows the calculation of average error for TKN concentration for 1996 data which show the calculated value of –0.31 which indicate the model under simulated the observed values. Average error of prediction in Port River only was 0.18 (see Appendix 16), while 0.48 (see Appendix 17) for Barker Inlet. Therefore, there is a significant over-prediction of TKN in Barker Inlet.

Significant error in the prediction of TKN is expected. The reason is that TKN is not a water quality parameter modeled by WASP5, and TKN concentrations in the observed data were used as input into the model to replace the Nitrate. In fact, initial condition and boundary condition data was input by using TKN concentration. The WASP5 model takes into account the mechanism related to Nitrate concentration, and not TKN.

Figure 6.29 and Figure 6.30 show the comparison of predicted and observed values of Phosphate concentrations at sites 1 to 7. As can be seen, there is a good agreement between the observed and the predicted values, with the value of IoA for site 1 to site 7 is 0. 547 (see Appendix 18), and the value of average error is 0.197 (see Appendix 21), which show that in average, the model over-simulates the observed data.

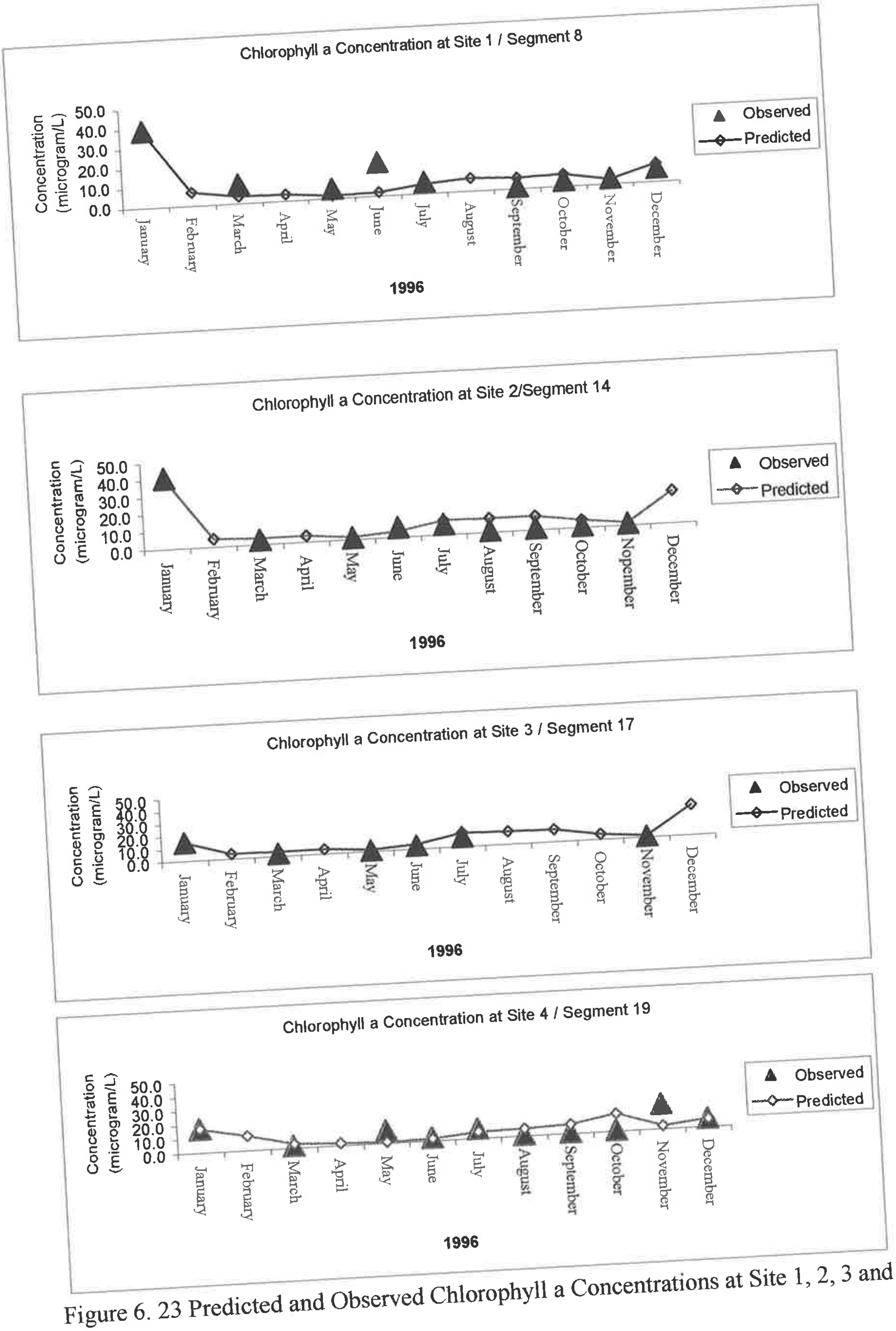


Figure 6. 23 Predicted and Observed Chlorophyll a Concentrations at Site 1, 2, 3 and 4

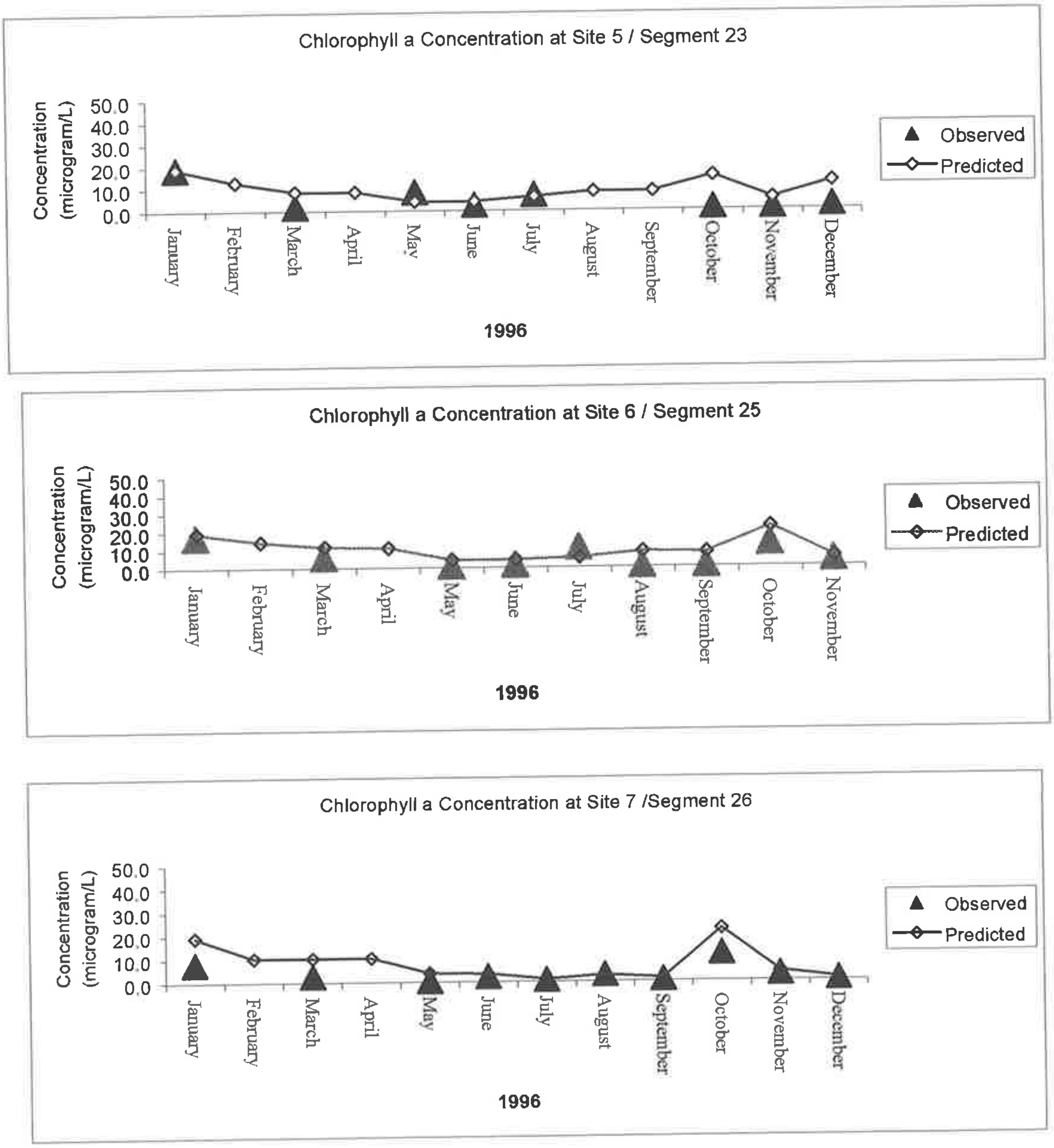


Figure 6.24. Chlorophyll a Concentration at Sites 5, 6 and 7

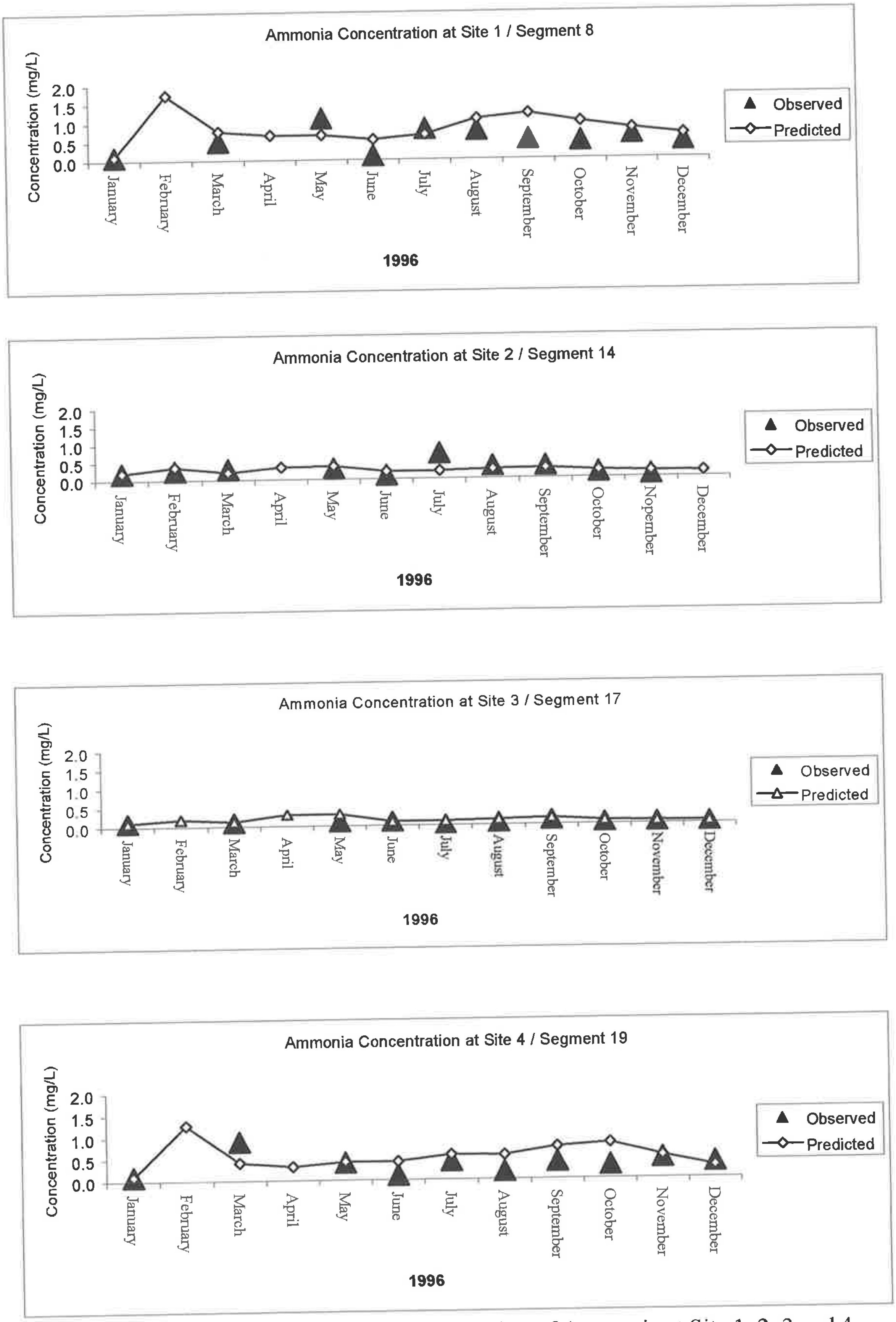
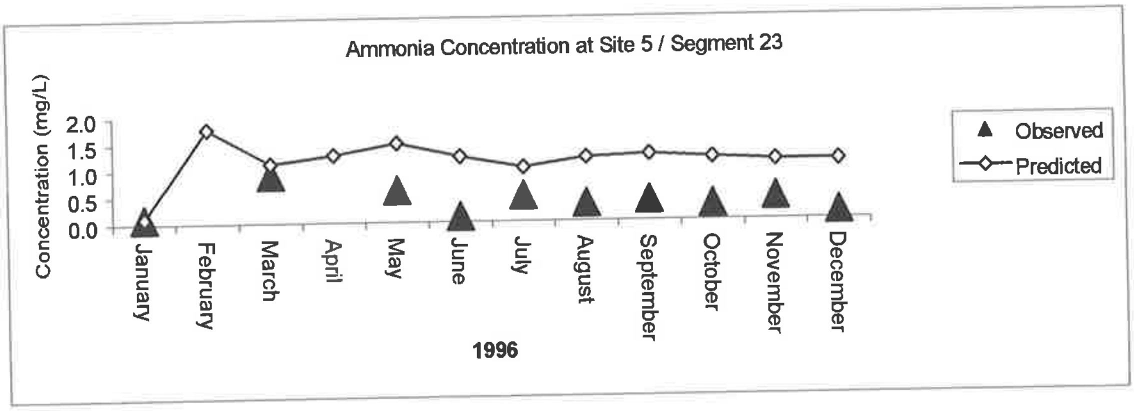
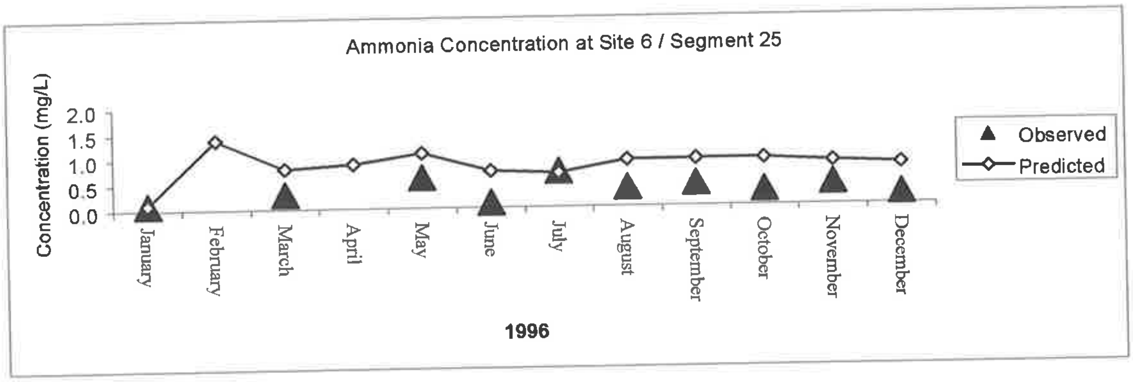


Figure 6. 25 Predicted and Observed Concentration of Ammonia at Site 1, 2, 3 and 4





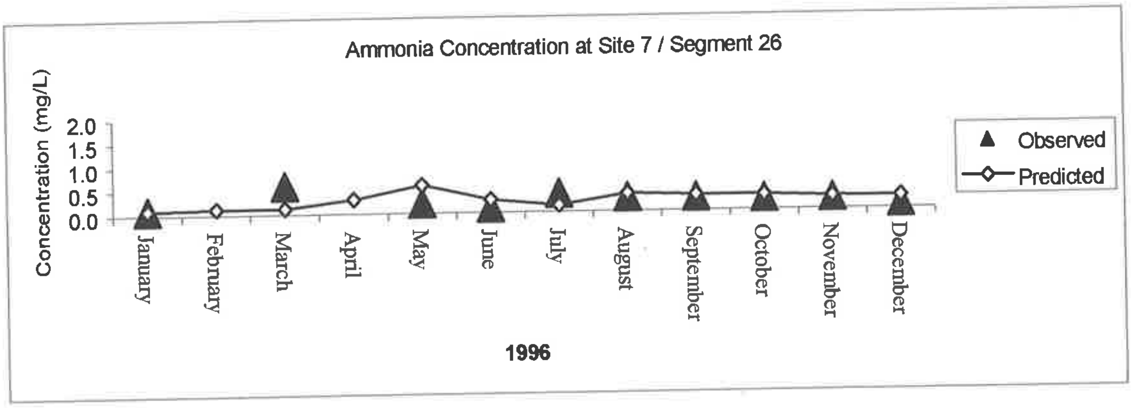


Figure 6.26 Predicted and Observed Concentration of Ammonia at Sites 5, 6 and 7

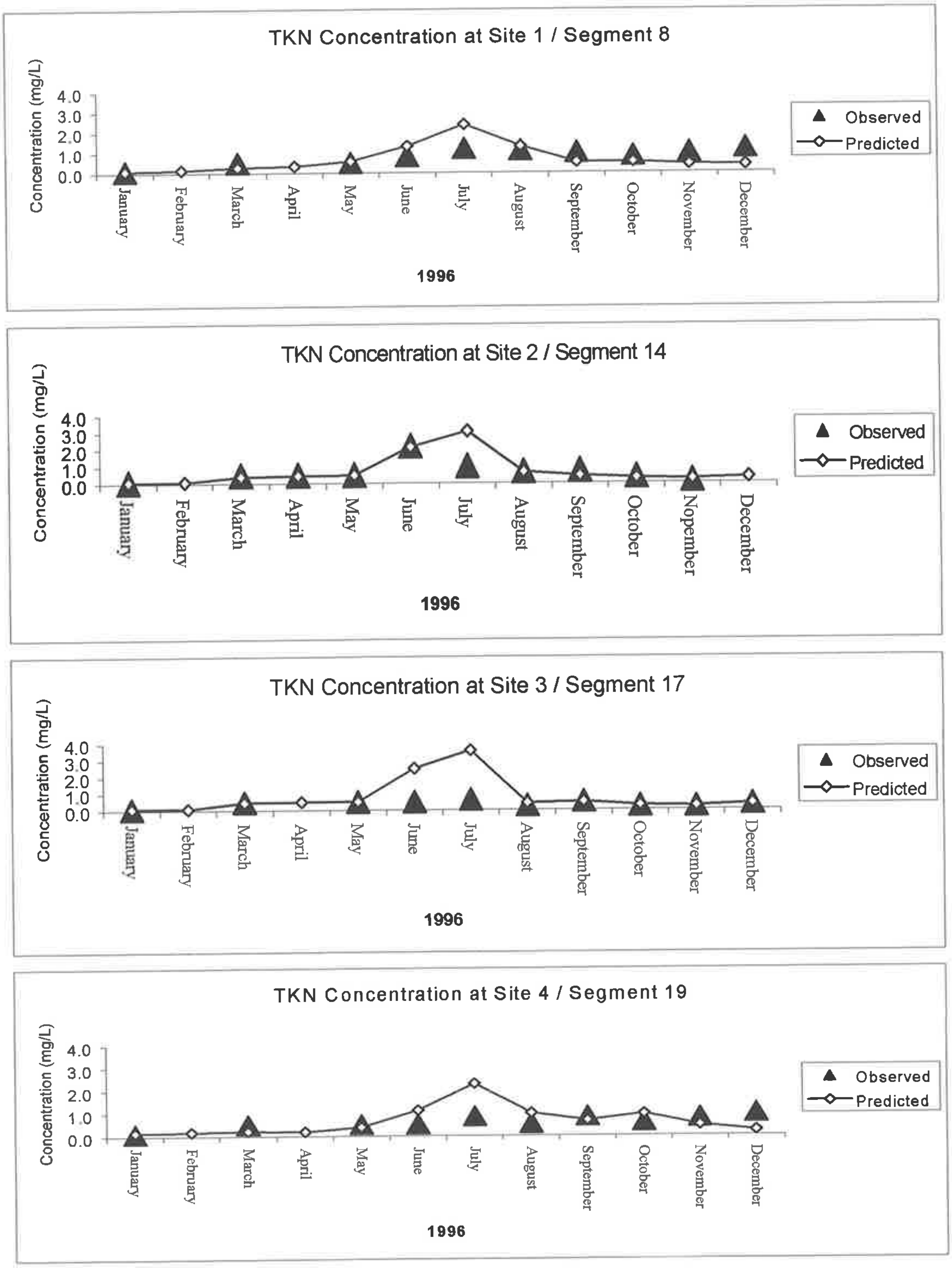
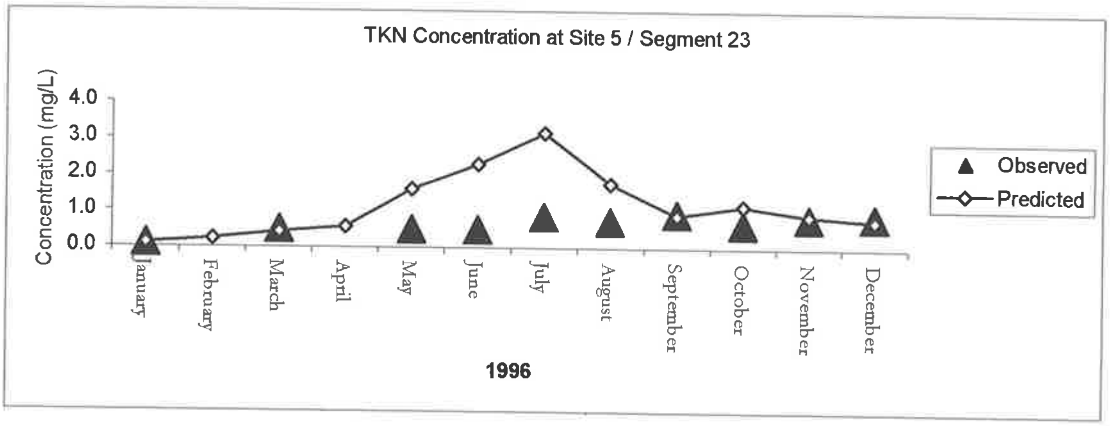
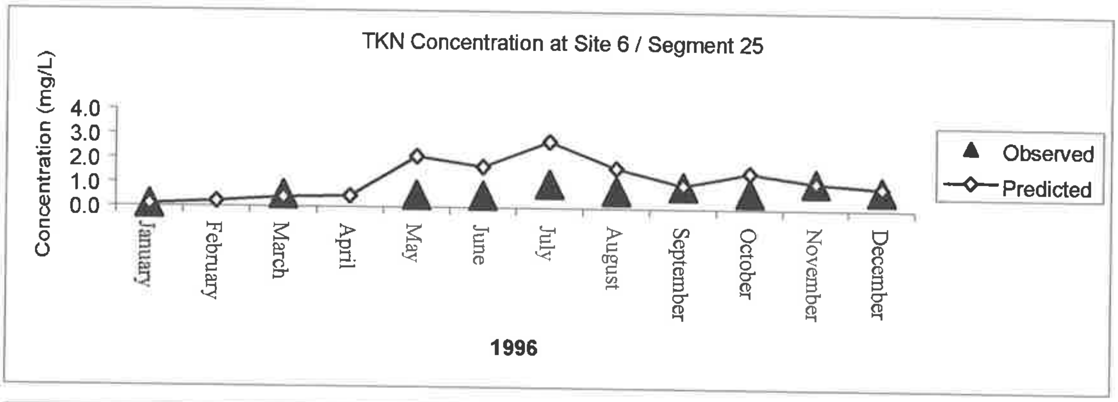


Figure 6. 27 Predicted and Observed TKN Concentration at Site 1, 2, 3 and 4





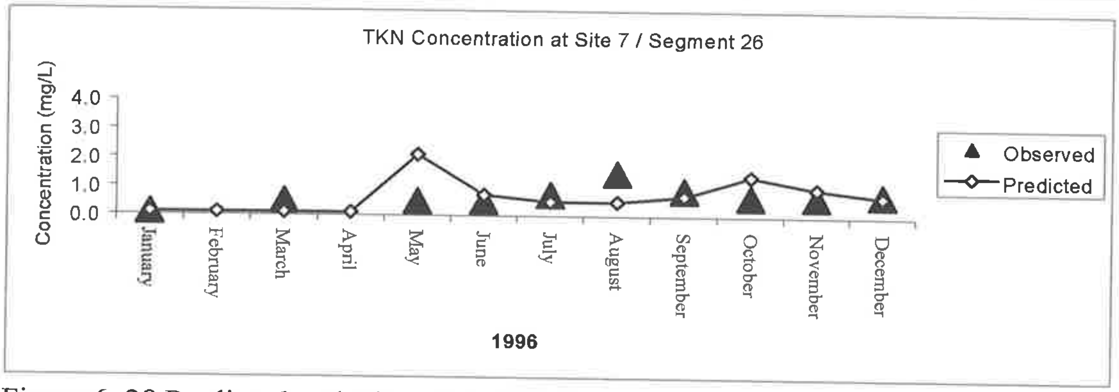
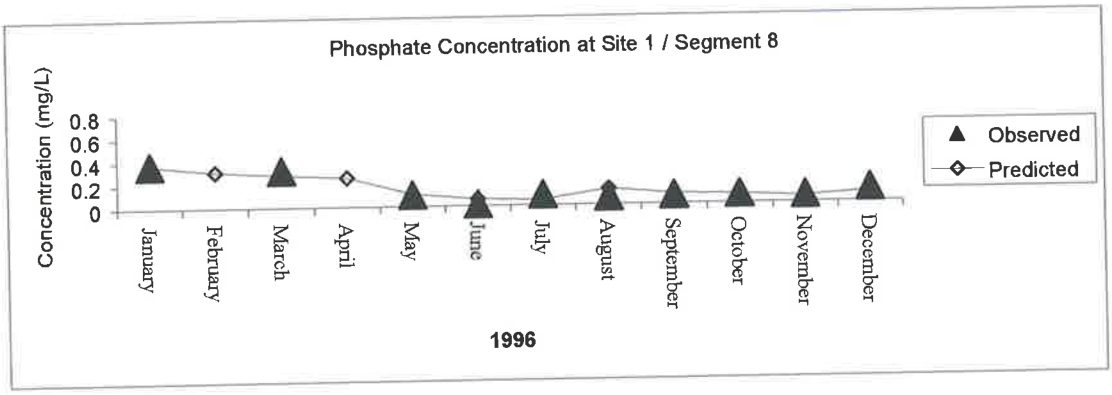
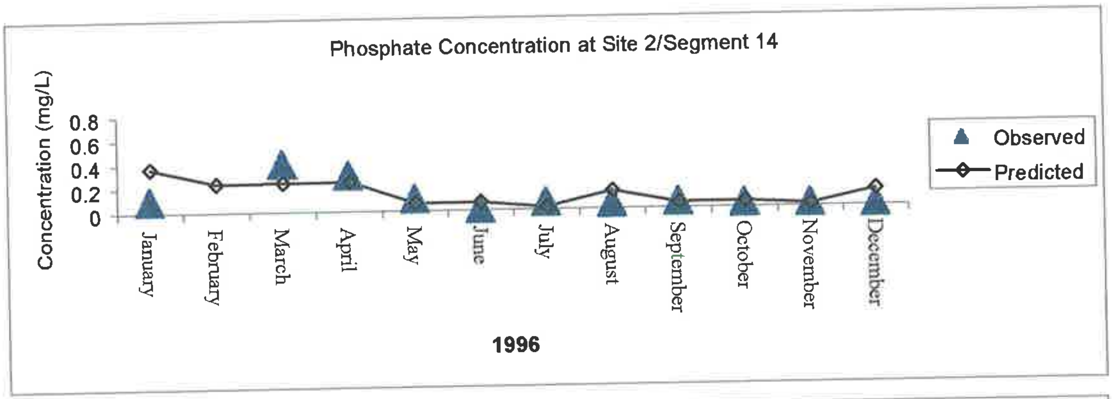
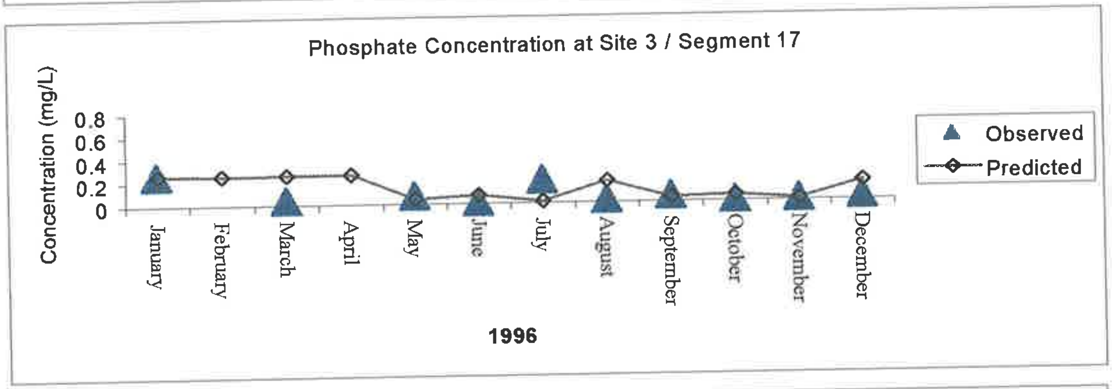


Figure 6. 28 Predicted and Observed TKN Concentration at Site 5, 6 and 7.

Considering the Port River only, the calculated IoA is 0.84 (see Appendix 18), and 0.535 (see Appendix 20) for Barker Inlet. This provides evidence that, in general, the prediction of four water quality parameters is better in the Port River estuary than Barker Inlet estuary. This suggests that depth is likely to be the main factor which determine the results of water quality modeling.







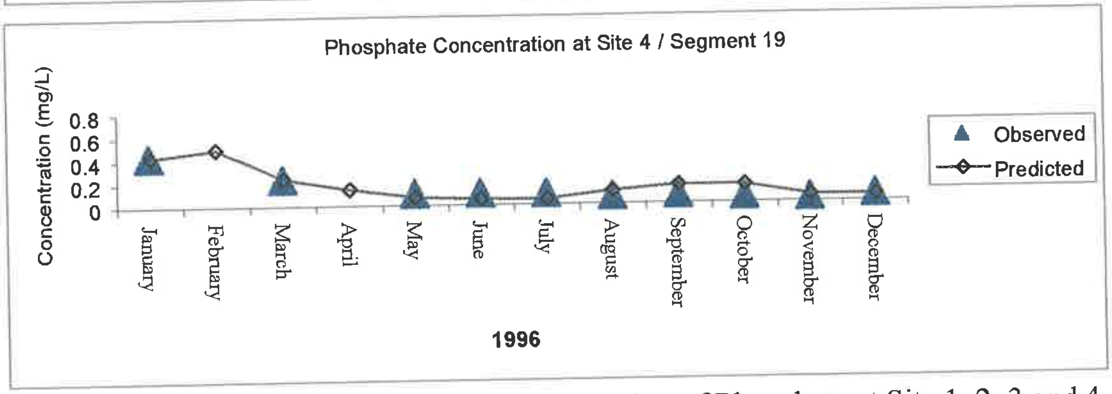
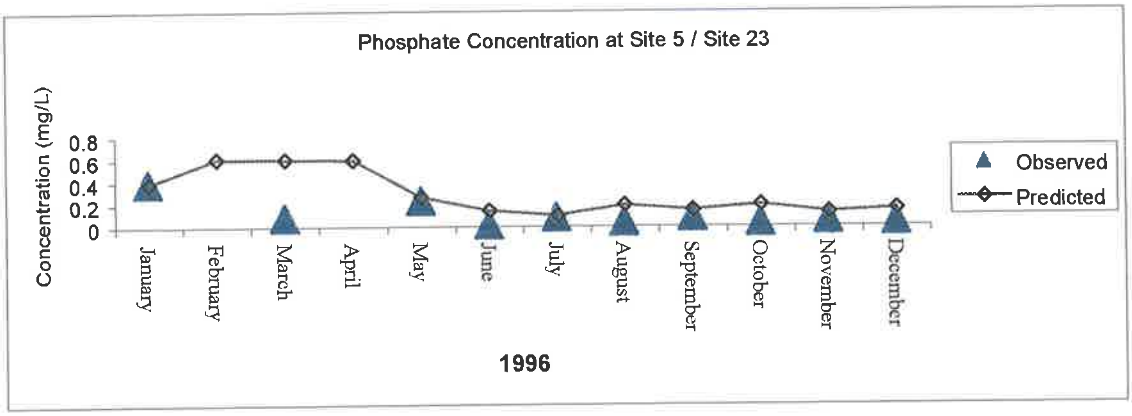
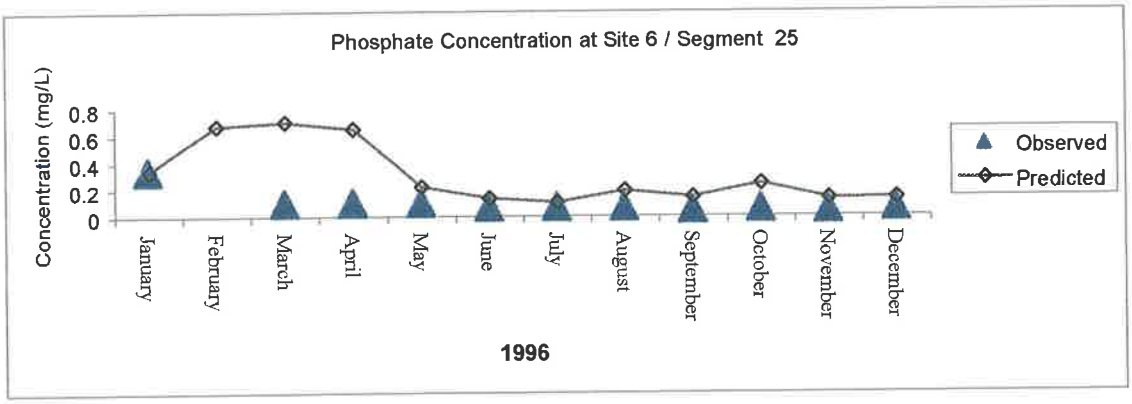


Figure 6. 29 Predicted and Observed Concentration of Phosphate at Site 1, 2, 3 and 4





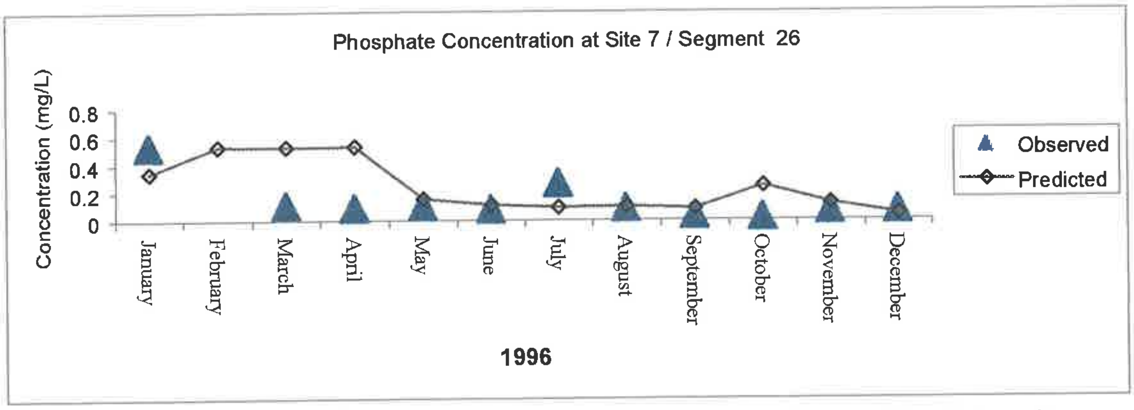


Figure 6. 30 Predicted and Observed Concentration of Phosphate at Site 5, 6 and 7

Above all, considering the pattern as shown in these figures for 1996 data set, it is clear that the model is considered sufficiently accurate to reproduce the observed data. For the purpose of assessing further the performance of the model, a different data set was employed. A data set from 1997 was used to test the performance of the model. The following sub section illustrates the results.

6.6.2 Testing WASP5 Model for Different Data Set

For the purpose of testing the performance of the model, parameters and constants from modeling using 1996 data set were employed to predict the concentration of Chlorophyll a, Ammonia, Phosphate and TKN for the 1997 data set. It was expected that the model will provide similar performance.

The following figures provide the results. As can be seen in Figures 6.31 and 6.32, the model is generally capable of reproducing the patterns in the observed data. As can be seen in Figure 6.31 and Figure 6.32, WASP5 can not reproduce the peak concentrations of Chlorophyll a (as shown in Figure 6.31 for sites 1 and 4, Figure 6.24 for sites 7). For site number 3 and 6 WASP5 model seems to overestimate values from observed concentration. Constants have been changed so that the predicted values can approach the observed ones. However, a large value of the most sensitive constants for Chlorophyll a only have a very little effect on achieving peak concentration. The value of IoA for Chlorophyll a for 1997 data set is 0.762 (see Appendix 22) and Average Error = -0.464. This value of average error indicates that the model slightly underestimate the observed concentration of Chlorophyll a for the 1997 data set. Considering Port River and Barker Inlet only, the calculated IoA were 0.79 (see Appendix 23) and 0.551 (see Appendix 24).

Figure 6.33 and 6.34 compare the predicted and observed concentrations of Ammonia for 1997 data set. From both Figures (6.33 and 6.34), it would appear that for site numbers 2, 3 and 7, WASP5 model predicted the pattern of changes quite well. A good example is segment 17 which shows the strong agreement between observed and predicted concentration of Ammonia. The value of IoA for Ammonia for 1997 data set for site 1 to 7 was 0.50735 (see Appendix 25), much lower value compared to that by using 1996 data set. The value of average error is equal to 0.1185 (see Appendix 28), indicating that the model slightly overestimated the observed Ammonia concentrations in 1997 data set. The result of IoA calculation in Port River only is 0.69 (Appendix 26), and 0.33 (Appendix 27) for Barker Inlet.

Similar results as in 1996 data set can be seen in the Figures 6.35 and 6.36 for TKN prediction for 1997 data set. Figure 6.35 and Figure 6.36 show the predicted and observed concentration of TKN for 1997 data set. The value of IoA shows that there is slight agreement between predicted and observed concentration. The value of IoA for TKN was 0.436 (Appendix 29). This value is consistent with IoA for TKN for 1996 data set, i.e. 0.406. It is likely to be the case that the explanation given for TKN in previous section for 1996 data set is held for TKN in 1997 data set. The results of the calculation of IoA of TKN for Port River and Barker Inlet only are 0.45 (Appendix 30) and 0.42 (Appendix 31) respectively.

Figure 6.37 and Figure 6.38 will show the comparison of observed and modelled phosphate concentration at sites 1 to 7. As can be seen, there is a good agreement between predicted and observed values for site 1 to site 7, with the IoA is 0.538 (Appendix 32) and average error is 0.056 (Appendix 35), which show that the prediction is slightly overestimate the observed values. However, considering Port River and Barker Inlet in separation, the calculated IoAs were only 0.127 (Appendix 33) and 0.039 (Appendix 34) respectively. These values indicate the significant reduction of the values of IoA for 1996 data set, although by considering overall, the performance of model is quite satisfactory. From the overall results of IoA and Average Error, it is clear that on average the WASP5 model performs reasonably well. Therefore, for the purpose of modelling cumulative effects, this is considered reasonable. For further development of WASP5 model in the study area, it is necessary to obtain information about the sensitive parameters and this will be explained in the following section (Section 6.6.3).

6.6.3 Sensitivity Analysis

Sensitivity analysis was conducted using 1996 data set. In this regards, constants and load values were changed. 20% change of values were assigned to each constants and load,

(1) original values plus 20% of these values;

(2) original values minus 20% of these values.

Some constants were changed, other were remained unchanged. Constants that were changed for the purpose of sensitivity analysis were:

(1) Carbon to Chlorophyll ratio (CCHL);
(2) Nitrification rate (K12C);
(3) Denitrification rate (K20C);
(4) Saturated growth rate of phytoplankton (K1C);
(5) Nitrogen Half-saturation constant (KMNG1);
(6) Endogenous Respiration rate of phytoplankton at 20°C(K1RC);
(7) Non-predatory phytoplankton death rate (K1D);
(8) Nitrogen to Carbon ratio in phytoplankton (NCRB);
(9) Saturation light for phytoplankton growth (ISI);
(10) Saturated growth rate of phytoplankton (K1C);
(11) Temperature Coefficient for Nitrification (K12T);
(12) Nitrogen Half Saturation Constant for Phytoplankton Growth (KMNG1);
(13) Nitrification Rate (K12C);
(14) Respiration rate (K1C);
(15) Endogenous respiration Rate of Phytoplanktoan at 20°C (K1RC);
(16) Temperature Coefficient for Phytoplankton Respiration (K1RT);
(17) Temperature Coefficient for Denitrification Rate (K20T).

The following figures (Figure 6.39 to 6.42) illustrate the results of the sensitivity analysis. These figures were selected for only those items which provided changes in the sensitivity analysis. As can be seen, model is most sensitive to the changes of CCHL (Carbon Chlorophyll a ratio). Besides, changes in CCHL values also resulted in changes in concentration of Ammonia. Every constant which relate to Chlorophyll a concentrations used in this modelling was changed, however, it was found that model seems to respond sensitively to the changes of only CCHL. Load changes only slightly affect the concentration of Chlorophyll a concentration. The effect of CCHL on both

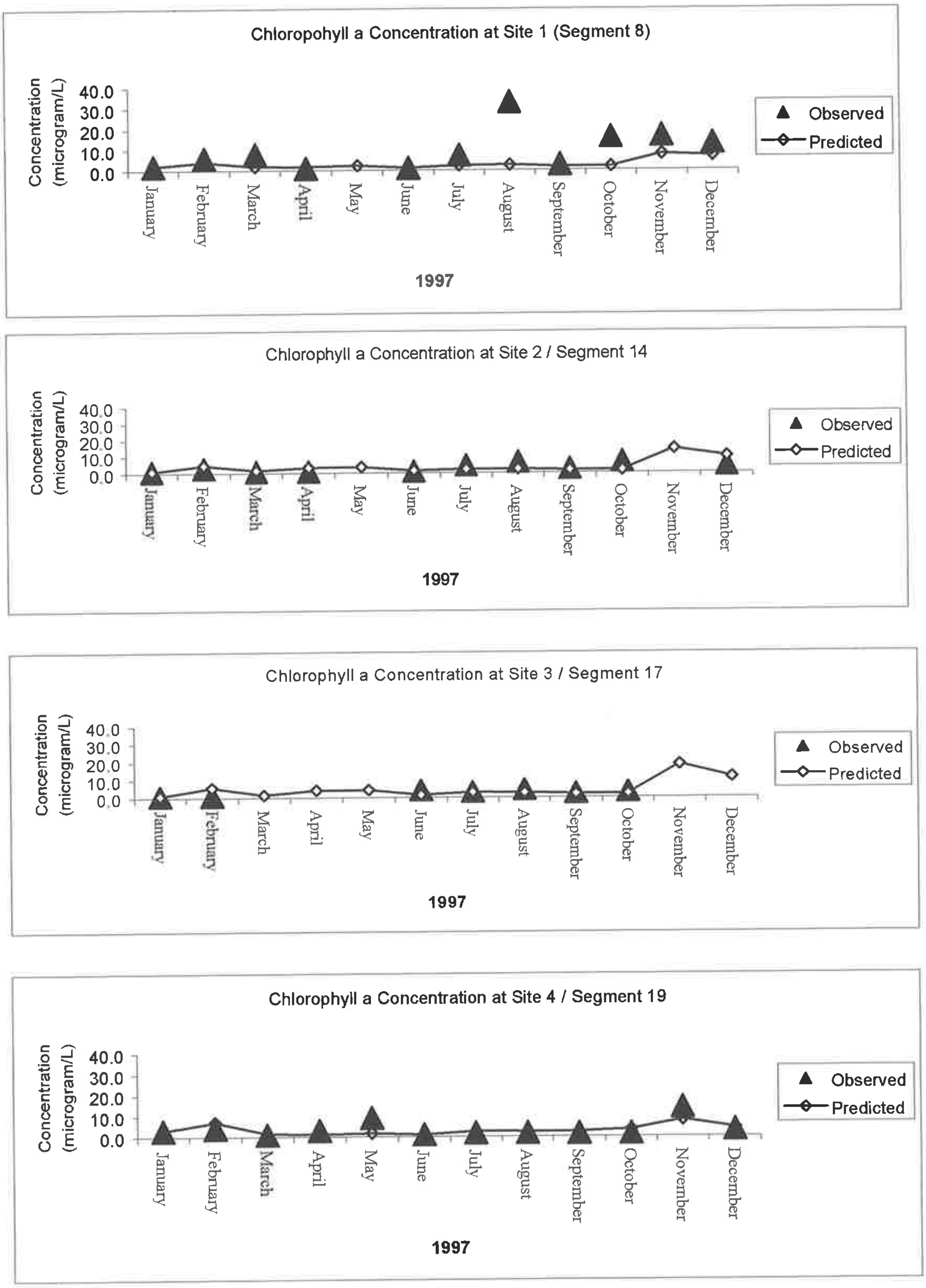
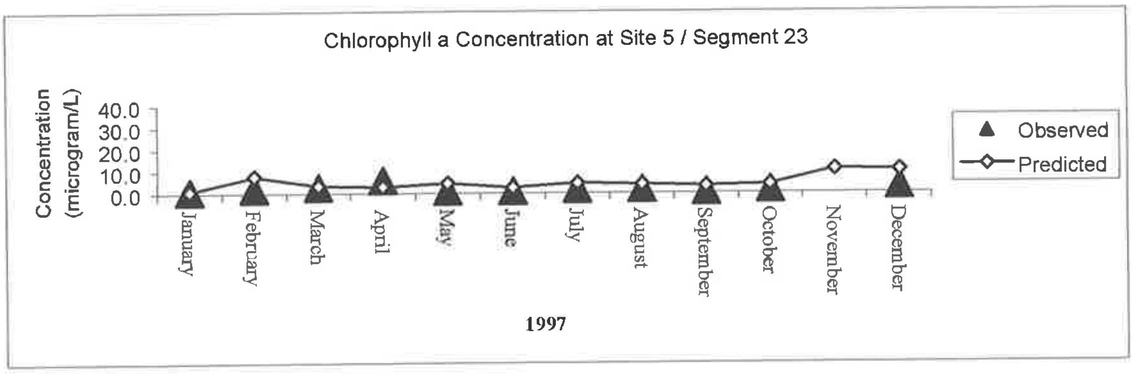
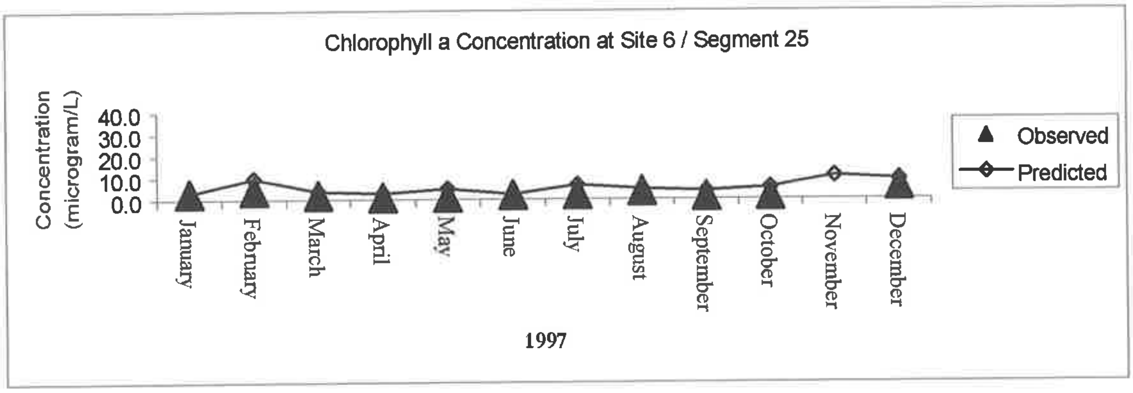


Figure 6. 31 Predicted and Observed Chlorophyll a Concentration at Sites 1, 2, 3 and 4 for 1997 Data





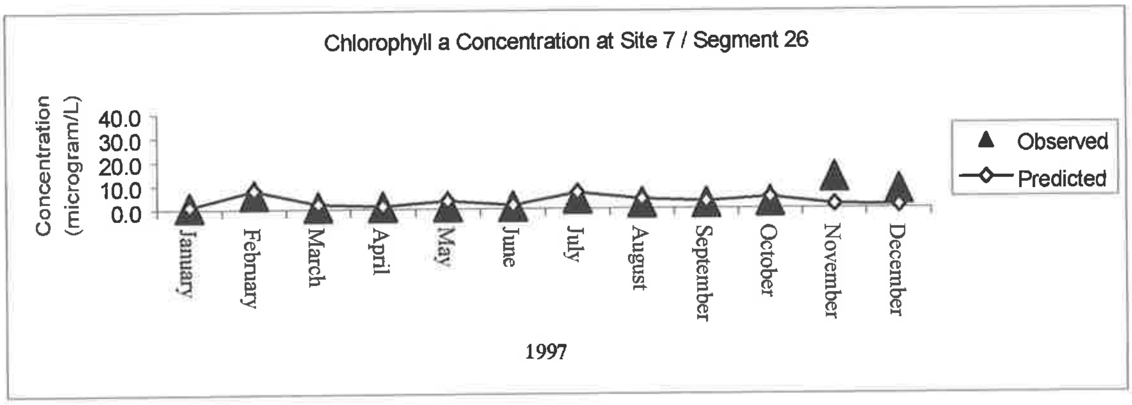


Figure 6. 32 Predicted and Observed Chlorophyll a Concentration at Sites 5, 6 and 7 for 1997 Data

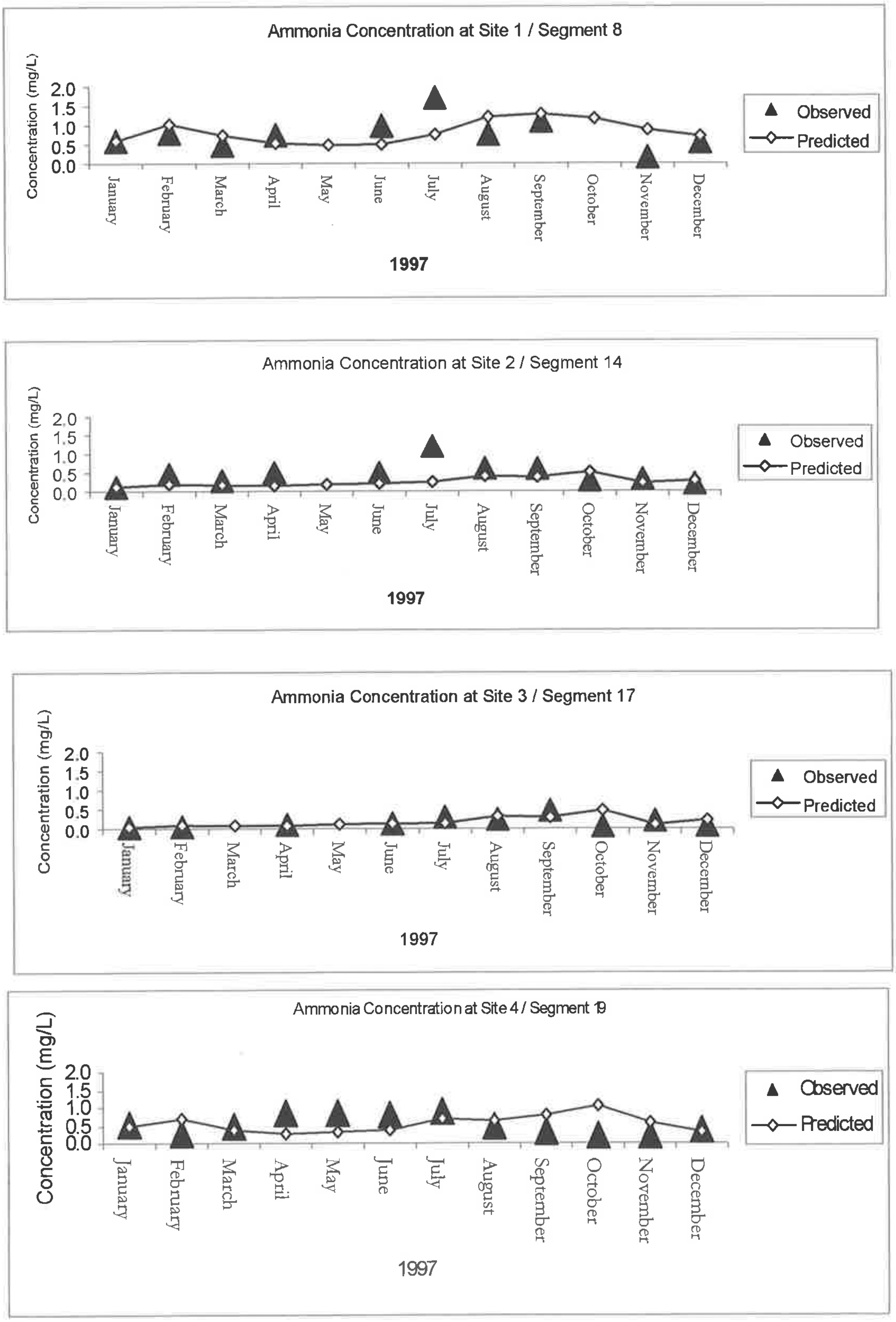
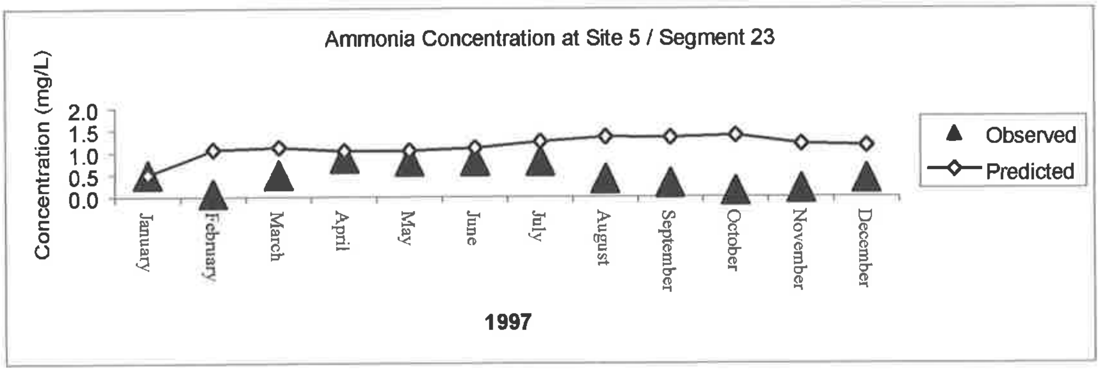
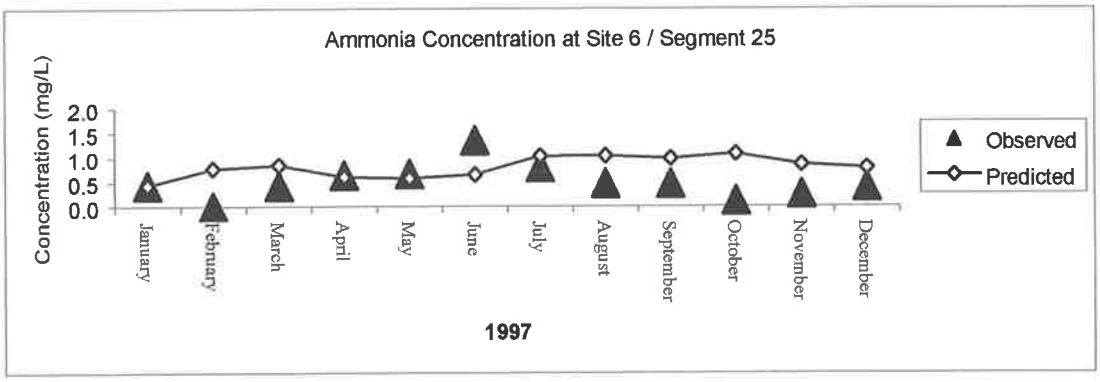


Figure 6.33 Predicted and Observed Concentration of Ammonia at Sites 1, 2, 3 and 4 for 1997 Data Set





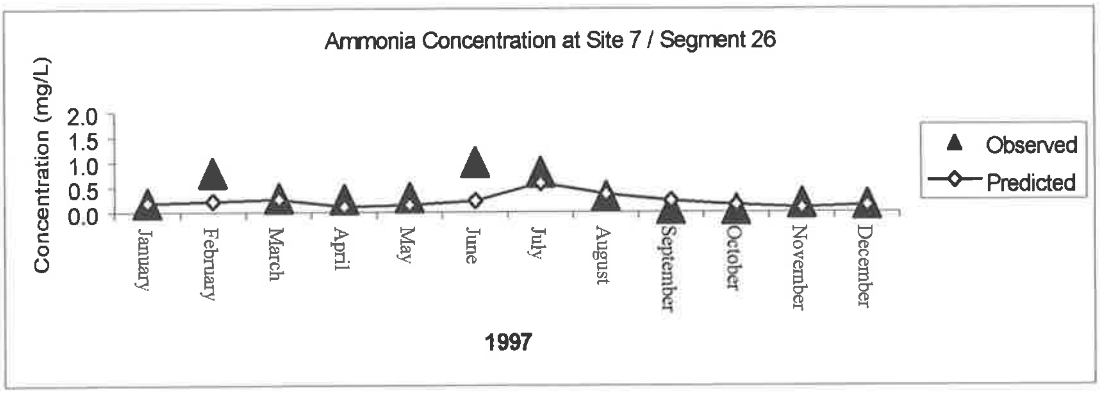
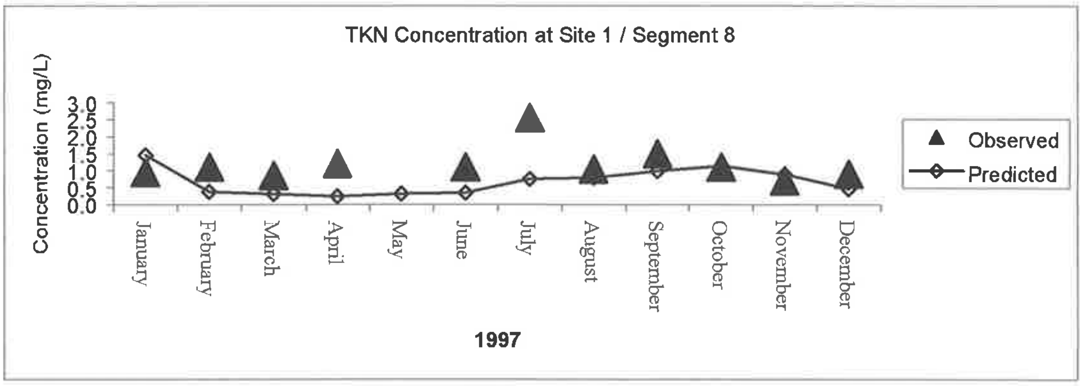
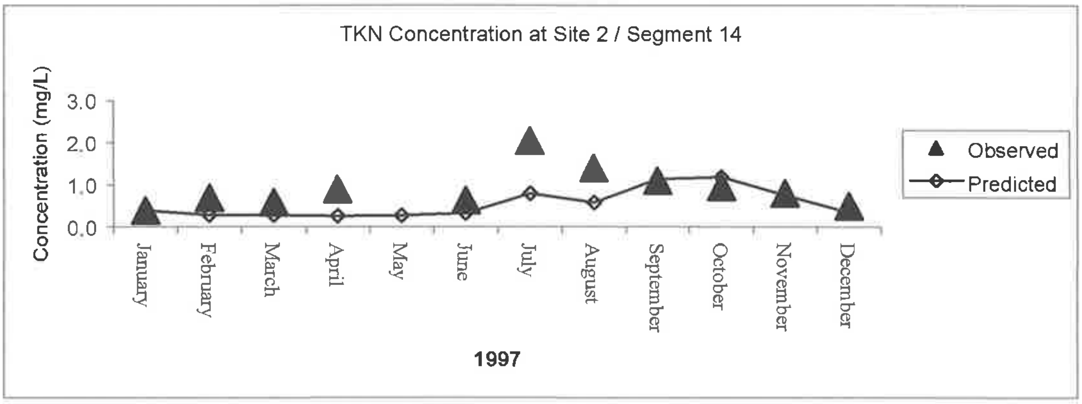
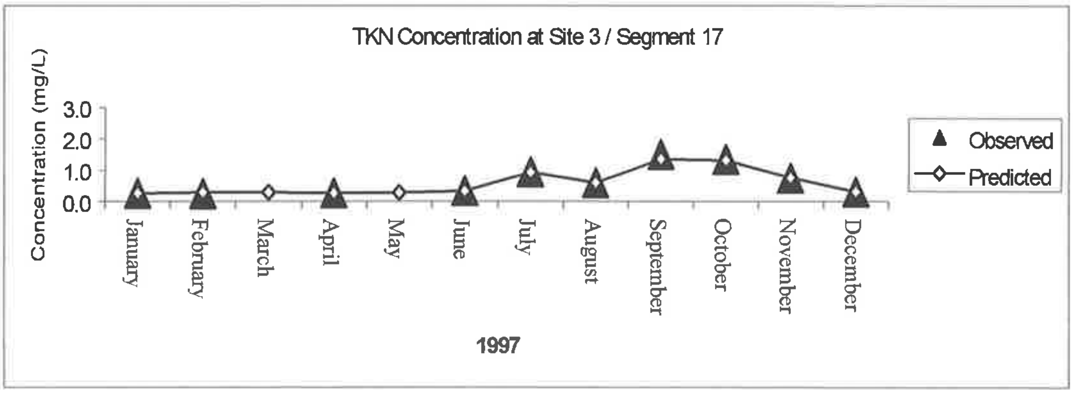


Figure 6. 34. Predicted and Observed Concentration of Ammonia at Site 5, 6 and 7. For 1997 Data Set







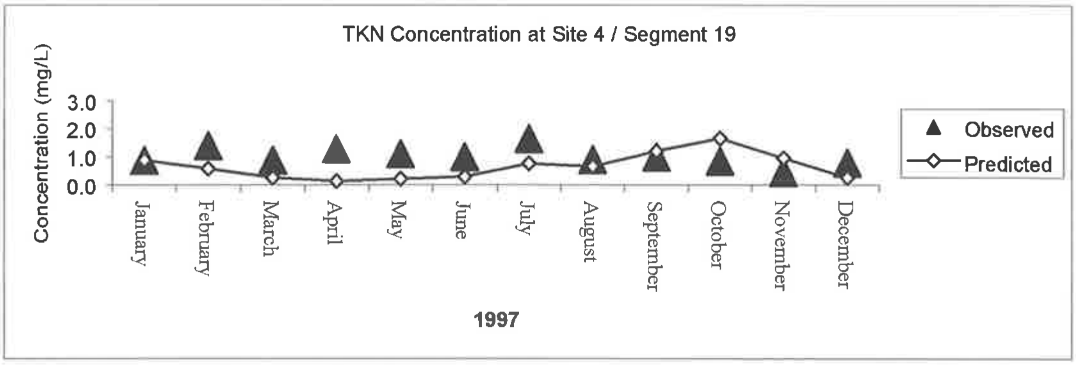
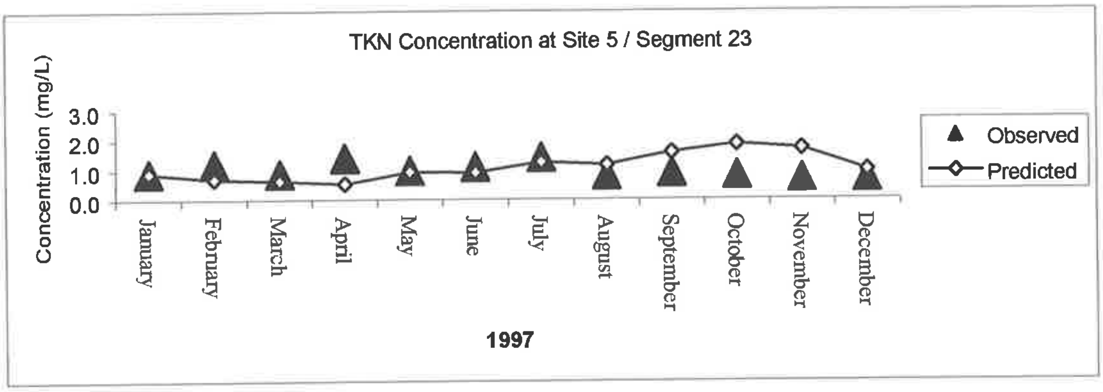
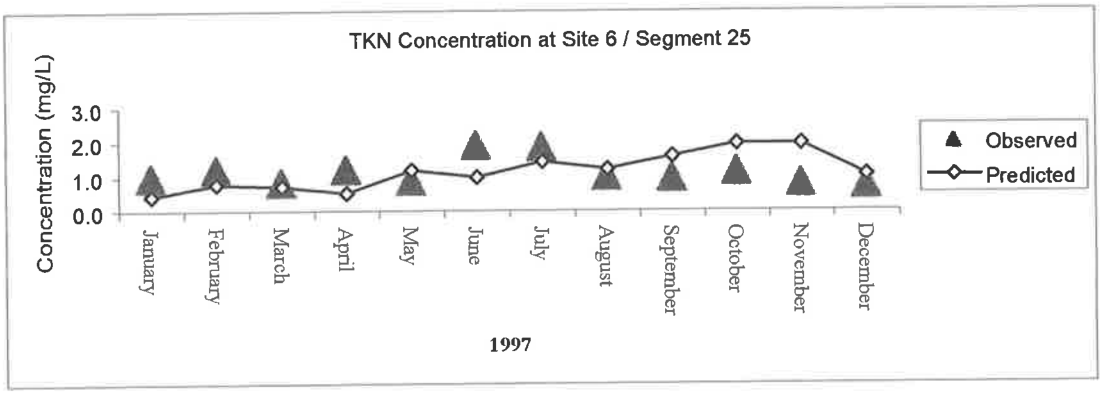


Figure 6.35 Predicted and Observed Concentration of TKN at Site 1, 2, 3 and 4
For 1997 Data Set





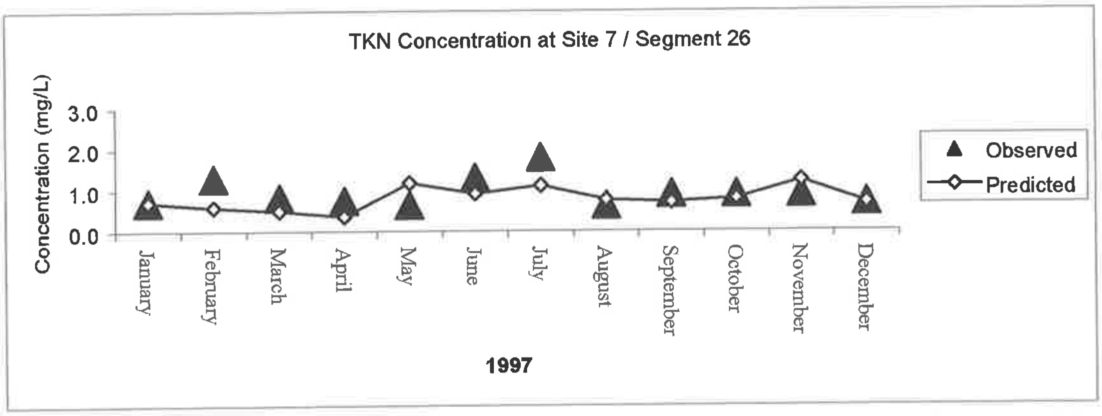
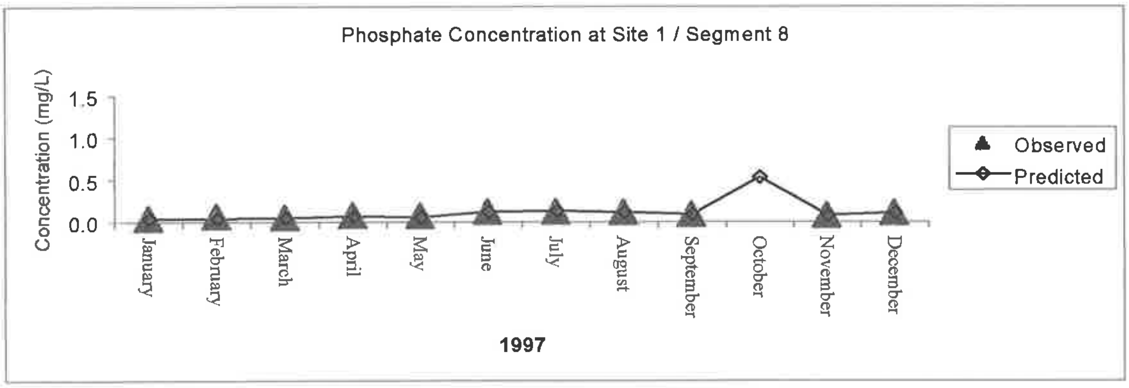
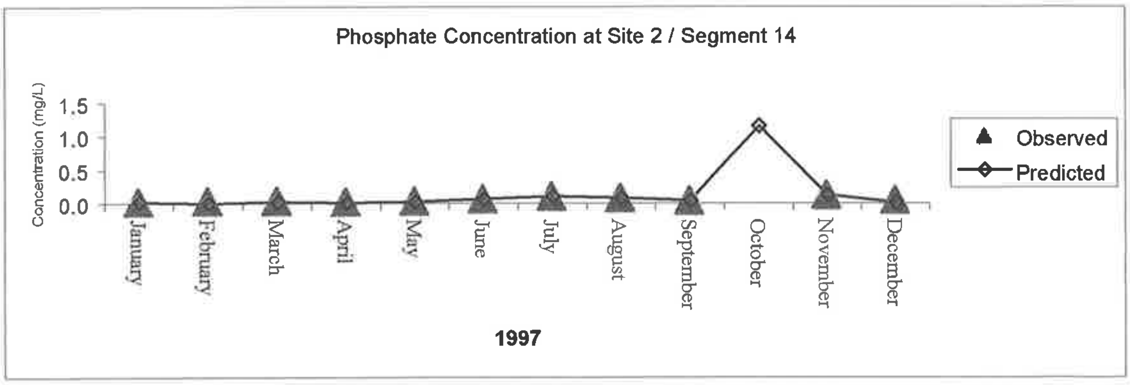
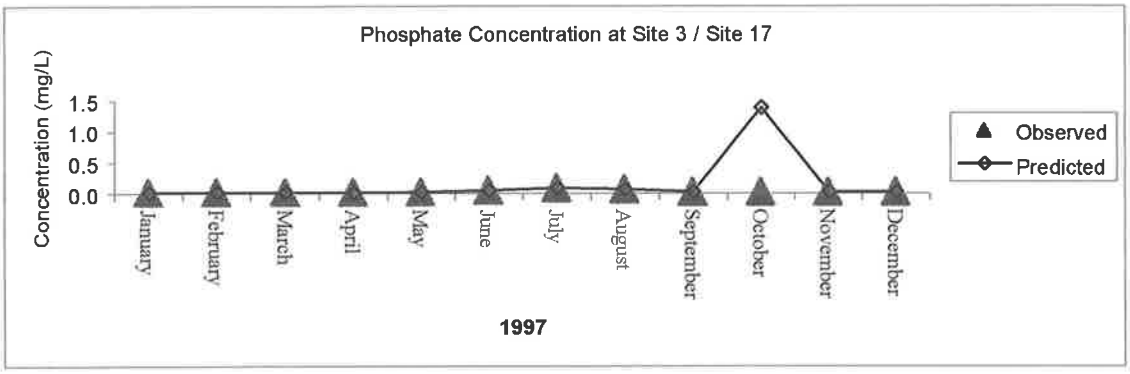


Figure 6.36 Predicted and Observed TKN Concentration at Site 5, 6 and 7 for 1997 Data







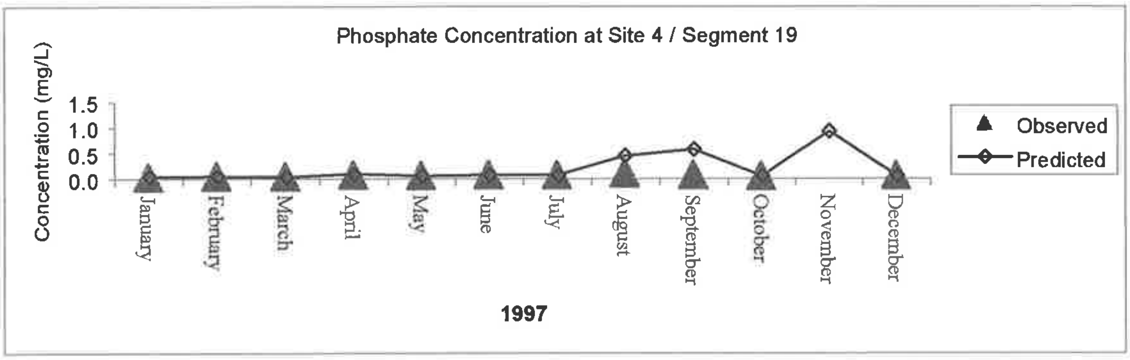
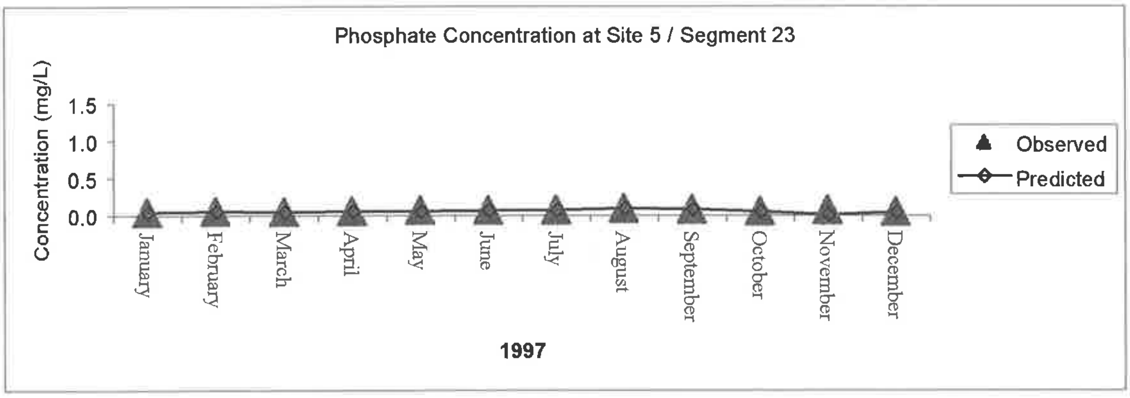
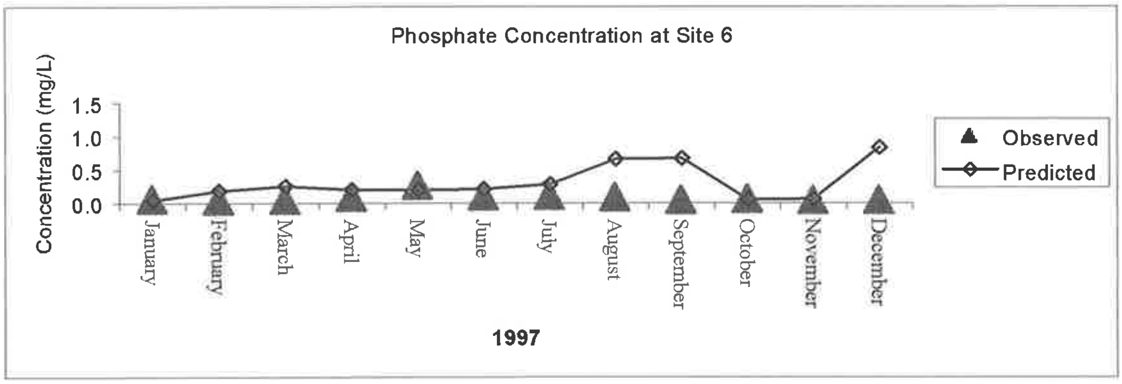


Figure 6.37 Predicted and Observed Concentration of Phosphate at Site 1, 2, 3 and 4 for 1997 Data Set





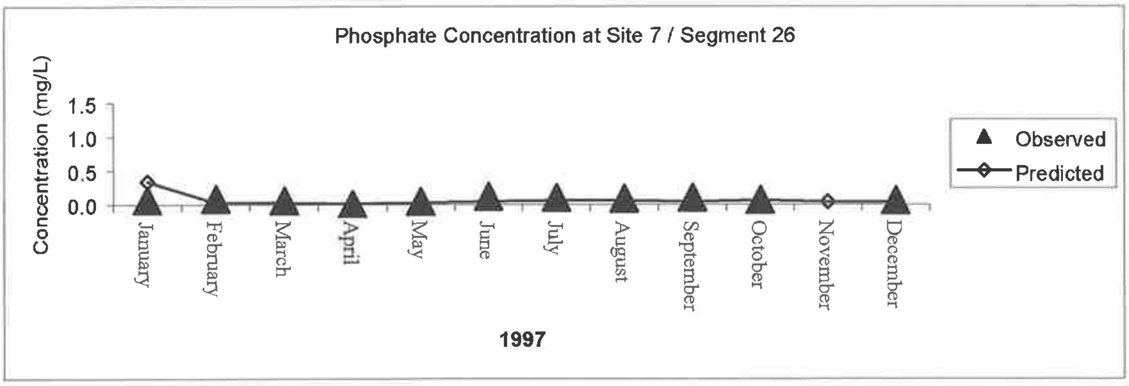


Figure 6.38 Predicted and Observed Concentration of Phosphate at Sites 5, 6 and 7 for 1997 Data Set

chlorophyll a and Ammonia concentration may indicate that Ammonia is the preferred nutrient for phytoplankton growth. According to Jin, Egashira and Chau (1998:233), there is variation in the values of CCHL due to seasonal variations. In addition, they claim that CCHL is the constant which is affected by factors, such as light intensity, temperature and nutrient availability. Therefore, in the study area, the combination of light intensity, temperature and nutrient availability are likely to be the factors responsible for nutrient enrichment and phytoplankton bloom. The inability of the model to pick up the peak concentration may indicate that there may be the different values of CCHL that should be included for every season.

6.6.4 Conclusion

The results of modelling show that there is spatial and temporal variability of four water quality parameters (Chlorophyll a, Ammonia, TKN and Phosphorusus), which result from the combination of activities. As explained, the WASP5 model performed well for most water quality parameters (Chlorophyll a, Ammonia and Phosphate). As shown from the results of modelling, the characteristics of water quality parameters are different spatially in the sense that the values of the concentrations of water quality are different from one site to the others. The temporal characteristics of water quality parameters are likely also to be different. Therefore, variation does exist. This variation is likely to result in the differences in the occurrence of types of cumulative effects, such as spatial crowded effects, temporal crowded or other types.

The following chapter discusses the types of cumulative effects, their determination and their roles in determining the aggregated cumulative effects.

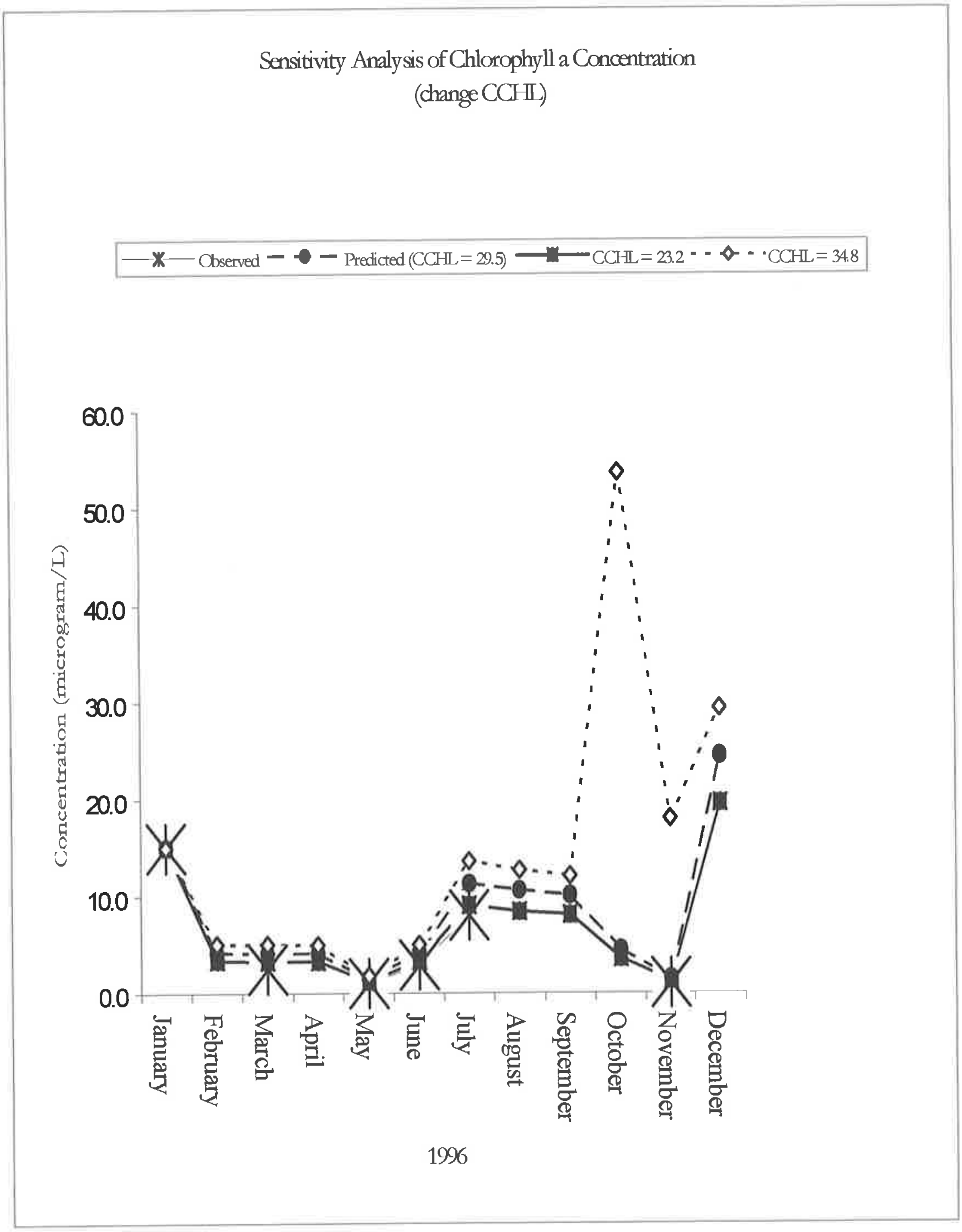


Figure 6. 39 Sensitivity Analysis of Chlorophyll due to changes in CCHL

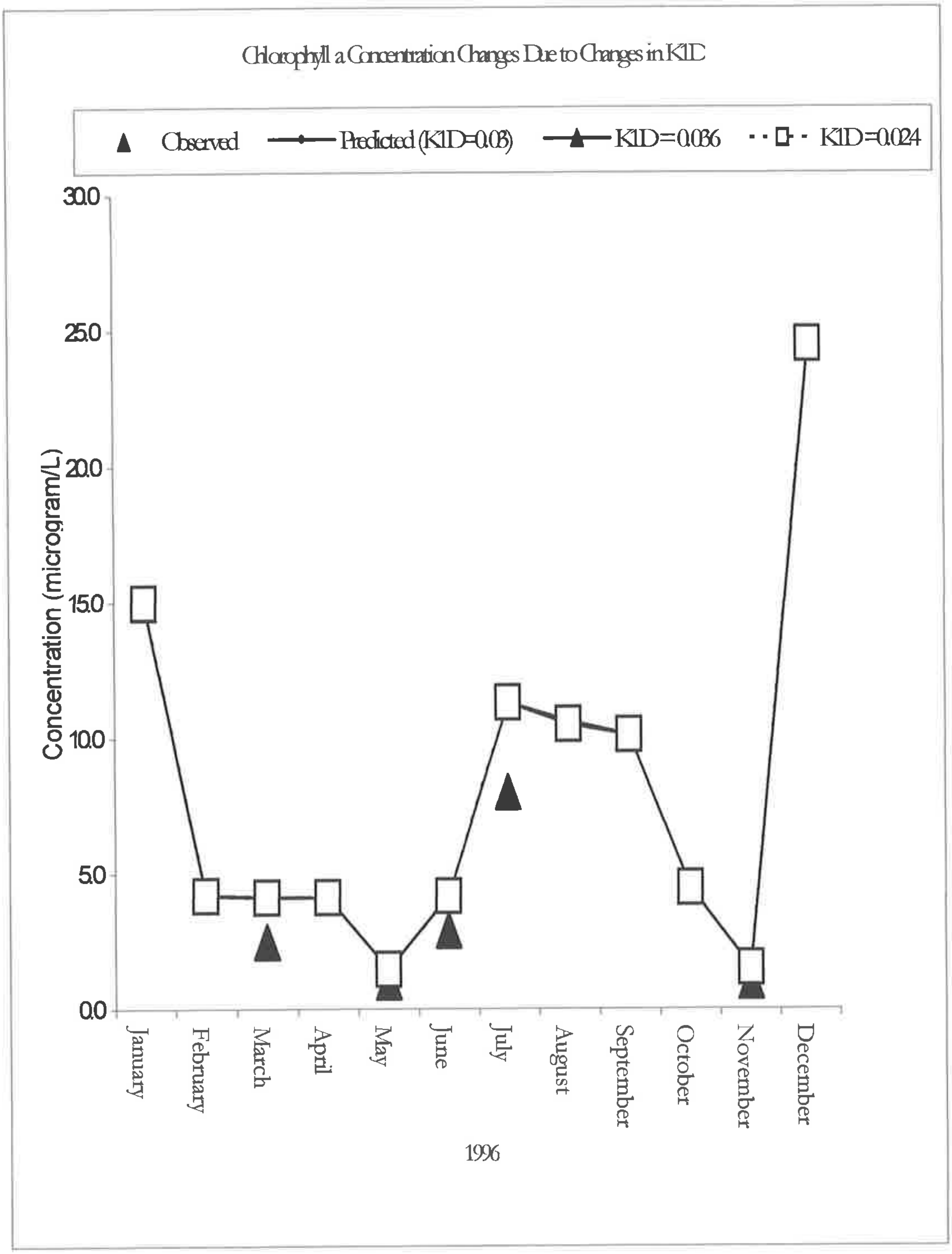


Figure 6. 40 Sensitivity Analysis of Chlorophyll a due to changes in K1D

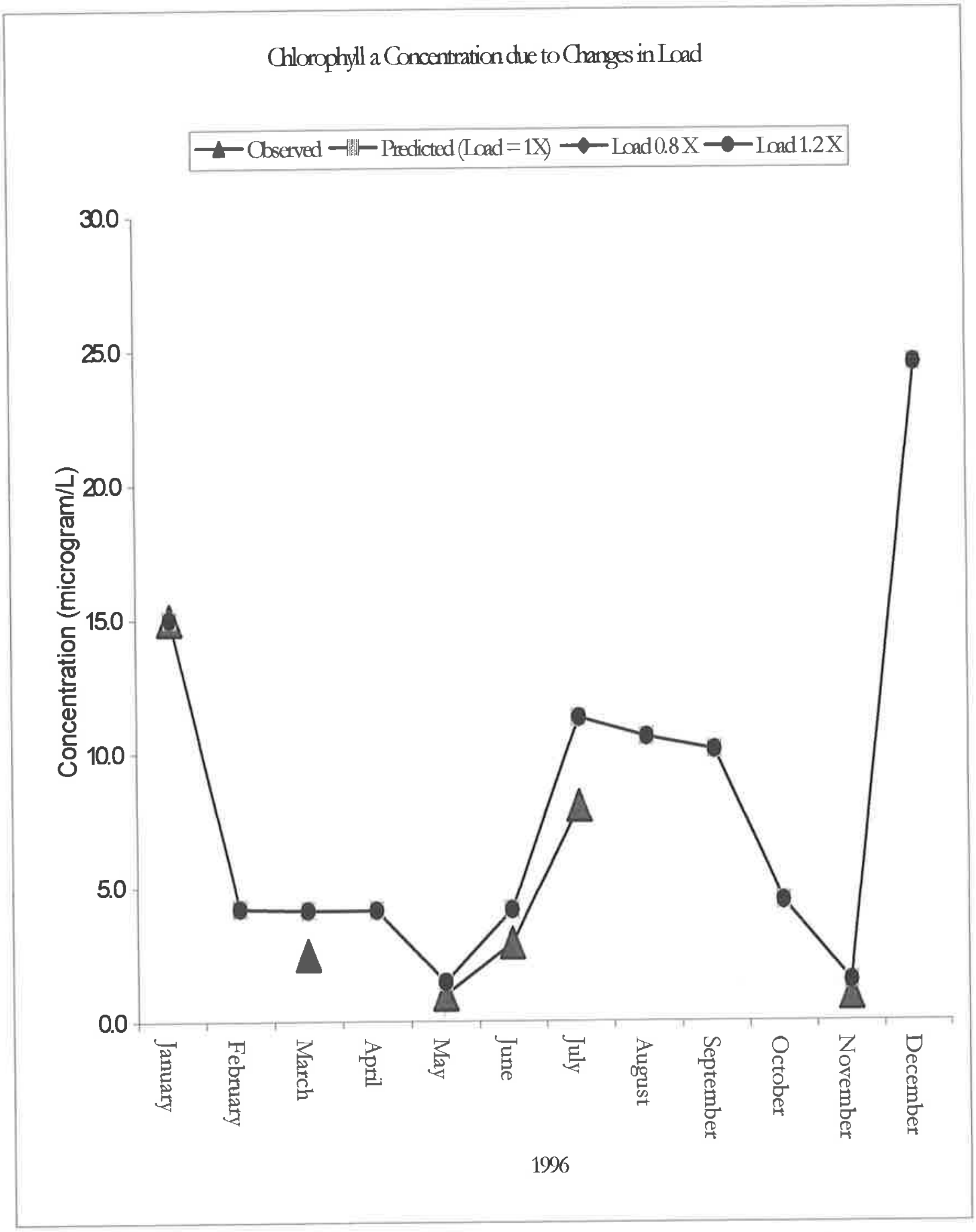


Figure 6.41 Sensitivity Analysis of Chlorophyll a due to changes in Loads

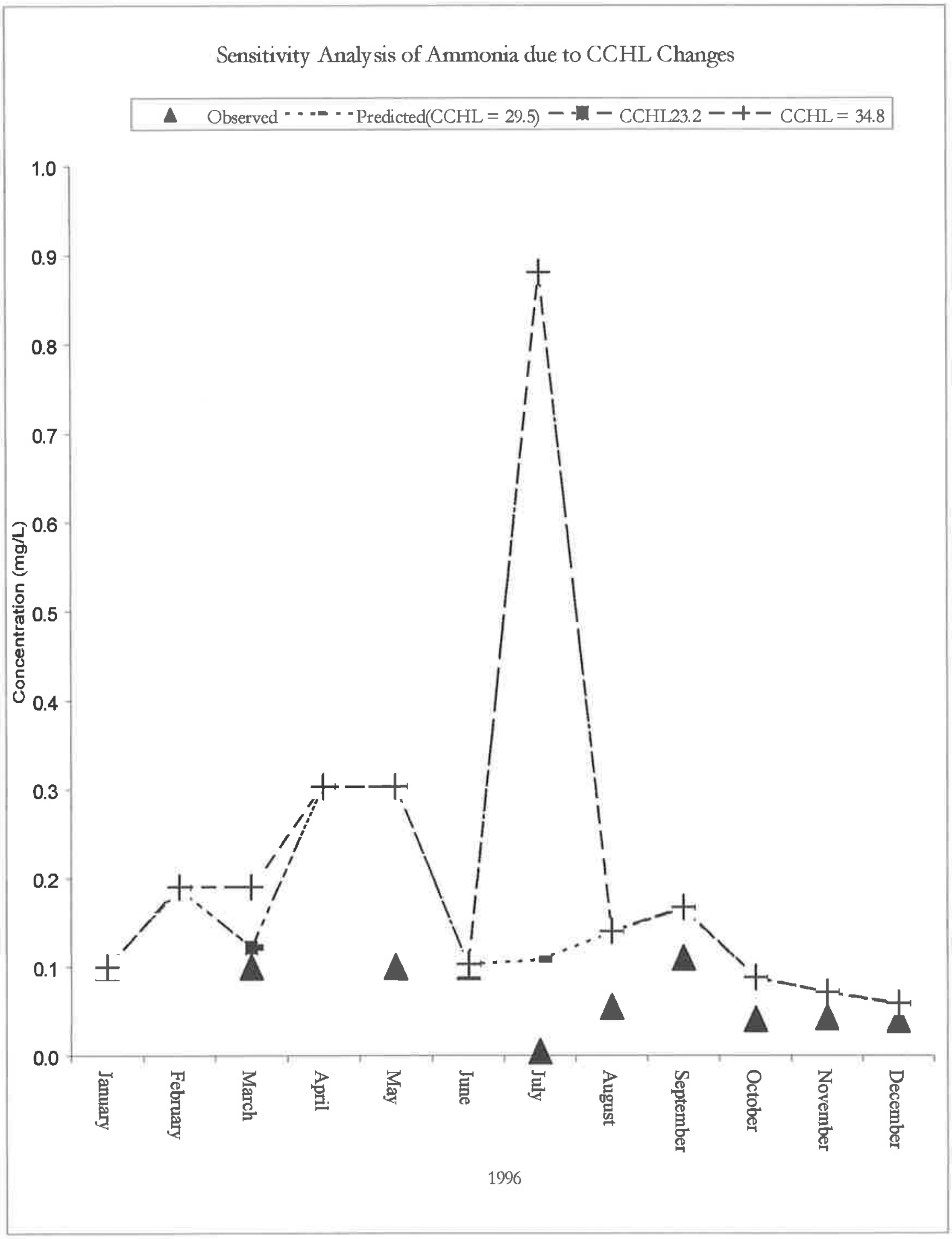


Figure 6.42 Sensitivity analysis of Ammonia due to CCHL changes

VII. Cumulative Effects

7.1 McDuffies' Scaling and Weighting in the Methodology Used in this Study

The procedures to conduct scaling and weighting can be explained below. The reason for using scaling technique is the fact that the concentrations of water quality parameter, that is TKN, Ammonia, Chlorophyll a and Total Phosphorus (they are called sub-sub indices) have different measures. Because of this, direct mathematical operations can not be conducted on these data. For the purpose of combining these data, transformation is required. For transforming the data of water quality parameters, this study used McDuffie's index (Ott, 1978). The reasons for choosing McDuffie's index are as follows.

(1) McDuffie's index is simple and easy to use and the results of this calculation can be used as the indicator for changes in water quality parameters.

(2) McDuffie's index is a linear transformation meaning that the higher or the lower the values of this index will coincide with the higher and the lower concentrations of water quality parameters. This characteristic of McDuffie's index is appropriate for showing cumulative effects.

(2) Depending on the availability of data, many other water quality parameters can be included in the analysis.

(3) This index used the comparison to the baseline condition that is natural level of the pollutant variable so that the calculated indices represent the condition of effects after it is compared to the baseline condictions.

The formula of McDuffie's index is as follow. As can be seen, this consists of two main variables: the observed value of the pollutant variable and the natural level of the pollutant variable.

$$I_i = 10(\frac{X}{X_N})_i$$

(Source: McDuffie and Haney, 1973 in Ott, 1978:218)

In this regards,

I_i is sub-index for the i^{th} pollutant variable;

X is observed value of the pollutant variable

X_N is natural level of the pollutant variable

Considering the components of this formula, finding the natural level of the pollutant variable (X_N) is the problem because data were not available. Data on natural level of pollutants from other estuaries could be used, however different conditions of estuaries may lead to the different value of natural level of the pollutants. For this reason, obtaining the natural level of the pollutant in this study was conducted by running water quality model (WASP5) without any nutrient loads entering the estuary of the study area. Using model without nutrient loads may not be a satisfactory procedure because this may not represent the natural level of pollutants in the study area with the result that this can not represent an accurate estimate of natural level of pollutants in the study area. Nevertheless, this is not the main aim to provide reliable estimates of natural level of pollutants in the study area, the building of methodology is the main emphasis of this study, instead. Therefore, the results of running WASP model without nutrient loads are considered as the natural levels of the pollutants variable.

The main procedure for conducting scaling in this study using McDuffie's index are as follow:

(1) The concentration of each water quality for each segments used for water quality modelling was entered in EXCEL (Microsoft Office 2000) as one column of data.

(2) The concentrations of water quality obtained from running the model without nutrient loadings (assumed to be the natural level of pollutant level) were input as the second columns.

(3) The calculation of the index was then conducted by using McDuffie's formula.

(4) The indices obtained from (3) were then input into Geographical Information Systems.

(5) In combination with original data and statistical analysis of original data, the indices produced were used to determine magnitude and significance of each type of cumulative effects. The complete procedure for determining each type of cumulative effect and their significance can be seen in the following sections.

The procedures explained above are only for the scaling of effects, weighting is an additional procedure for determining the significance of cumulative effects. Elliot (1981:26) proposed formula for use in weighting, called "weighting-summation procedure". The formula is as follows.

$$U(F) = \sum_{i=1}^{n} w_{i.}f_i$$

(Source: Elliot, 1981:26)

in which:

U(F) is desirability or utility, either along a composite dimension of concern (such as water quality) or along an overall index of environmental quality

Wj is the i^{th} weight, and

f_i is the i^{th} impact factor.

In the past, the application of this formula was mostly for aggregating impacts from single activity from different measures and different environmental components. In this study it will be used for aggregating the significance of each type of cumulative effects. Weights were provided to the determination of the significance of each type of cumulative effects.

Elliot (1981:26) claims that the aggregation or amalgamation of effects is a common technique in environmental assessment and judgments are required about relative weights (or significance) of the contribution of each variable. In this case, the determination of weights for calculating the significance of cumulative effects becomes crucial. The following sections describe the determination of types of cumulative effects.

Figure 7.1 explains the general procedure used for the determination of types of cumulative effects in the form of an aggregated index. As can be seen in Figure 7.1, scaling and weighting are the main techniques used for determining the significance of each type of cumulative effects. Figure 7.1 can be explained as follow. All of the processes for the determination of types of cumulative effects were based on the main premise that Valued Environmental Components/VEC(s) has been selected from scoping, that is water quality.

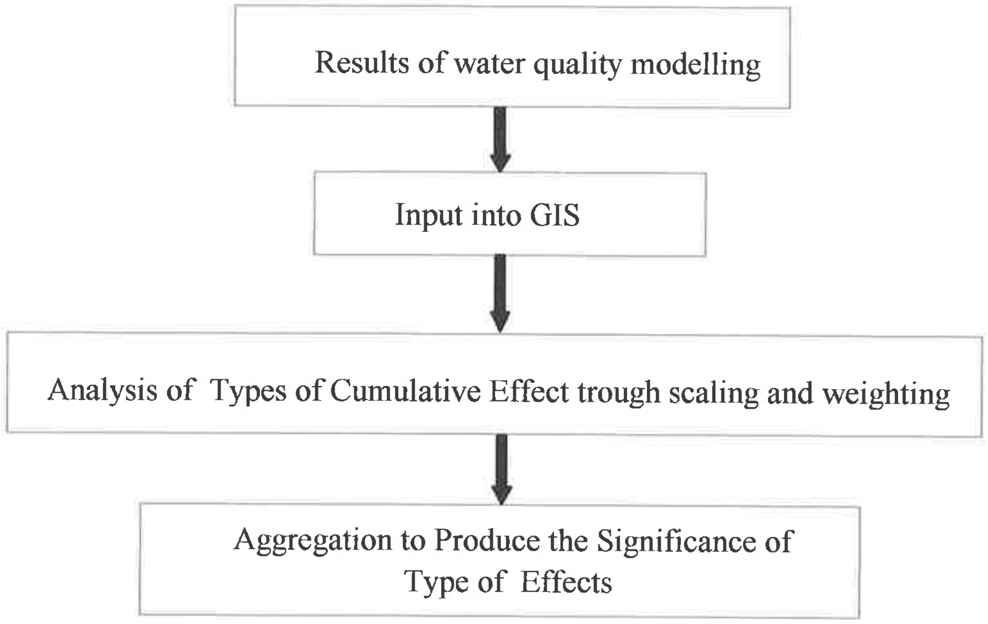


Figure 7.1 Procedure for Determining Type of and the Total Cumulative Effect

There is a component of spatial and temporal variability of water quality parameters in the study area. For example, it was observed that there is a temporal component of the maximum concentration of water quality parameters in the study area (see section 6.1) and in other estuaries (Mallin, et al., 1999; Thompson, 1998) which lead to the determination of which concentration of water quality parameters are appropriate for further analysis. For this reason, this study used only maximum concentrations of each water quality parameter for every year or activities modelled and these maximum concentration values were used for further analysis.

The results of water quality modelling are in the form of numeric values (concentrations) for every water quality parameters (Chlorophyll a, Ammonia, TKN and Total Phosphorus). These are, then input into Geographical Information Systems (GIS). The selected water quality parameters are then processed to result in the significance of each type of cumulative effects through scaling and weighting. In this regard, cumulative effects are defined as the sum of the significance of each type of cumulative effects.

7.2 Determining Types of Cumulative Effects

The following sections will explain the methodology for determining each type of cumulative effects.

7.2.1 Determining Space Crowding and Temporal Crowding Types of Cumulative Effects

Space Crowding and Temporal Crowding effects are two types of cumulative effects that are likely to relate to each other. The example of these types of cumulative effects in an estuary can be explained as follows. If there is no significant difference between high concentrations of particular water quality parameters in segments used for the water quality model in the consecutive times of analysis, this will show that the density of impacts is high.

This indicates that activities and their impacts on a particular VEC are close together so that their combined effects have resulted in a high density of adverse effects from one time to the other. Considering this, the space crowding type of cumulative effects is the most likely to occur.

In this study, spatial and temporal crowding types of cumulative effects will be analysed together because the results were from water quality modelling, which considered spatial and temporal dimensions in combination. These two types of cumulative effects are difficult to separate (Cocklin, Parker and Hay, 1992a). If a high concentration occurs in every part of estuaries from one time to the other, then this is likely to be the indication of space crowding effects. Therefore, spatial dimension should be investigated firstly and then the temporal dimension would follow. To deal with the spatial crowding effects, Geographical Information Systems (GIS) is the most appropriate method.

Various techniques in GIS can potentially be employed for analysing space crowding type of cumulative effects. The analysis of spatial autocorrelation is available in the Arc/Info Geographical Information Systems. The Grid Module is a part of Arc/Info 8.1 for analysing raster data and there are two spatial autocorrelation techniques available in GRID, these are the "Moran index" and "Geary index". The Moran technique was chosen due to the fact that the values of indices can be interpreted in similar ways to the conventional idea of positive or negative correlation. The following is the interpretation of Geary and Moran Indices.

Spatial autocorrelation is a statistical methodology, derived originally from serial trends in econometrics, which quantifies spatial relations and has been applied to many geographical problems (Cliff and Ord, 1973; Tiefelsdorf, 1997 in Roberts, Hall and Calamai, 2000:186).

Table 7.1 Interpretation of Moran Indices of Spatial Autocorrelation
(Sources: Summary from Odland, 1988)

Geary (c)	Moran (I)	Interpretation
$0 < c < 1$	$I > 0$	Similar, regionalized, smooth, clustered
C=1	$I = 0$	Independent, uncorrelated, random
c>1	$I < 0$	Dissimilar, contrasting, checkerboard

This kind of spatial statistic is based on the premise that everything is related to everything else, but closer objects tend to be more related (Goodchild, 1987). Two objects which are close together and that have very similar properties are highly correlated. The formula for calculating the Moran index is:

$$I = \frac{n}{\sum_{i=1}^{i=n} \sum_{j=1}^{j=n} W_{ij}} \bullet \frac{\sum_{i=1}^{i=n} \sum_{j=1}^{j=n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{i=n} (x_i - \bar{x})^2}$$

(Source: Odland, 1988:10)

From this formula,

Wij	is the binary weight matrix of the general cross-product statistic, such that Wij = 1 if locations i and j (e.g. two different cells or points) are adjacent and zero for all cells, points or regions which are not adjacent and by convention Wij=0 (a cell or region is not adjacent to itself).
x_i	The values
$\bar{x}$	Mean value

The implication for the determination of spatial autocorrelation using the Moran index is that if the calculated values of the index are high, then this will indicate that there has been similar, regionalised and clustering of effects. This means that effects are spatially distributed and consequently spatial accumulation of effects are likely to occur. By comparing temporal values of Moran indices, this will lead to the identification of space crowding type of cumulative effects. Temporally high values of Moran indices can be used as the indication that space crowding type of cumulative effects is likely to occur.

However, the results of this analysis should be interpreted carefully because high values of spatial autocorrelation indices can relate to the equal distribution of either high or low values of the concentration of water quality parameters. Therefore, the values of indices resulted from the analysis using "spatial autocorrelation techniques are not the only measure for identifying the "space crowding" type of effects. In other words, there is no relationship between high values of spatial autocorrelation and the magnitude and significance of space crowding type of cumulative effects, this only indicates the spread of impacts. Spatial autocorrelation technique is useful to differentiate the local and regional types of cumulative effects.

There is flexibility in analysing space crowding effects using GIS. The analysis may focus on some segments to study the changes of the values of the Moran index. For example, the calculation of the index can focus on part of the study area: either the segments in Barker Inlet or Port River estuary. The analysis for overall segments was conducted, and then the results were compared. This provides information about the characteristic of space crowding effects for each estuary.

Stages used for identifying and determining space crowding effects are listed below. The process for identifying the presence or the absence of space crowding type of cumulative effects can be seen in Figure 7.2. Figure 7.2 is only the procedure for determining the presence and the absence of space crowding type of cumulative effects. This figure is not that for determining the magnitude and significance of space crowding type of cumulative effects. The procedure for identifying the space crowding type of cumulative effects is as follow.

(1) Existing segment (junction) coverage was viewed and the centre points for every segment was, determined.
(2) Attributes of these points were then assigned. The values of the concentration of chlorophyll a, Ammonia, Phosphorus Total and TKN per segment were put into a GIS. The maximum, mean and minimum of water quality parameters for each segment are entered as the attributes of the points. In this regard, every segment has one value.
(3) Spatial autocorrelation was then conducted using raster GIS.
(4) Interpretation of the values of Moran indices obtained.

The procedure as stated above (using the centre points of segments for analysing space-crowding type of cumulative effects) can be easily criticised by considering the within-segment variability of the concentration of water quality parameters. Applying this procedure for other estuarine areas should consider the following conditions:

(1) The size of the estuary being studied. The smaller the size of the estuary, this procedure is likely to provide the reliable estimate of the values of Moran indices. For example, in the study area, there are varying sizes of segments used for water quality modelling and the larger the cell size would provide variability more that the smaller cell size. It is no doubt that this would affect the way the pattern can be recognised from the values of Moran indices.

(2) The cell size used. The cell size can also determine the values of the Moran indices. If this kind of procedure is applied in larger cell size and larger area, this will also affect the results of the Moran indices. To provide a reliable estimate of the Moran indices, the size of the segments in the large estuary must be in sufficiently detail.

(3) Finally, the availability of data would determine the values of Moran indices if this procedure is used. The larger the resolution of the data (the larger the amount of data), the more accurate the data, the more accurate the Moran values calculated.

From these three components above, it is clear that the accuracy of the data and the configuration of sampling locations of the data (e.g. water quality parameters in estuary) determine the reliability of the estimation of Moran indices.

The following procedures were used for the determination of the significance of space and temporal crowding effects.

(1) The results of the analysis using water quality modelling for every time/activity were input into GIS. The analysis of space crowding type of effects using Moran indices was then conducted.

(2) Operations on these layers (the layers of sub-indices) were conducted to create final index of space and temporal crowding type of cumulative effects through aggregation.

(3) In this analysis, the first aggregation was conducted for every activity or every date. In this study, date and activities selected were 1996 data set, 1997 data set, time when dredging, after dredging, after dredging and no nutrient loadings and nutrient loading increase 3%. In terms of aggregation, the sub-sub-indices for TKN, Chlorophyll a, Ammonia and Phosphorus Total were aggregated for 1996 data set, 1997 data set, time when dredging, after dredging, after dredging and no nutrient loadings and nutrient loading increase 3% respectively.

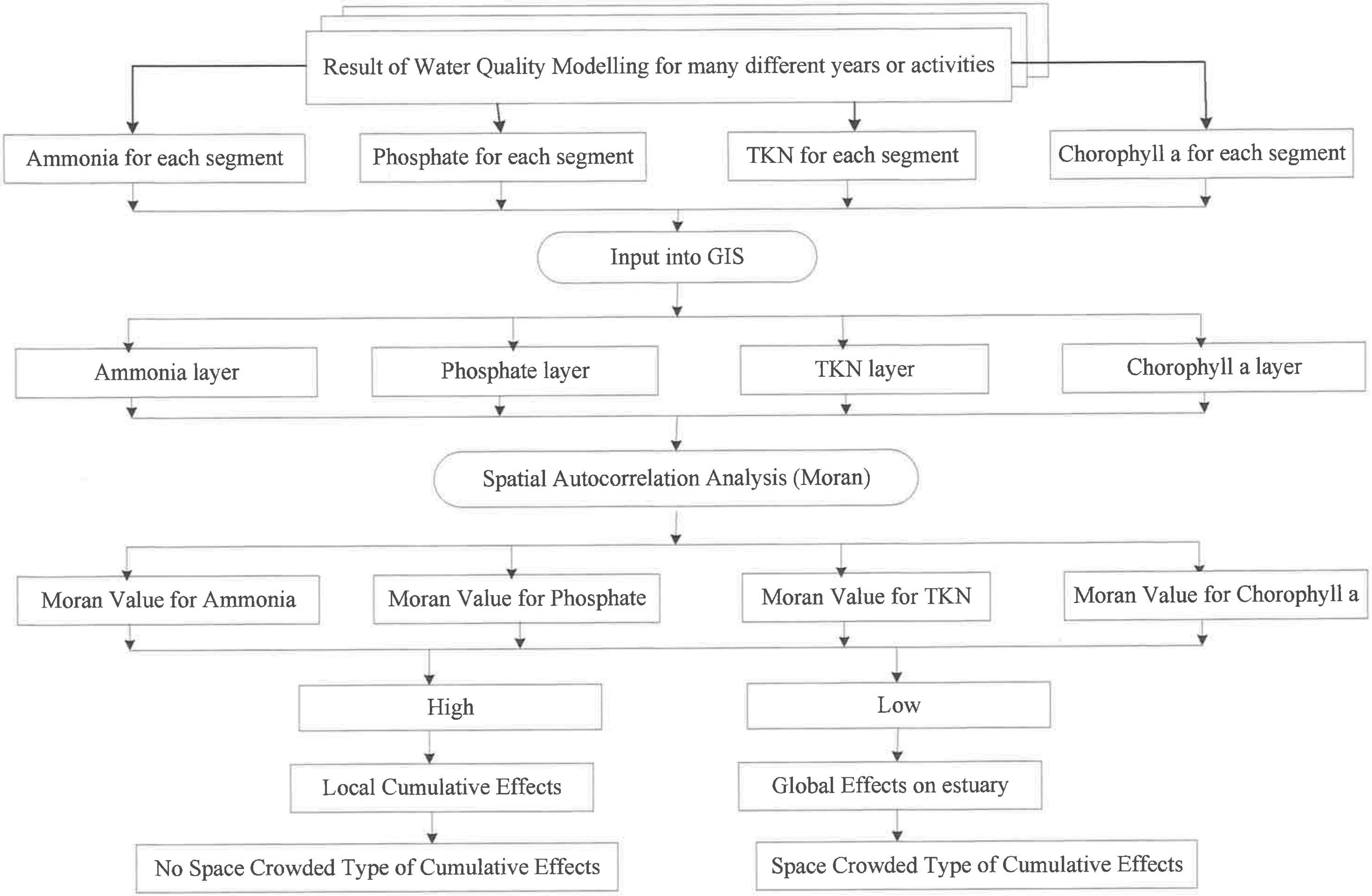


Figure 7.2 The Procedure for Identifying The Presence and The Absence of Space Crowded Type of Cumulative Effects

In this regard, the summation of sub-sub-indices was conducted after the scaled values were given the weights. The weights were determined proportional to the values of Moran indices for every water quality parameters for every time or activity. This resulted in the sub indices. This means that the higher and the lower the weights provided coincide with the higher and the lower values of Moran indices.

(4) Further aggregation was conducted for determining the significance of space crowding type of cumulative effects. This was conducted by summing the sub-indices to result in an index of the significance of space crowding type of cumulative effects.

(5) Reclassification of the index produced was conducted in Geographical Information Systems (GIS). The classes used for this purpose can be listed in Table 7.2. The ranges of the values are obtained from the determination of class according to the distribution of data.

Table 7.2 Classes Used to Differentiate Space and Temporal Crowding Type of Cumulative Effects (Source: Analysis in GIS)

Significance Classes of Space and Temporal Crowding Type of Cumulative Effects	Range of Values
Not Significant	0 - 450
Significant	451 - 900
Very Significant	More than 900

The classes of significance of space and temporal crowding type of cumulative effects as shown in Table 7.2 have generic use. This means that if there is no evidence of space and temporal crowding types of cumulative effects, this can be used to differentiate the significant classes of temporal or space cumulative effects. The complete procedure for determining the magnitude and significance of space and temporal crowding type of cumulative effects can be seen in Figure 7.3 below.

7.2.2 *Determining Threshold Type of Cumulative Effects*

Spaling and Smit (1995a:107) and the Council on Environmental Quality (1997:9) define thresholds or triggers as disruptions to environmental components or processes that fundamentally alter system behaviour or structure or functions. They provide some examples of threshold type of cumulative effects, such as the depth of the water table and the moisture that are altered by the drainage or global climate change.

The determination of thresholds beyond which cumulative effects significantly degrade a resource, ecosystem and human community is often problematic (Council on Environmental Quality, 1997: 7) and difficult to define (Reid, 1998:122). The problems in the determination of thresholds type of cumulative effects relates to the inclusion of subjective factors. Different stakeholders may have different opinions about the conditions, which cause the fundamental change. Obtaining information about fundamental change may require significant amounts of information, which is not always available.

"The ideal threshold would be an easily recognised value separating significant and insignificant effects" (Reid, 1998:122). But, the words "significant and insignificant could have different meanings for different person" (Reid, 1998:122). Standard water quality values can be used for assessing threshold levels (EPA in http://es.epa.gov/oeca/ofa/cumula.html). In addition, EPA also suggests that some considerations for choosing a threshold are: practical, scientifically defensible, and fit the scale of the analysis and can be qualitative and quantitative. The values set in the standards on water quality were used in this study to determine the thresholds. The implication of using these values of thresholds may be that particular segments in the estuary may have different responses to perturbations so that parts of the estuary may have experienced conditions in which they have exceeded the thresholds.

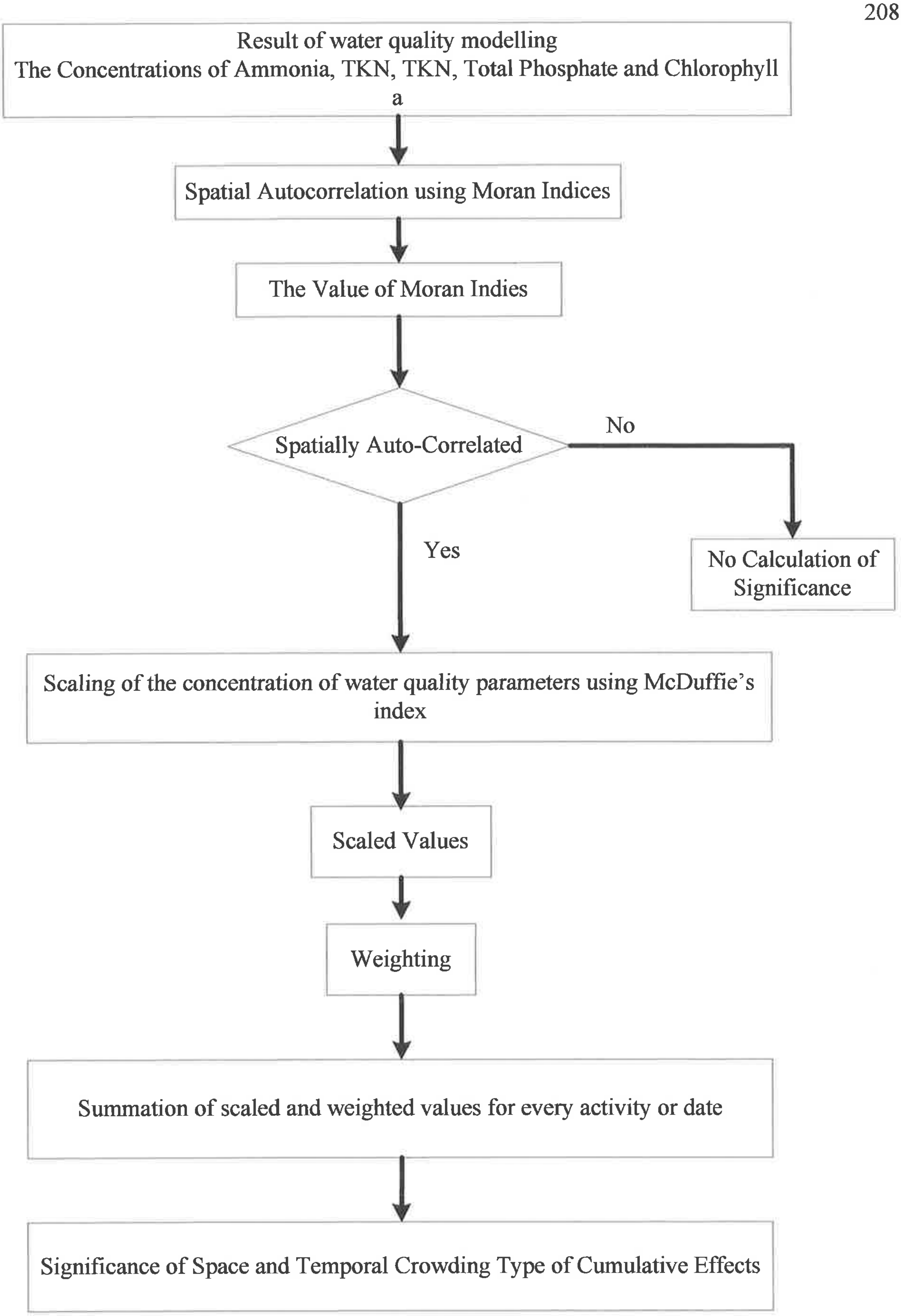


Figure 7.3 The Procedure for Identifying and determining the significance of Space and Temporal Crowding Types of Cumulative Effects

The importance of the determination of a threshold in this study is to determine which parts of the estuary have experienced and will experience the concentration of particular water quality characteristics that exceed threshold levels. Knowing the distribution of the segments which have the concentrations exceeding threshold values from one time to the other is crucial. This is due to the fact that this understanding leads to identification of the presence or the absence of threshold type of cumulative effects for each segment. This would then assist in the determination of the significance of threshold type of cumulative effects.

The following procedures were used for the determination of the threshold type of cumulative effects. The process of identification of threshold type of cumulative effects can be seen in Figure 7.4, while Figure 7.5 shows the stages used for determining the significance of threshold type of cumulative effects.

(1) The results of water quality modelling were input into a GIS.

(2) The layers of threshold levels were created. These threshold levels are the standard values of water quality for TKN, Ammonia, Chlorophyll a and Phosphorus.

(3) The thresholds were then determined by subtracting the layers of four water quality for 1996 data set, 1997 data set and the modelled results to the threshold levels. If the result of this subtraction were positive for a particular segment, this means that the concentration of particular water quality parameter exceeds the threshold.

(4) Weights were also given to each segment used for water quality modelling. There were only two weights provided, 0.9 for segments which have the concentration of water quality parameters exceeding the threshold values and 0.1 for segments which did not exceed the threshold values. The sum of weights provided must be equal to 1. Subjective judgment was used to determine the values of weights of 0.9 and 0.1 by using the main considerations from the management point of view. From the management perspective, the segments which have the values exceeding threshold will be much more difficult to manage than those which have the lower values than thresholds values. It is assumed that there is a significant difference in

the management efforts between these two conditions. Therefore 0.9 and 0.1 are weights for those which represent extreme conditions.

(5) Summing all the scaled indices and their associated weights produces an index of the significance of threshold type of cumulative effects.

The values used to set the threshold level were obtained from Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000:3.3-14) in http://www.ea.gov.au/water/quality/pubs/wqg-ch3.pdf. The values set for threshold level can be seen in Table 7.3 below. This table only shows the selected records from the original table available in the above web site.

The values set in the estuarine environment (bold and italics) in Table 7.3 are the main concern in this study. These values for estuaries were used to set the threshold for four water quality parameters. Because values for TKN and Ammonia are not available, the values set for Ammonia were those available for $NH4^+$ in Table 7.3 and the values set for TKN were those for TN.

Table 7.3 Default Trigger Values for Physical and Chemical Stressors for South-west Australia (Sources: Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2000:3.3-14)

Ecosystem Type	Chl a (µg/L)	TP (µg/L)	TN (µg/L)	$NH4^+$ (µg/L)
Upland River	Na	20	450	60
Lowland River	3-5	65	1200	80
Freshwater lakes and Reservoir	3-5	10	5	10
Wetlands	30	60	1500	40
Estuaries	***3***	***30***	***750***	***40***
Marine Inshore	0.7	20	230	5
Marine Offshore	0.3	20	5	5

The values resulted from the aggregation of threshold type of cumulative effects were then reclassified in Geographical Information Systems (GIS). The following table (Table 7.4) shows the range of values used to determine the classes of significance of threshold type of cumulative effects.

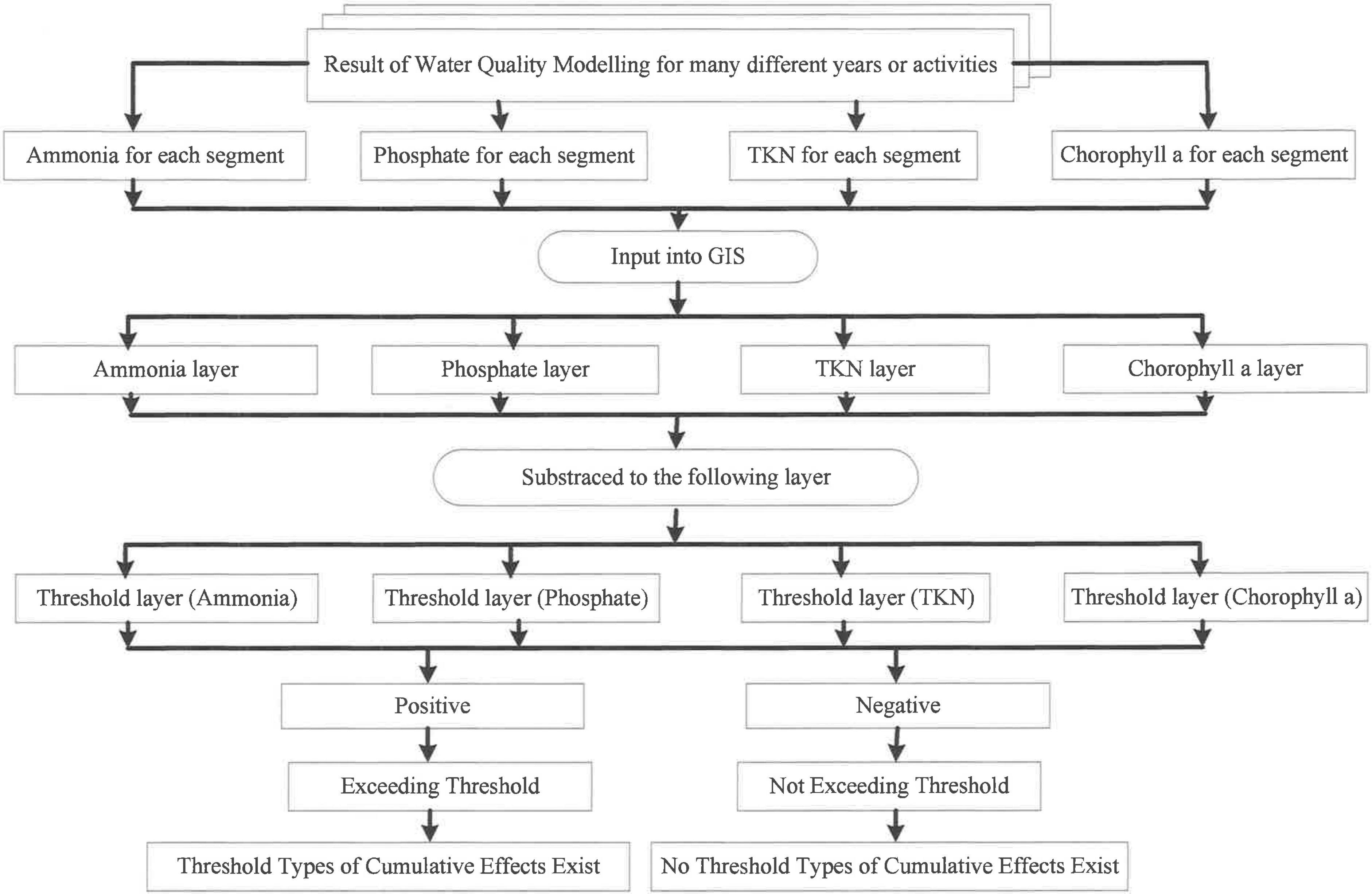


Figure 7.4 The Procedure for Identifying Thhreshold Type of Cumulative Effects

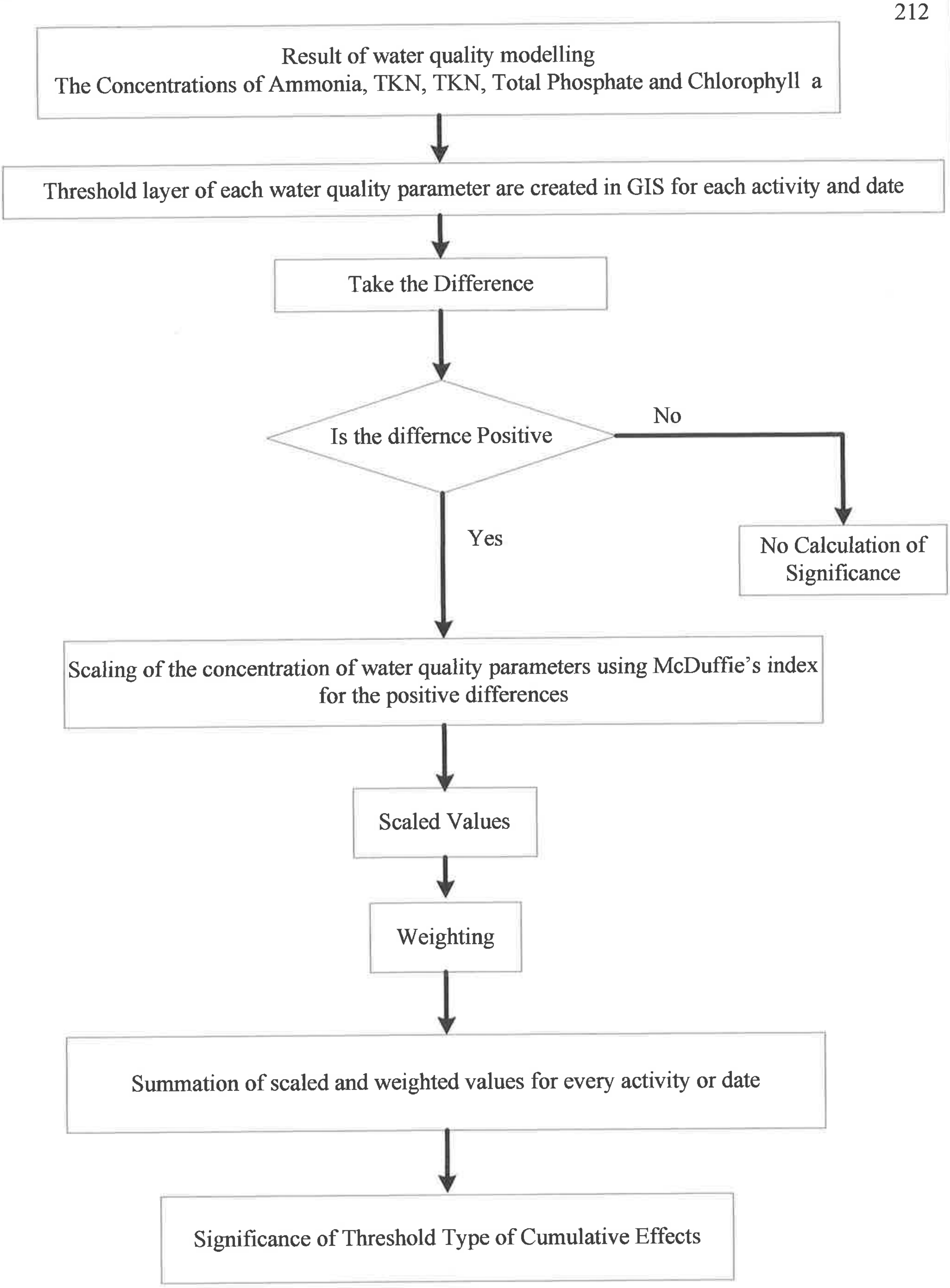


Figure 7.5 Procedure Used for Determining The Significance of Threshold Type of Cumulative Effects

Table 7.4 The Significance Classes of Threshold Type of Cumulative Effects (Source: Analysis in GIS)

Significance Classes of Threshold Type of Cumulative Effects	Range of Values
Not Significant	0 - 450
Significant	451 - 900
Very Significant	More than 901

Using GIS and water quality modelling as the above procedures stated, not only can the significance of threshold type of cumulative effects be determined, but also its locations can be identified. Similar to the analysis of previous types of cumulative effects, the analysis of this type of cumulative effects was conducted in raster GIS. This analysis was based on the main premise that some parts of the estuary may have reached threshold values, while other may have not. In other words, there may be the spatial variability of threshold type of cumulative effects in the study area and by using GIS, the spatial variability of threshold type of cumulative effects can be identified.

7.2.3 The Determination of Synergistic Cumulative Effects

This section briefly describes the problems in the determination of the synergistic type of cumulative effects, which is then followed by the methodology used for the determination of the synergistic type of cumulative effects.

The determination of the synergistic type of cumulative effects is considered difficult due to two main reasons: the lack of knowledge and definitions. The most obvious reason for this difficulty is the fact that knowledge of complex interaction embedded in the synergistic cumulative effects is lacking. Besides, the difficulties in the determination of this type of cumulative effects relates to the fact that there are a number of bewildering definitions (Morgan, 1998:201). Apparently, there is no readily available definition which leads to the development of a practical methodology for identifying and determining synergistic types of cumulative effects. The following definitions of synergistic cumulative effects come from previous studies.

(a) Synergism is the interaction of different types of disturbance produce effects qualitatively and quantitatively different from the individual disturbance (Preston and Bedford, 1988:567).

(b) Compounding is synergistic effects arising from multiple sources on a single environmental component (Cocklin, Parker and Hay, 1992a:35).
(c) Compounding can occur when two or more environmental changes interact to contribute to another environmental change (Spaling and Smit, 1995:106).
(d) Compounding effects (synergistic) is the effects of two or more impacts being exacerbated by their coincidence in the same place or same environmental system (Morgan, 1998:202).
(e) Addition is less than their interaction and combination (Power, 1997: 157 and 166).
(f) Although not explicitly defined "synergistic effect is the aggregated impacts in which their addition is less than their interaction and combination (Power, 1997: 157 and 166).
(g) The general principle of synergism underscores the observation that the whole is more than the sum of its part in magnitude, severity, intensity or complexity. Synergism is not simple aggregation but interaction, combination and new pattern (Vlachos, 1985:62).

As can be seen, there are seven definitions of synergistic effects, other definitions may exist. In addition, there have also been different terms for synergistic effects. For example, Cocklin, Parker and Hay, (1992a:35); Spaling and Smit, (1995:106); and (Power, 1997: 157 and 166) view synergistic as compounding effects. A more operational view of synergistic cumulative effects is contained in the last two definitions (Power, 1997; Vlachos, 1985) compared to the others. The last definition is used in this study, although it is clear that this definition is subject to many different interpretations. The reason for choosing the last definition is that this provides a mechanism to assess the significance of cumulative effects, such as the magnitude, intensity and severity.

Considering the last definition only, it is clear that there are two main components of the general principle of synergism, the first one is the "whole", and the second one is "part". These two words are important because by considering "the whole" and "the part", may provide guidance to the development of a methodology for determining synergistic type of cumulative effects in the sense that impacts resulted from the whole component would be greater than the part or parts of components. The determination of a method, which is capable of differentiating the effects of "part" and that of "whole", is needed.

In fact, there have been studies that focus on the synergistic type of effects, although they are not explicitly states as cumulative effects. Previous studies (Vlachos, 1985;

Cocklin Parker and Hay, 1992a; Cocklin Parker and Hay, 1992b; Power, 1996; Spaling and Smith, 1995) recognise that the determination of synergistic cumulative effects is complicated. The main reason for this is that understanding of ecosystem mechanisms is very limited so that the processes of accumulation of impacts are only partially understood.

Examples of methodologies for determining synergistic effects can be found in Drener, et al. (1998); Power (1997); Folt, et al. (1999); Crowder, Squires and Rice, (1997); Lin, et al. (1996); Power (1996); Breitburg (1999) and Ashended, Bell and Rafarel (1996). The study by Drener, et al. (1998) emphasises the interaction of nutrient loading and omnivorous fish to phytoplankton on lakes. The synergistic effects of the combination of multiple stressors on the fish community are the main emphasis of the study by Power (1997). The methodological aspects of these studies are:

(1) Experiments were conducted to assist in the determination of synergistic effects. Observation of the combination of stressors and their associated effects are conducted.

(2) Comparisons of the results of their combinations were then conducted to determine whether impacts were synergistic or additive.

The obvious characteristic of these studies is that studying synergistic effects requires designed experiments to find out the possible combination of stressors that causes impacts. Therefore, experimenting with the combination of stressors and observing the results of their combination will likely to be the main procedures for studying synergistic cumulative effects. Treating stressors and responses as variables will not only provide the synergistic information, but this may also provide information on the additive effects. In this study, the stressor used was the amount of nutrient loads entering the estuary, whereas the responses were water quality parameters (Ammonia, Total Phosphorus, Total Kjeldal Nitrogen (TKN) and Chlorophyll a). The reasons for choosing these stressors and responses are:

(1) Data are limited to possibly analyse another VEC. For example, seagrass or mangroves may be an interesting variable to show synergistic effects of different water quality parameters, but the quantitative data of these VEC(s) are lacking to possibly analyse them.

(2) These four water quality parameters have been the main concern in the study area since 1980s when the algal bloom becomes the significance issue of environmental problem in the study area.

The methodology used for determining synergistic cumulative effects in this study can be explained as follow. The indicators used for this analysis were derived from the water quality modelling: TKN, Ammonia, Total Phosphorus and Chlorophyll a.

The analysis of synergistic effects is the analysis of the interaction. Because of the fact that the main problem in the study area relates to the excessive nutrient from three main sources (Port Adelaide Sewage Treatment Works, Bolivar Sewage Treatment Works, Penrice Soda Products), then the nutrient loads in the in the input WASP5 model were changed and combined to other sources of nutrient loads. One additional nutrient loading sources was analysed, namely nutrient loading from stromwater. For this reason, the nutrient loads data (Data Group F in the WASP5 model) were changed (see Chapter VI). Because there are four sources of loads to the estuary (Port Adelaide Sewage Treatment Works, Bolivar Sewage Treatment Works, Stormwater and Penrice Soda Products), they were analysed singly or in combination with each other. The procedure for analysing synergistic type of cumulative effects can be explained below and refer to Figure 7.6 for identifying the synergistic type of cumulative effects. Figure 7.7 relates to the determination of the magnitude and significance of synergistic type of cumulative effects.

(1) The model was run for every activity without combination. For example, the model was run by considering the Port Adelaide Sewage Treatment Works only (Run1).

(2) The model was run for the combination of activities (Run 2, Run 3, Run 4, and so on until all activities selected in the scoping were analysed separately and in the combination).

(3) The graphs of box plot were drawn and interpreted to see visually the differences.

(4) Analysis of Variance. This analysis was aimed at showing whether a significance difference can be observed or not amongst the treatments. The treatments are meant the activities and the dates either single or combination. For example, the concentration of water quality for 1996 data set (this refers to date) is compared to when dredging is conducted to determine whether the significant difference can be observed or not.

(5) Determine the significance of synergistic type of cumulative effects through scaling and weighting (see Figure 7.7 for the procedures used).

If there is significant difference between treatments in terms of the 25th, 50th and 75th quartiles, then this will indicate the presence of synergistic effects. In addition, the results of ANOVA will indicate the significant difference amongst treatments. Therefore, using this kind of analysis, the dependent variable will be the concentration of TKN, Ammonia, Total Phosphorus and Chlorophyll a and the independent variables were the nutrients loads from different effluents. The results of determining the significance of synergistic effects were, then reclassified. The following table (Table 7.5) shows the range of values used for reclassifying the aggregated values of the significance of synergistic type of cumulative effects.

Table 7.5 The Significance Classes of Synergistic Type of Cumulative Effects
(Source: Analysis in GIS)

Significance Classes of Synergistic Type of Cumulative Effects	Range of Values
Not Significant	0 - 250
Significant	251 - 500
Very Significant	more than 501

7.3 Aggregation of Effects

The most important objective of aggregating effects in CEA is to determine the magnitude and significance of cumulative effects. There is the difference between magnitude and significance in terms of aggregation. With regard to the determination of

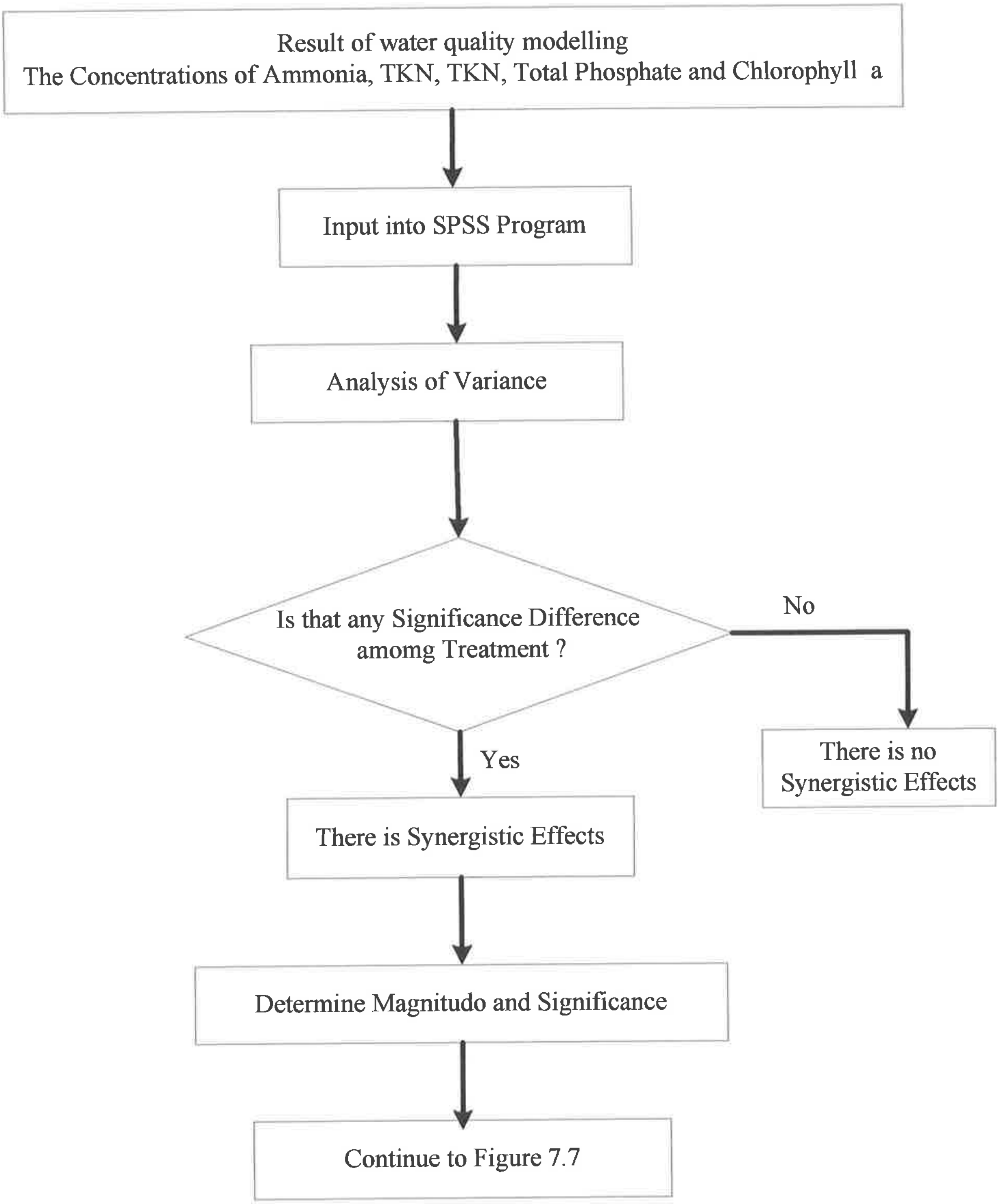


Figure 7.6 The Procedures for Identifying Synergistic Type of Cumulative Effects

the magnitude of cumulative effects, the Council on Environmental Quality (1997:42) in conjunction with the determination of the magnitude of cumulative effects states that::

> Initially, the analyst will usually determine the separate effects of past actions, present actions and proposed actions (and reasonable alternatives), and other future actions. Once each group of effects is determined, cumulative effects can be calculated.

This statement shows that magnitude can be calculated, as evidence from Table 2.5 in Chapter II (Literature Review). As shown in Table 2.5, the summation of "air quality" resulted in the calculated cumulative effects of 35% increase in SO2, which was obtained from the summation of "No Effects in SO2 " for past action, "20% increase in SO2" for present action, "10% increase in SO2" for proposed action and "5% increase in SO2 " for future action. The summation of effects from past, present and future to determine the magnitude of cumulative effects (as Table 2.5 shows may not be appropriate for the estuarine environment, especially water quality.

In this study, magnitude of cumulative effects was the concentration of water quality parameters resulted from water quality modelling. In this regard, different to the determination of significance of cumulative effects, there is no further effort to aggregate the magnitude of cumulative effects. This results of modelling for every time or date or scenarios are the magnitude of cumulative effects. For example, the condition of water quality parameters provided in 1996 data set had been the accumulative performance of the condition of water quality until 1996. Because of the fact that in the effort of modelling water quality, the previous time or date or scenario (namely the results of 1996 data set), especially initial condition and boundary conditions, were used to determine the input data for the next scenario or time (namely dredging), the results of the modelling of current situation is assumed to reflect the condition of the previous time/data or scenario.For example, the result of modelling when dredging was conducted would provide the magnitude of cumulative effects when dredging and the conditions of water quality before dredging.

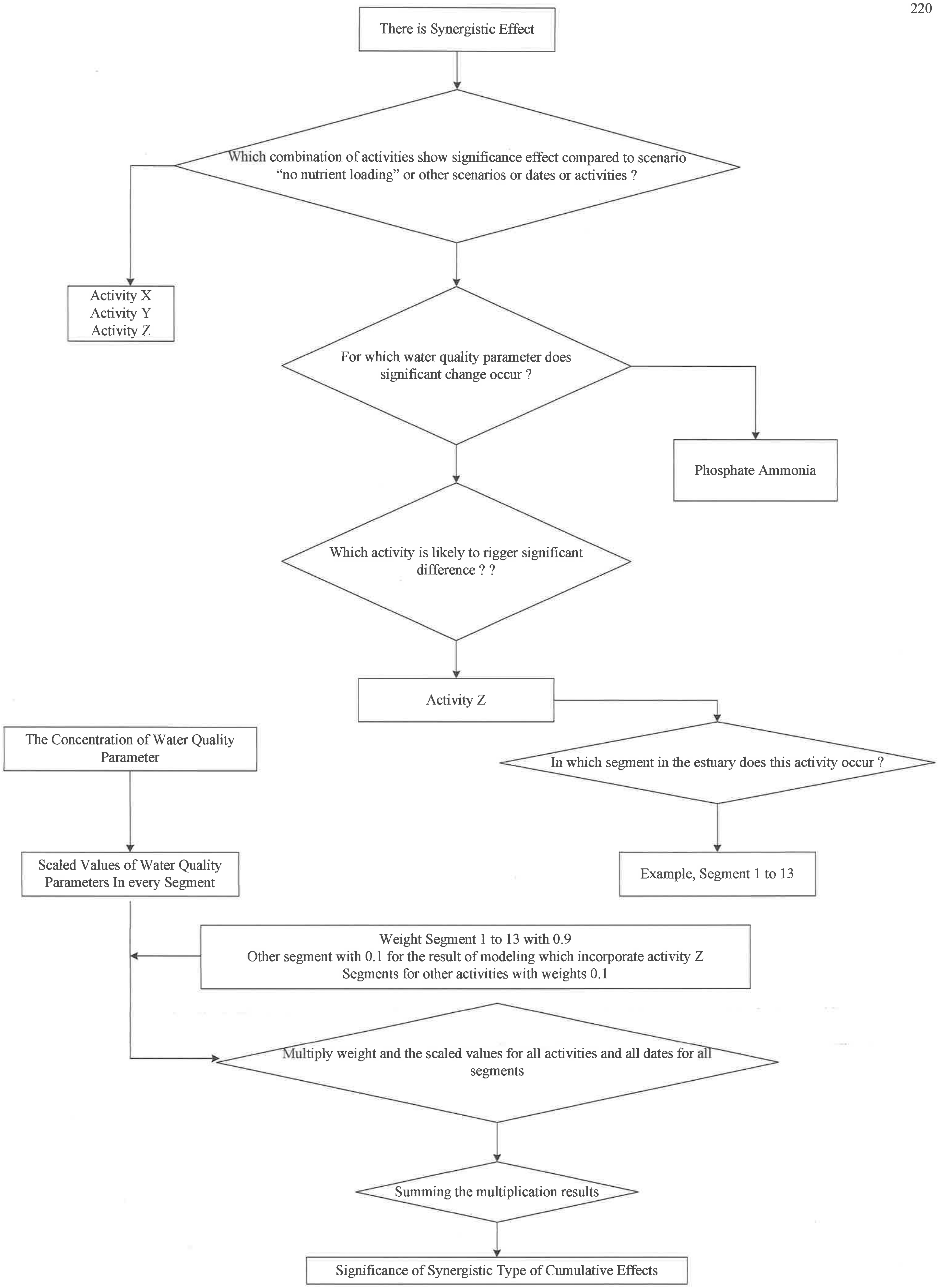


Figure 7.7 The Procedure for Determining The Significance of Synergistic

Significance of cumulative effects is a different issue to magnitude of cumulative effects because magnitude is one of factors that must be considered in the determination of significance. With regard to the determination of significance of cumulative effects, the Council on Environmental Quality (1997:44) claims that there are two basics for the determination of significance of cumulative effects, namely the context and the intensity. In addition, they state that context refers to the notion that the significance must be analysed in several contexts such as society as a whole (human and national), the affected region, the affected interests, and the locality, while intensity refers to the severity of effects, which include magnitude, geographic extent, duration and frequency of the effects. Chapter IV (Theoretical Framework) has described five factors that could affect the interpretation of significance. These five factors are crucial in this study because they were used for providing weights for significance determination of each type and for those for cumulative effects. In addition, Andrews, et al. in Duinker and Beanlands (1986:3) state that there are a number of criteria that should be incorporated for determining significance of environmental impacts. Some of these criteria are:

(1) Magnitude of the impacts.
(2) Spatial extent of impacts.
(3) Duration of impacts.
(4) Probability of occurrence.
(5) Confidence in the impact prediction.
(6) The existence of "set values" (e.g. air or water quality standards).

For determining the significance of each type of effects, the combination of these criteria is more likely to be appropriate than selecting one of them. As the results and discussion will show in the next section (section 7.4 and the sections which follow), the magnitude was the most fundamental prerequisite to determine the significance of cumulative effects.

In relation to the analysis of types of cumulative effects, some of the six criteria may have more relationships to types of cumulative effects than the others. For example, the combination of the magnitude of impacts, the spatial extent of impacts may relate closely with space crowding effects. The fourth criterion is very important in this study due to the fact that the probability of the area and timing for impacts to manifest in the estuarine water will depend on the probability of occurrence. This is crucial by considering the spatial and temporal patterns that can be observed in estuaries. Previous studies on estuarine water quality, as demonstrated in Chapter IV (Theoretical Framework) have shown that there are spatial and temporal patterns of water quality in the estuaries. For those parts of the estuaries which show a high concentration of some water quality parameters over time, these parts are more likely to have a higher probability to accumulate effects than the others.

In order to cover most of the criteria for determining the significance, while this also covers spatial and temporal dimensions, types of cumulative effects become a very crucial component. This study used types of cumulative effects as a fundamental component in the aggregation of effects because types of cumulative effects have relationship with five components and spatial and temporal dimensions, as illustrated in Chapter IV (Theoretical Framework), Section 4.2. The reason for choosing the types of cumulative effects in this study in relation to the five factors that influence the determination of significance has been explained in Chapter II (Literature Review) and Chapter IV (Theoretical Framework).

7.4 Results and Discussion

In this study, four types of cumulative effects are investigated, e.g. spatial crowding, temporal crowding, threshold and synergistic. The following section will illustrate each type of cumulative effects.

7.4.1 Space Crowding and Temporal Crowding Types of Cumulative Effects

Figures 7.8, 7.9, 7.10 and 7.11 show the distribution of four water quality parameters in accordance with activities. These figures were based on the classes of water quality parameters as seen in Table 7.6 below. The division of classes of water quality parameters refers to ANZEC (1992) in Environmental Protection Authority (1997:5).

As can be seen in these figures, there are changes of the extent of the classes of water quality parameters. Class II and Class III are of particular concern due to the significant effort that must be conducted to improve their conditions. From these figures, it can be stated that from 1996 to 1997, there was a decreasing pattern of the areal extent of class III of water quality. As the figures also show, it is predicted that there will be an increase in the area of class III for Chlorophyll a, TKN, Ammonia and phosphate from 1996 to the time when dredging will be conducted. Because nutrient loadings for the Port Adelaide Sewage Treatment Works, Bolivar Sewage Treatment Works, Penrice Soda Product and stormwater draining into the estuary did not change, it was assumed that there is no significant difference in the water quality condition since 1997 until the time when dredging.

Table 7.6 Criteria used to broadly classify water quality for nutrients, turbidity and Chlorophyll a (ANZEC, 1992 in Environmental Protection Authority (1997:5)

Criteria	TKN-N(mg/L)	Nitrate-N(mg/L)	Total Phosphorus (mg/L)	Ammonia-N (mg/L)	Chlorophyll a (μg/L)
Good (Class I)	<1.0	<0.1	<0.1	<0.05	<1
Moderate (ClassII)	1.0-10	0.1-1.0	0.1-1.0	0.05-0.5	1-10
Poor (Class III)	>10.0	>1.0	>1.0	>0.5	>10

Ammonia is the water quality parameter that shows a significant distribution of the areas of class III when dredging will be conducted. A quite significant increase can also be observed on Chlorophyll a, total Phosphorus, and TKN, although the increase will not as high as the Ammonia concentration. Significant increases in the concentration of Ammonia when dredging may relate to sediment as sources of Ammonia. An increasing concentration of these water quality parameters indicate that there is the phenomena of cumulative effects in the study area, especially from 1996 to the time when dredging will be conducted.

These figures also show that there is development of areas of classes of water quality parameters from 1996 until the loads from sewage treatment plants will cease. In this regards, the areas belong to Class III of water quality tend to decrease. These results may be the indication that loads from Bolivar Sewage Treatment, Port Adelaide Sewage

Treatment Work and Stormwater are three major sources of pollutants in the estuary, and stopping the loadings of nutrients into the estuary is likely to result in a better water quality condition.

Although Figures 7.8 to 7.11 provide information on the locations where changes of classes are likely to occur, they can not provide information about the actual extent of changes. The following figures (Figures 7.12 to 7.15) explain the development of classes of water quality parameters in terms of their extents. These figures also show the magnitude of cumulative effects in the estuarine water quality in the study area from one time to another. From these figures, it would appear that despite the reduction in the area of class III in four water quality parameters from 1996 to the scenario of "after dredging and no loads", class II tends to increase for Phosphorus, Ammonia and Chlorophyll a concentrations. The explanations that can be given to this can be related to the results of sensitivity analysis. The results of sensitivity analysis (Section 6.6.3) show that WASP5 (EUTRO5) is sensitive to Carbon to Chlorophyll a ratio (CCHL). Factors that affect the values of CCHL were stated to be light, nutrients and temperature. Therefore, the increase in the class II of Chlorophyll concentrations may relate to these factors. In other words, the limited amount of nutrients may still be able to trigger the algal bloom if light and temperature are available. This may also suggest that nutrient in the estuary will not completely removed when the nutrient loadings into the estuary cease.Increasing concentration of Ammonia and Phosphorus Total as shown in Figures 7.13 and 7.15 may relate to the sediments as the sources of Ammonia and Phosphorus for overlying water. TKN is the only water quality parameters, which shows relatively constant changes in the areas of classes, which may indicate that there is a balance between the sources and sinks of TKN.

Considering the spatial distribution of classes of water quality parameters as shown in Figures 7.8 to 7.11, it is clear that the upper part of the Port River Estuary is the area where it has significant effects of activities, especially the nutrient loadings from Port Adelaide Sewage Treatment Works. The reason for this is that this area experiences less tidal flushing. Spaling (1995a:106) describes cross-boundary flow as constant collection and transport of water and contaminants from one location to another, so that environmental change appears some distance away from the sources. The results of the analysis of space crowding effects show that the cross-boundary flow type did exist, The results also show that there is impact overlap observed. Considering this, the pattern of effects in the study area is likely to space crowding and temporal crowding

type of cumulative effects. Figure 7.12 to 7.15 provide evidence on the presence of temporal crowded type of cumulative effects, from 1996 to the time when dredging. For example, the concentrations of Chlorophyll a, Ammonia, TKN and Phosphorus Total increase, as shown in Figures 7.12 to 7.15.

7.4.2 Magnitude and Significance of Space and Temporal Crowding Cumulative Effects

The magnitude of the space and temporal crowding types of cumulative effects can be explained below. The result of the analysis of the magnitude and significance of space and temporal crowding types of cumulative effects can be seen in Figure 7.16. The segment where the “parting” exists, the segments connecting Barker Inlet and Port River estuaries, and the segments where the Penrice Soda Products discharge solid wastes are likely to show higher index of space and temporal crowding type of cumulative effects than the other segments. From Figure 7.16, the remaining parts of the estuary show class II (significant) temporal crowding cumulative effects which may suggest that tidal activity has a role in diluting the pollutants in these parts of the estuaries.

A similar pattern of accumulation of nutrients is most likely to be observed in the past, due to the similarity in the pattern of tidal movement. From this analysis, it can be concluded that space crowding and temporal crowding type of cumulative effects do exist in the study area. Consequently, three main regions were identified:

(1) The region having very high indices (Class III) of space and temporal crowding types cumulative effects: segments that connect the Port River and Barker Inlet estuaries, and the area where the “parting” is occurred.

(2) The region having high indices (Class II) of space and temporal crowding types of cumulative effects: segments in the Port Adelaide River and Barker Inlet estuaries.

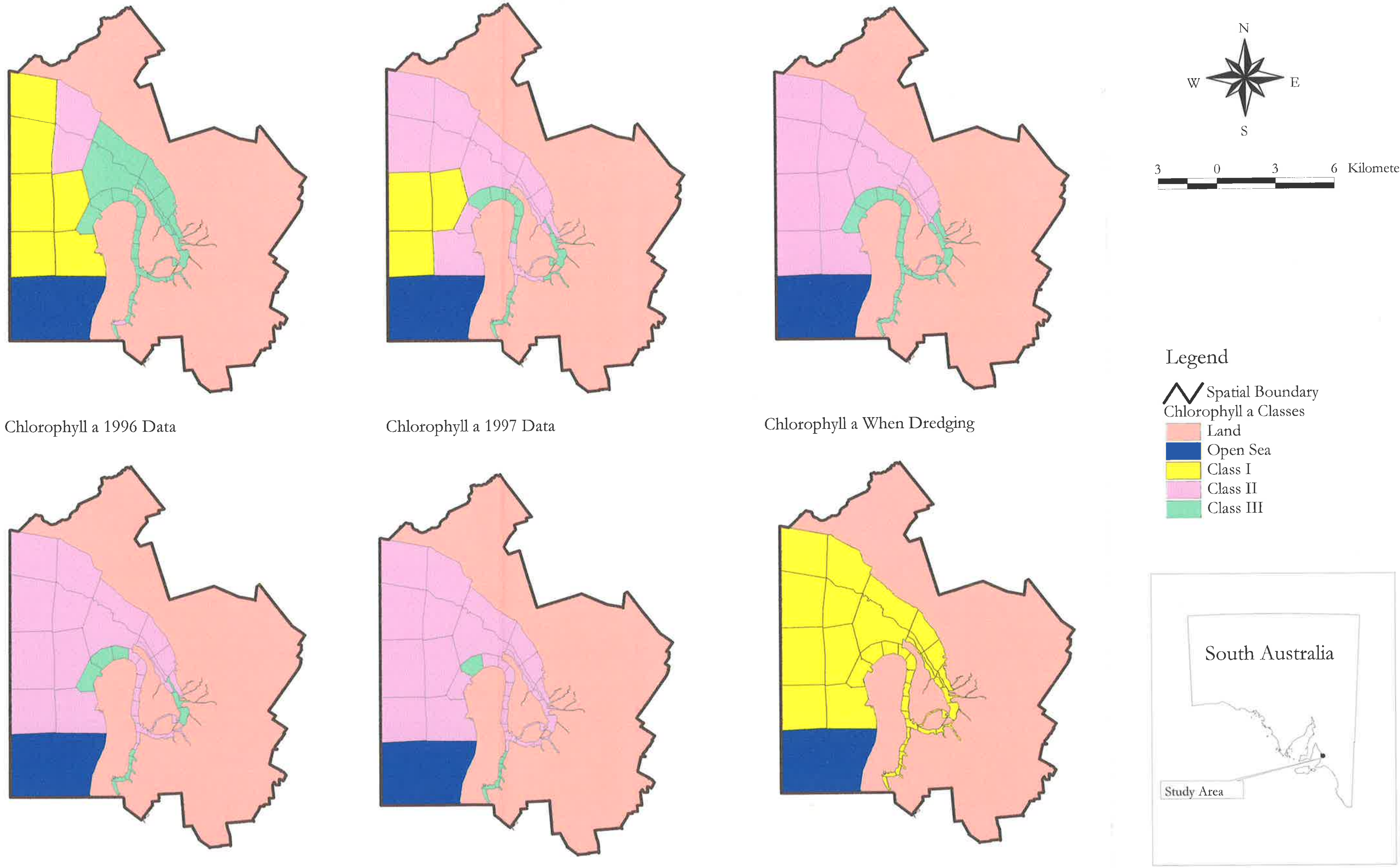
(3) The region having low value of indices (Class I) of space and temporal crowding types of effects: the remaining parts of the segments used for water quality modelling.

As explained, gaining information on space crowding type of cumulative effects can be crucial. The results show that the process of accumulation can be different from one location to the others. This emphasises the importance of including the variability in cumulative effects assessment.

These results show the merits provided by GIS, water quality modelling, scaling and weighting for the analysis of space crowding type of cumulative effects. Water quality modelling was very useful in providing the quantitative values of water quality parameters in space and time, while GIS was very useful for identifying the space crowding type of cumulative effects through spatial autocorrelation techniques. In addition, GIS in combination with scaling and weighting techniques were useful in combining the quantitative values resulted from modelling and qualitative (weighting) for the purpose of aggregating effects. The evidence the presence of space crowding type of cumulative effects can also be seen in the analysis of spatial autocorrelation in the following section.

From Appendix 36, it would appear that there are different values of Moran indices. Except for the Moran values of mean concentration of Chlorophyll a after dredging, all other values are more than 0.8, meaning that there has been similar, regionalised, smooth and clustered pattern of effects.

Figure 7.8 Chlorophyll a Classes in Accordance with Activities



Chlorophyll a 1996 Data

Chlorophyll a 1997 Data

Chlorophyll a When Dredging

After Dredging, Load are the same

After Dredging and No Load

After Dredging, Load increased by 3 %

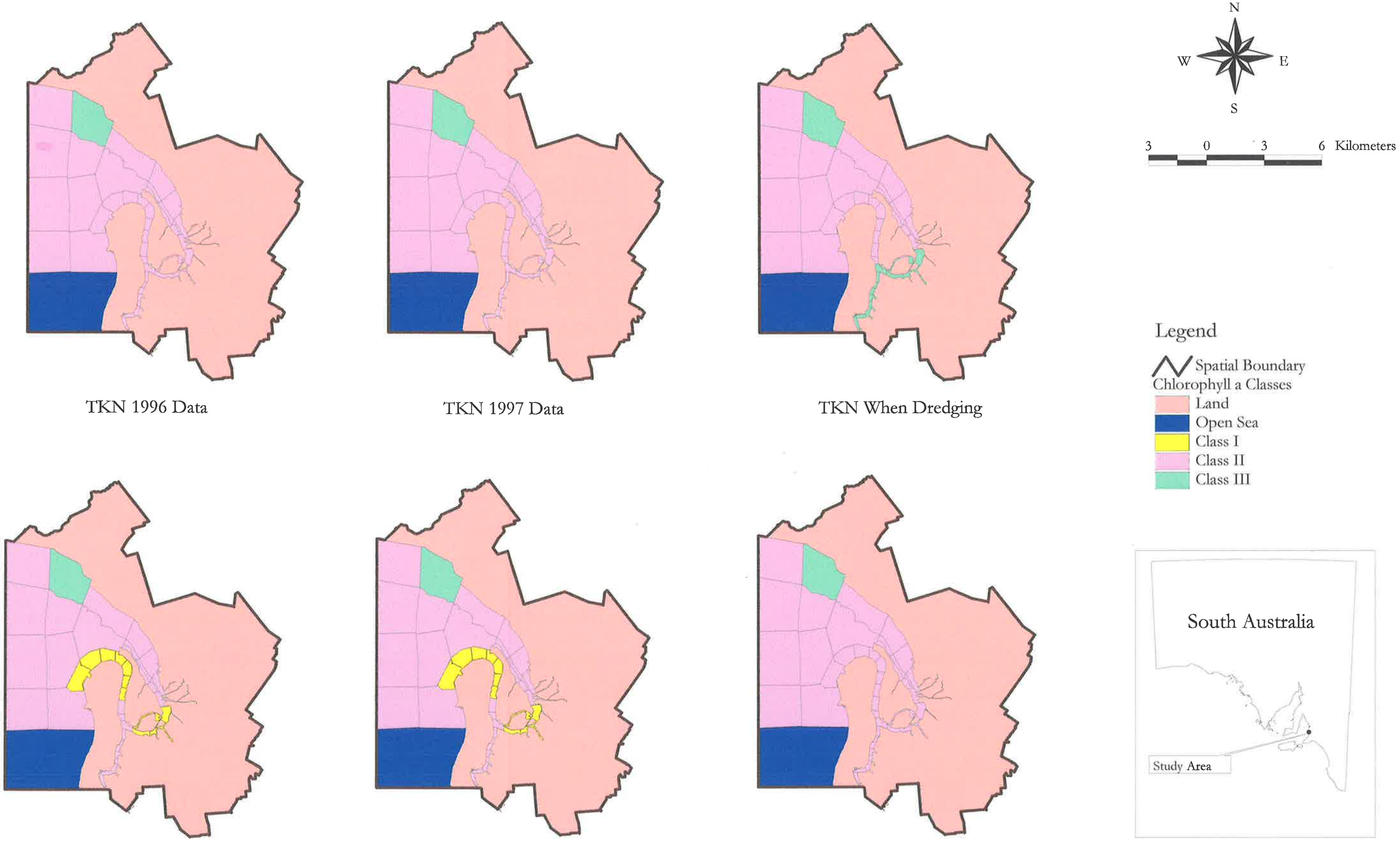


Figure 7.9 TKN Classes in Accordance with Activities

TKN 1996 Data

TKN 1997 Data

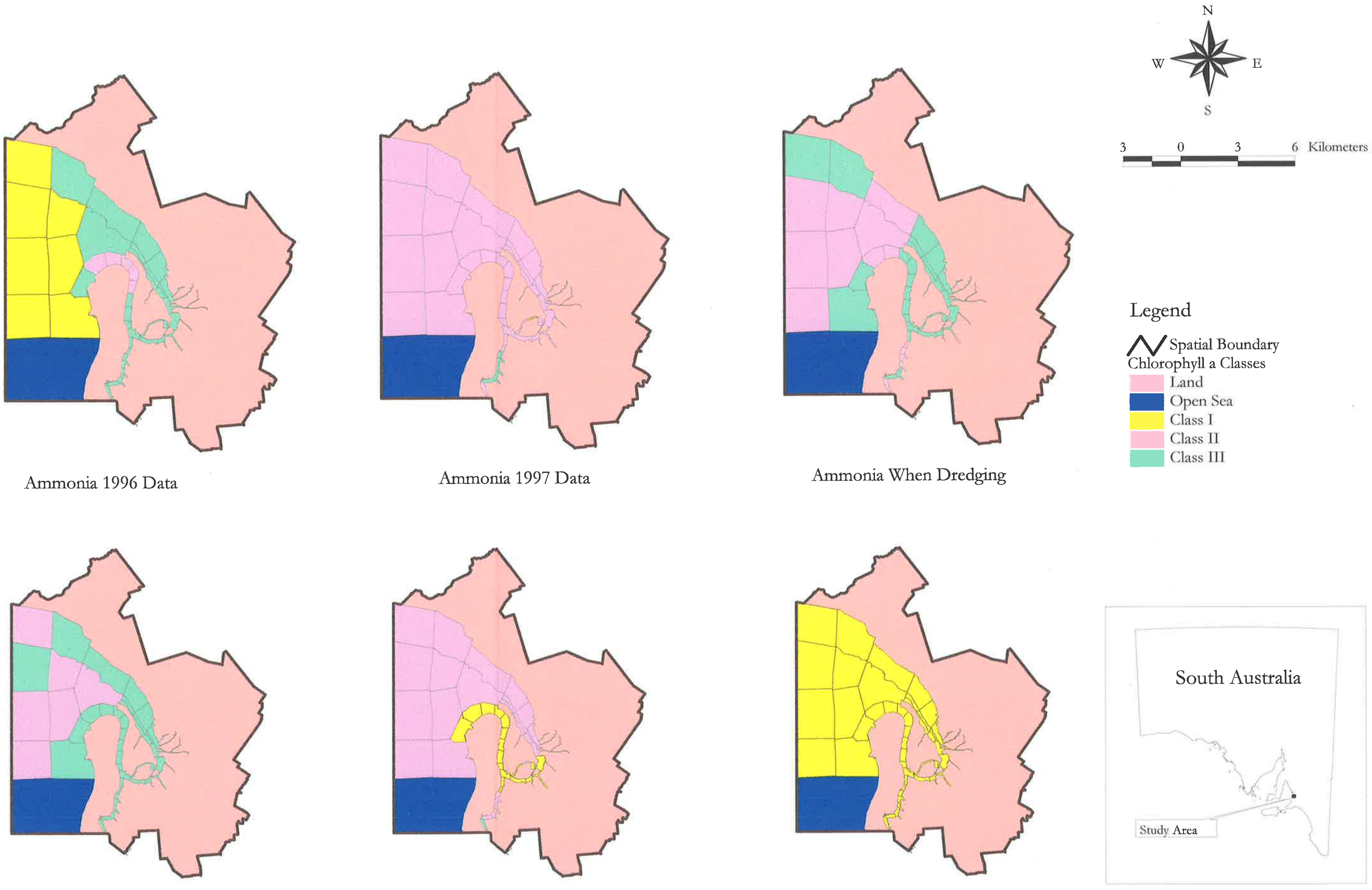
TKN When Dredging

TKN After Dredging, Load are the same

TKN After Dredging and No Load

TKN After Dredging, Load increased by 3 %

Figure 7.10 Ammonia Classes in Accordance with Activities



Ammonia 1996 Data

Ammonia 1997 Data

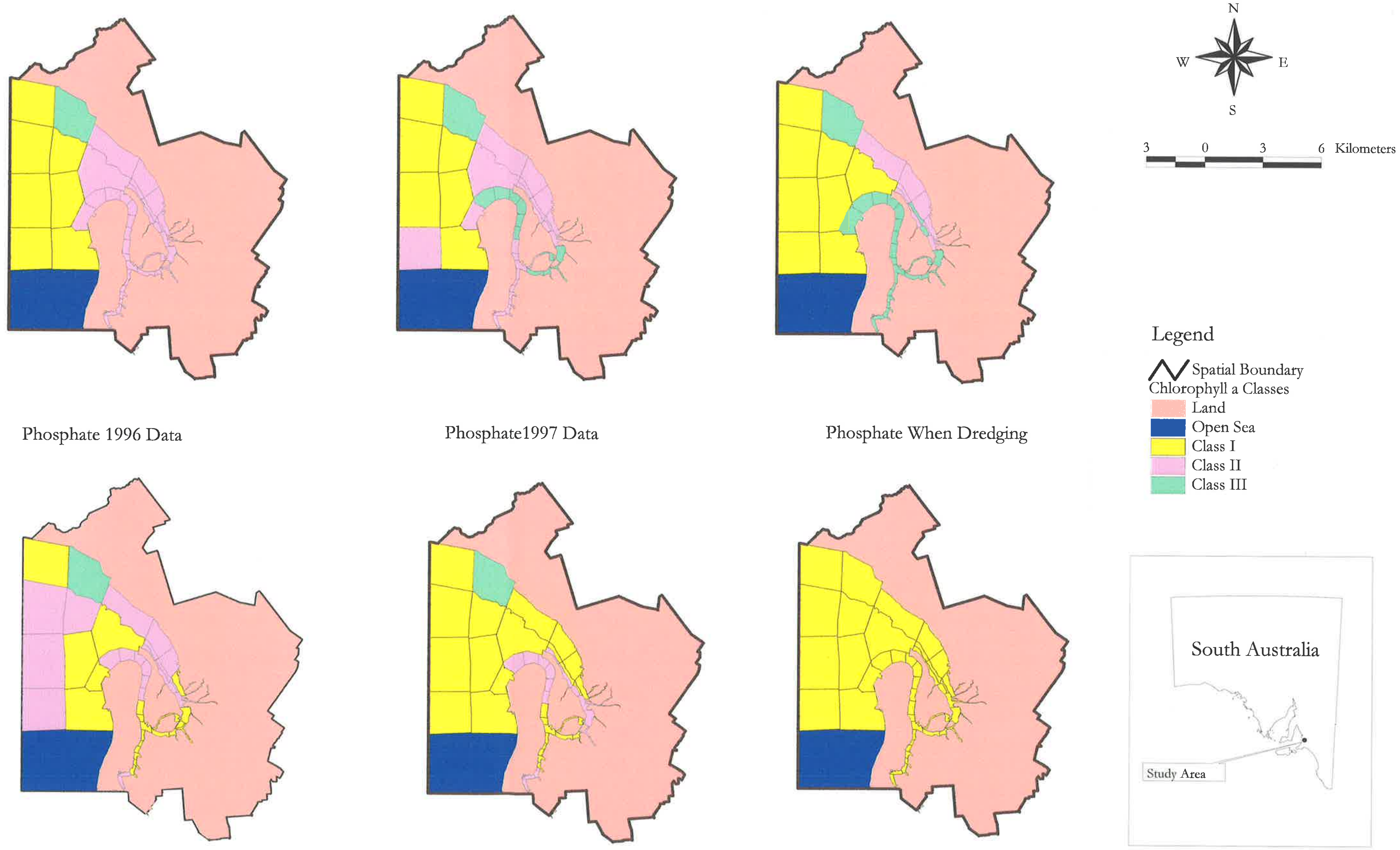
Ammonia When Dredging

Ammonia after Dredging, Load are the same

Ammonia After Dredging and No Load

Ammonia After Dredging, Load increased by 3 %

Figure 7.11 Total Phosphate Classes in Accordance with Activities



Phosphate 1996 Data

Phosphate1997 Data

Phosphate When Dredging

Phosphate after Dredging, Load are the same

Phosphate after Dredging and No Load

Phosphate after Dredging, Load increased by 3 %

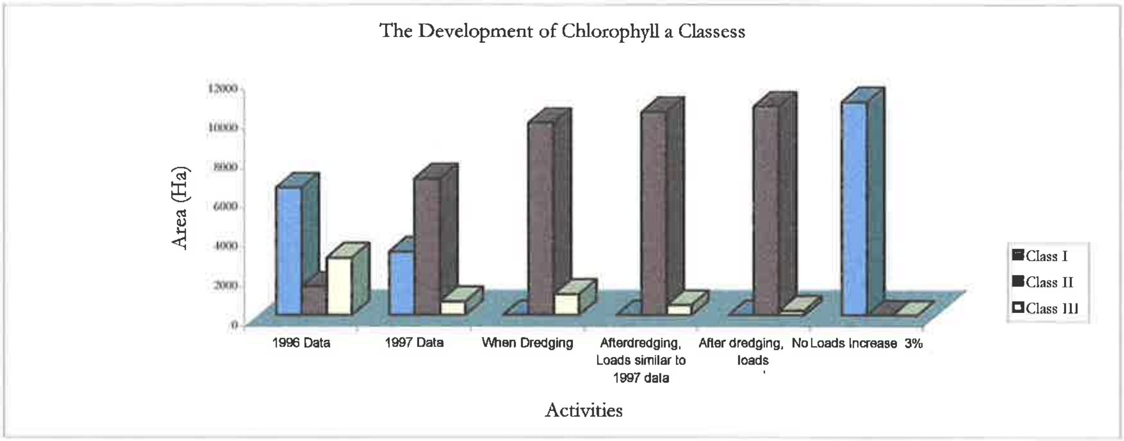


Figure 7.12 The Development of Water quality Classes of Phosphorus Total

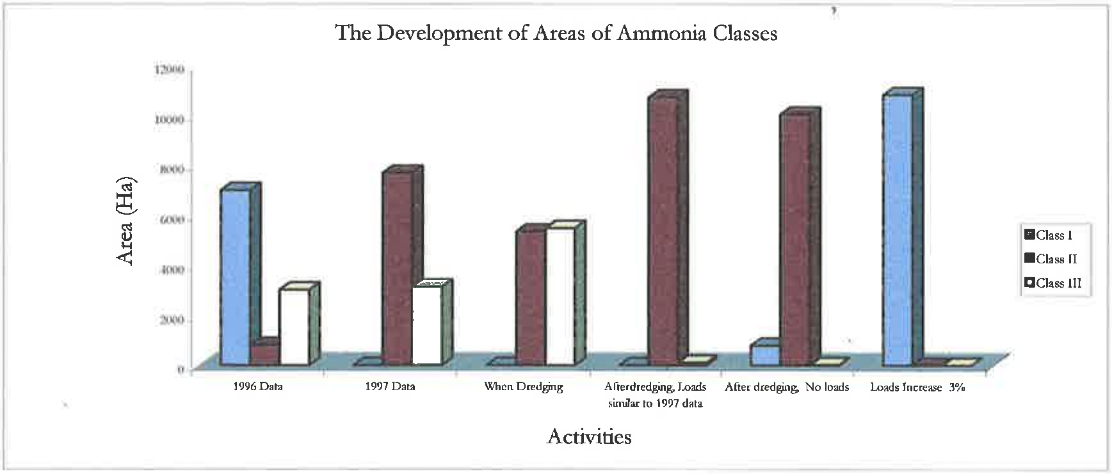


Figure 7.13 The Development of Areas of Classes of Ammonia Concentration

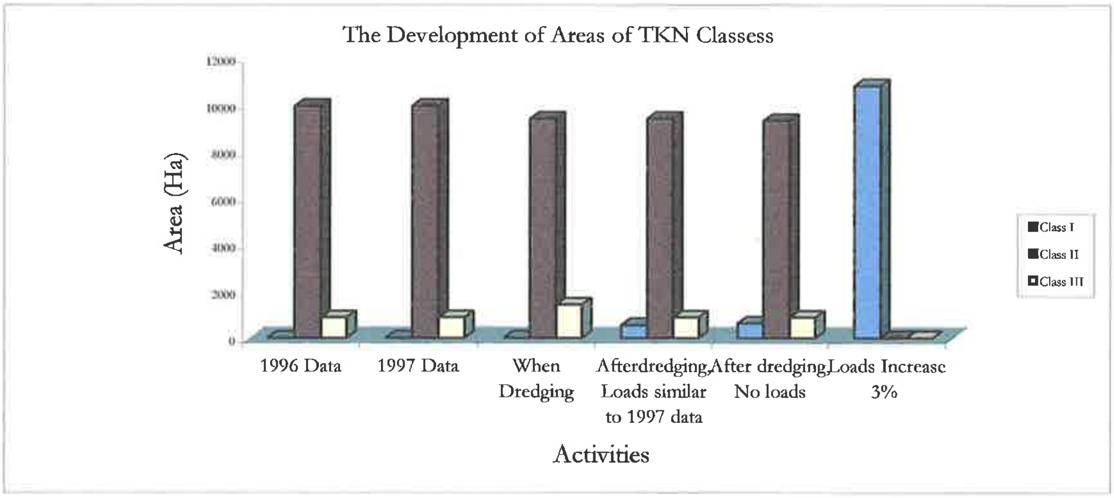


Figure 7.14 The Development of Areas of Classes of TKN Concentration

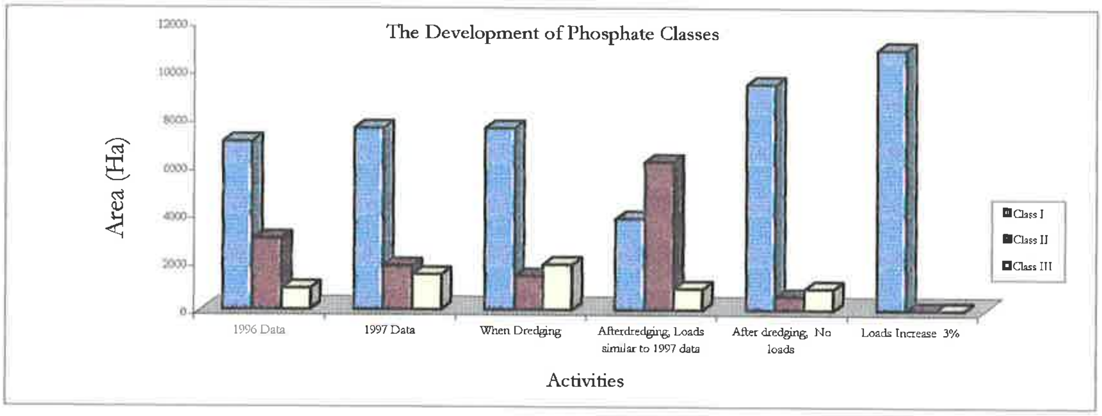


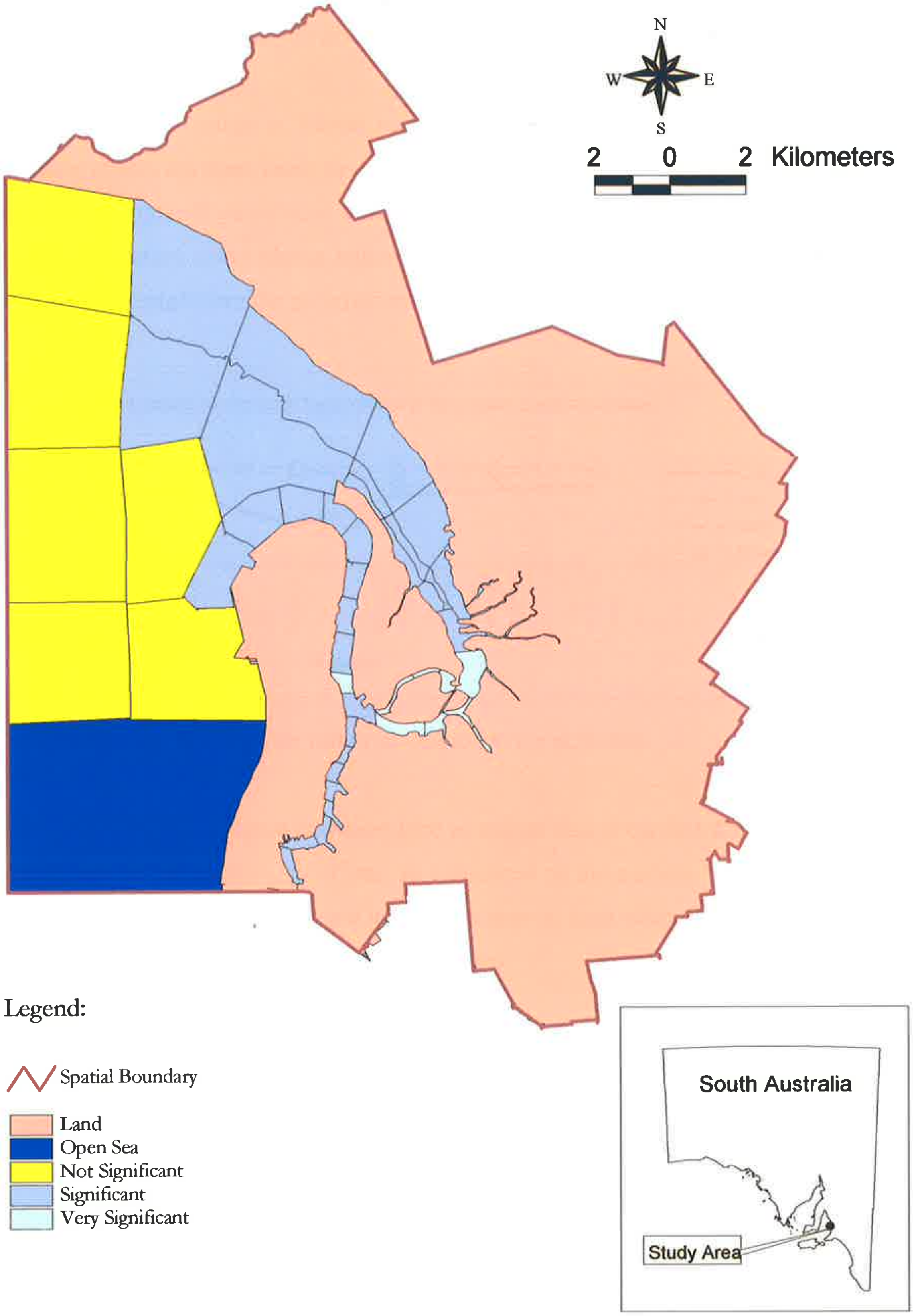
Figure 7.15 The Development of Areas of Classes of Total Phosphorus Concentration

The dynamics of the Moran index of Ammonia strongly indicate that the tendency towards the dissimilarity was observed after dredging, which may indicate the effects of dredging on the concentration of Ammonia before and after the deepening of the Port River estuary. Figure 7.17 shows the dynamics of Moran values obtained from the analysis of spatial autocorrelation of four water quality parameters in relation to the activities or times or year. From this figure, it would appear that except for the concentration of phosphate, the other three water quality parameters show a reducing pattern of similarity and show the pattern of dis-similarity when dredging. This may also be an indication of the localised effects of dredging that is only in Port River estuary. This explanation is likely to be the case for chlorophyll, Ammonia and TKN concentrations, and not for Phosphorus Total, which shows consistent (high) values of Moran indices for overall activities. High values of Moran indices of Phosphorus Total occur for every scenarion, which signify a more regionalised effects. This indicates that there are localised segments having high concentration of Phosphorus Total.

The results of the analysis employing Moran indices, however, must be interpreted carefully due to several reasons:

(1) High values of Moran indices do not necessarily relate to high concentrations of pollutants studied, instead they explain the spatial structure of effects. The higher the values of Moran indices, the more the clustering effects would be. This means that the effects are likely to affect limited areas.

Figure 7.16. The Significance of Spatial and Temporal Crowding Type of Cumulative Effects Index



(2) The values of Moran indices could not provide any information about segments having more concentrations than the other segments. However, results show that there are different values of Moran indices from one time to another which suggested that different parts of the estuary may have a different pattern of the spread of effects for different times or activities for different water quality parameters.

Considering most of the values of Moran indices, which are more than 0.8, it is clear that space crowding effects are most likely to occur in the estuary of study area. This may indicate that space crowding type of cumulative effects occurred in the study area. From the analysis of spatial autocorrelation using Moran indices in GIS, it is apparent that the values of these indices can provide insight into the presence or the absence space crowding effects.

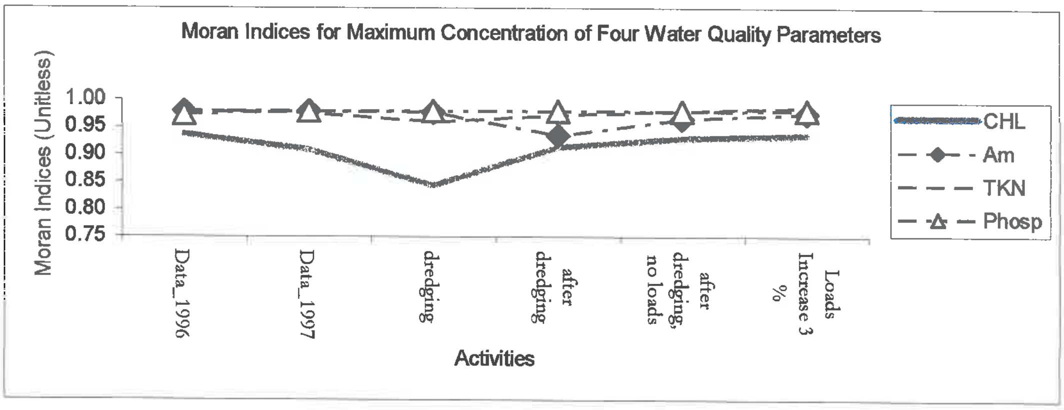


Figure 7.17 The Dynamics of Moran values in relation to the activities

The results of the analysis of space crowding type of effects also show that study area can be categorised as having high density of effects, as evidenced on the analysis of Moran indices. This means that although perturbations are not in proximity to each other, the tide is likely the major component which determines the spread of effects.

The analysis of spatial autocorrelation is suggested as the main prerequisite for analysing space crowding type of effects. This means that Moran spatial autocorrelation must be employed before determining the significance of the space crowding cumulative effects. Therefore, usefulness of the analysis of spatial autocorrelation is clear in that this can be sued to identify the presence of space crowding type of effects. If space crowding type of effects is identified, then the procedure for determining the significance of this type of cumulative effects in this study can then be employed.

However, the analysis of spatial autocorrelation is not the only measure for the identification of space crowding type of effects. This must be checked against the temporally actual values of water quality for every segment for every water quality parameters in order to determine the significance of space crowding type of effects. This can be explained by using the results showing the fact that although high values of the significance of space crowding types of effects occurs in the segments where the locations of major activities exist, the indices of Moran indicate the similarity of values.

The use of spatial autocorrelation technique in this study is generic in characteristic. This means that this technique can be applied on other conditions, such as land-based, water-based or watershed-based cumulative effects assessment. The main aim of the use of this technique is to find the spatial pattern of effects, an important component in determining the significance of cumulative effects.

7.4.3 Thresholds Cumulative Effects

The results of the analysis of the threshold type of cumulative effects can be seen in Figure 7.18. As can be seen, there are a number of segments showing significant and very significant classes. The spatial distribution of thresholds type of cumulative effects as seen in Figure 7.18 can be explained as follows. The locations having very significant class of threshold type of cumulative effects are likely to be observed in:

(1) Almost all segments in the body of both Port Adelaide estuary and Barker Inlet estuary, including the segments where parting do exist.

(2) Segments where there is the effluent from Bolivar Sewage Treatment Works. The loss of seagrass and mangroves in the areas close to the Bolivar Sewage Treatment Works as stated in Chapter III (Study Area) is an indication that the condition of water quality has reached the threshold level.

From the results of the analysis of threshold type of cumulative effects, it is clear that most of the parts of the estuary have experienced the concentration of water quality parameters that exceed threshold levels. The results of this analysis are expected due to the long-term use of the study area as nutrient discharge of major industrial effluents. The continuing phenomenon of algal bloom in the study area has been observed for many years which indicate the responses of waters due to the excessive nutrient loadings.

Comparing the results of the analysis of Moran indices and threshold type of cumulative effects, the results seems to agree each other in the sense that while the values of Moran indices show the presence of spatial crowding, the significance of threshold type of cumulative effects show that most of segments have "very significant" class. The detailed explanation will be discussed in section 7.5

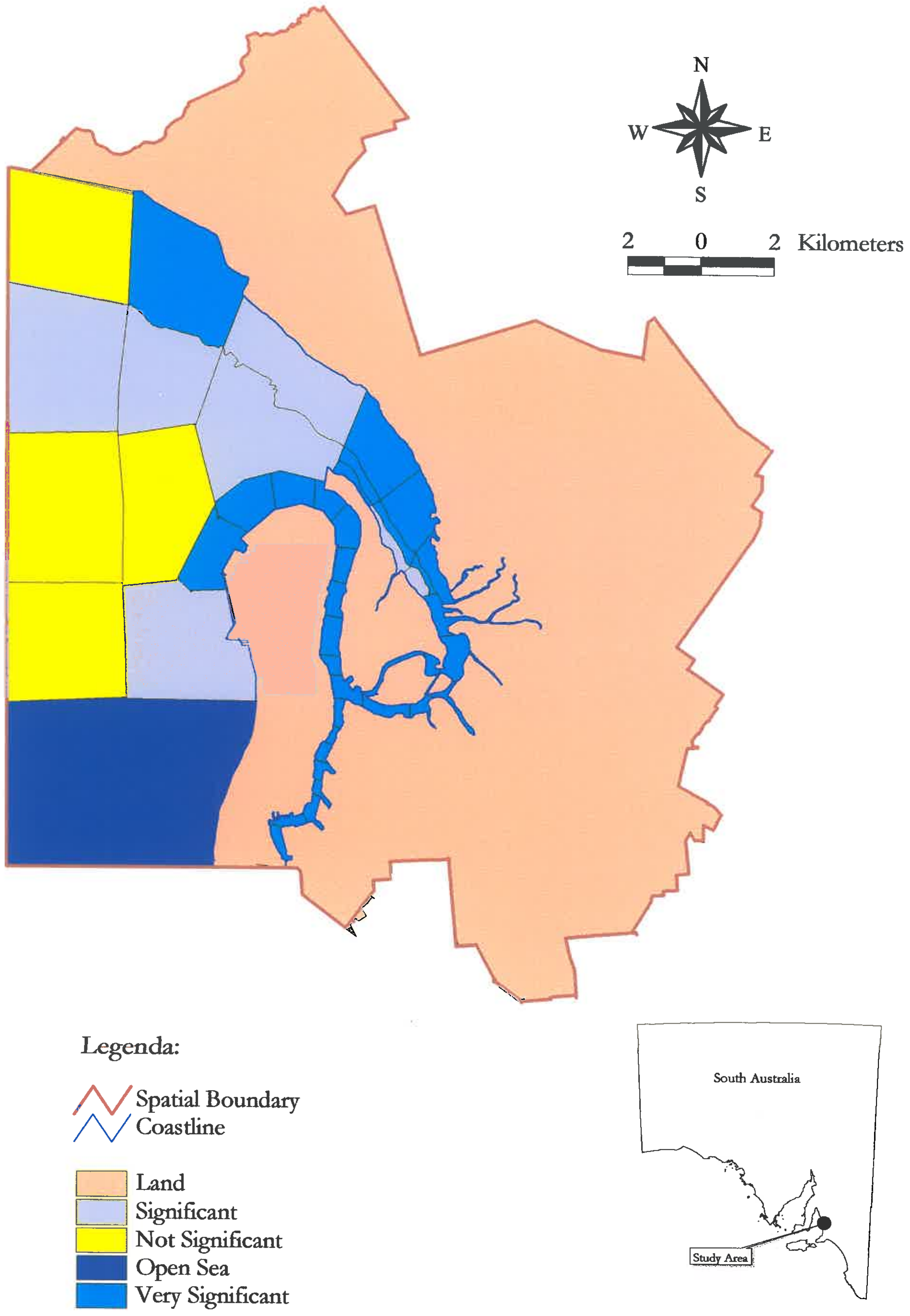
7.4.4 Synergistic Cumulative Effects

The following figures (Figure 7.19, 7.20, 7.21 and 7.22) show the whisker and box plots of the concentration of Chlorophyll a, TKN, Ammonia and Phosphorus to show the effects of an activity and the combination of activities on the concentration of water quality parameters. Some scenario used were:

(1) When dredging.
(2) After dredging.
(3) After dredging and no nutrient load.
(4) After dredging and nutrient loads increase 3 % by assuming that the population size increases by 3 %.

Some other scenarios can be added, such as the effects of further increase in the size of population for the next 100 years or the effects of sea level rise, however, this study only focused on four scenarios explained above. The main emphasis of this study was

Figure 7.18 The Significance of Threshold Cumulative Effects



on the development of a methodology. In other words, the procedures in CEA are the main emphasis rather than accurate results of CEA.

From Figure 7.19 for Chlorophyll a concentration, it would appear that according to the values of 50th percentiles, the 1996 data has the highest overall level of the concentration of Chlorophyll a followed by some scenarios having similar 50th percentiles, that is

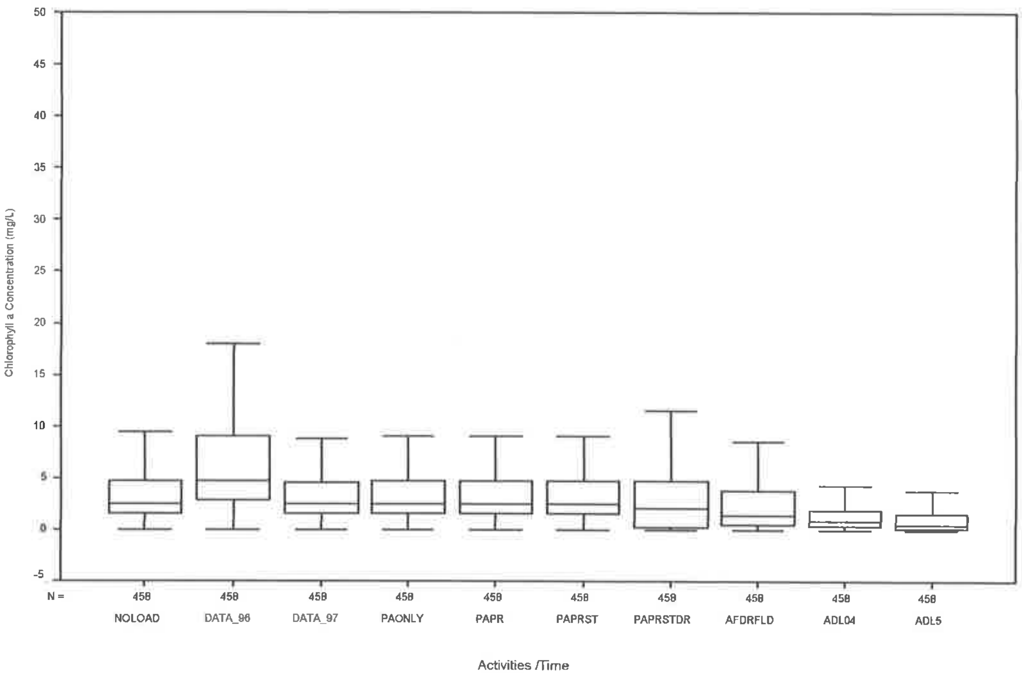
1. NOLOAD (no nutrient loading entering the estuary).
2. DATA_97 (modeled data 1997).
3. PAONLY (Port Adelaide Sewage Treatment Only).
4. PAPR (Port Adelaide Sewage Treatment Works and Penrice Soda Product).
5. PAPRST (Port Adelaide Sewage Treatment Works, Penrice Soda Product and Stormwater).

Lower values of 50th percentiles are then observed for PAPRSTDR (PortAdelaide Sewage Treatment Works, Penrice Soda Products, Stormwater and Dredging), AFDRLD (after dredging and loads similar to 1997 data set), ADLO4 (After dredging, nutrient loads are zero), and ADL5 (nutrient loads increase to 3%).

The overall distribution of the concentration of Chlorophyll a shows a severely positively skewed distribution. Likewise, other water quality parameters (Ammonia, TKN and Phosphorus Total) show the positive skewed distribution of data. From Figures 7.19, to 7.22, it is clear that Phosphorus Total and Ammonia are two water quality parameters which have higher values of 50th quartiles than TKN.

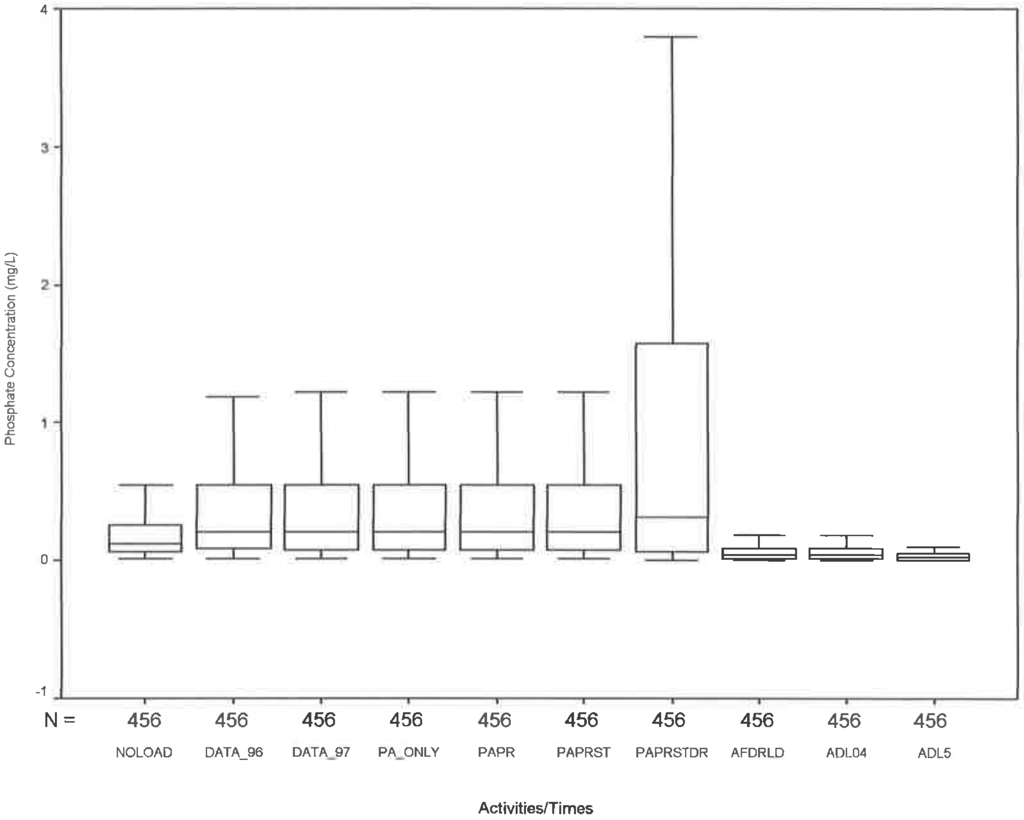
TKN seems to show the constant concentration, as shown in Figure 7.22. As can be seen, similar values of 50th quartiles are observed in : NOLOAD, DATA_97, PAONLY, PAPR, and PAPRST. Slight changes are observed when dredging. After that, significant reduction in the values of the 50th quartiles is in evident.

From Figure 7.19 to 7.22, except for TKN, other water quality parameters show a major fall in the scenarion of “after dredging and loads increase 3%”. This may be unexpected due to the fact that the scenario of “after dredging and no loads” shows the higher concentration than the scenarion of “after dredging and loads increase 3%”, the expected pattern may be the reverse one. This may show the effects of deepening some segments in the Port River estuary after dredging were conducted so that this affects the dilution of pollutants. This pattern may also suggest that the effects of deepening estuary on water quality can not be observed directly.



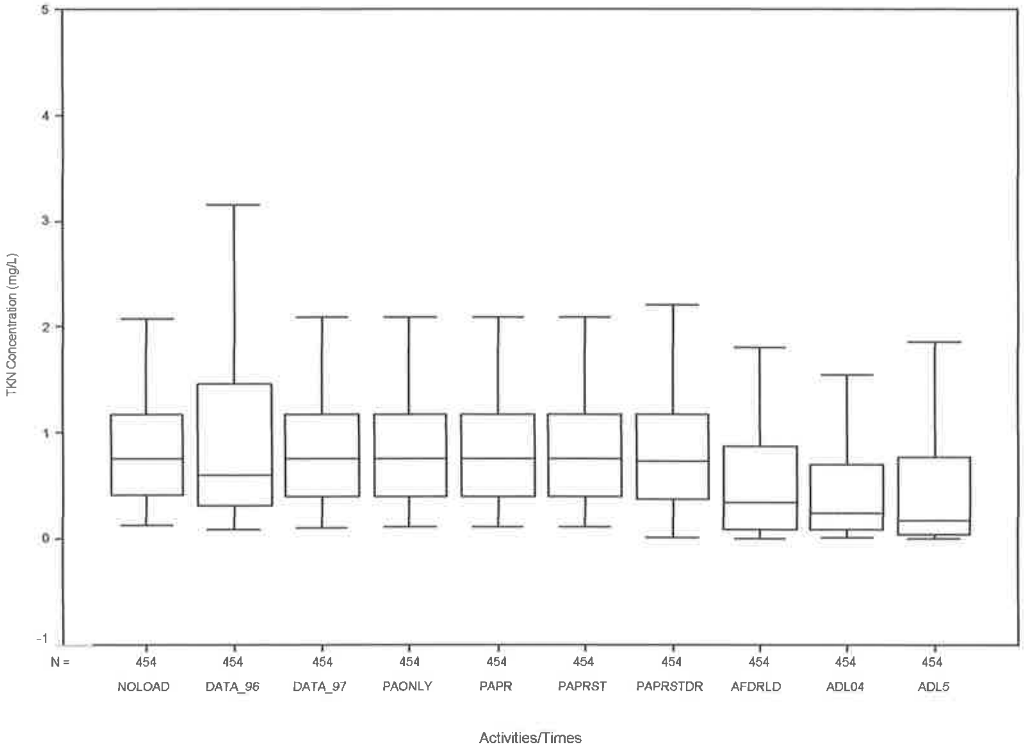
NOLOAD = no nutrient loads entering the estuary
DATA_96 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1996 Data Set
DATA_97 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1997 Data Set
PAONLY = Nutrient loads from only port Adelaide
PAPR = Nutrient loads from Port Adelaide and Penrice Soda
PAPRST = Nutrient loads from Port Adelaide Sewage Treatment, Penrice Soda Product, Stormwater
PAPRSTDR = Nutrient loads from Port Adelaide Sewage Treatment Work, Penrice Soda Products, stormwater and when dredging
AFDRLD = after dredging nutrient loads like DATA_97
ADL04 = after dredging and no nutrient loads
ADL5 = After dredging and increasing nutrient loads predicted from population projection

Figure 7.19 Box and whisker plots summarising the concentration of Chlorophyll a



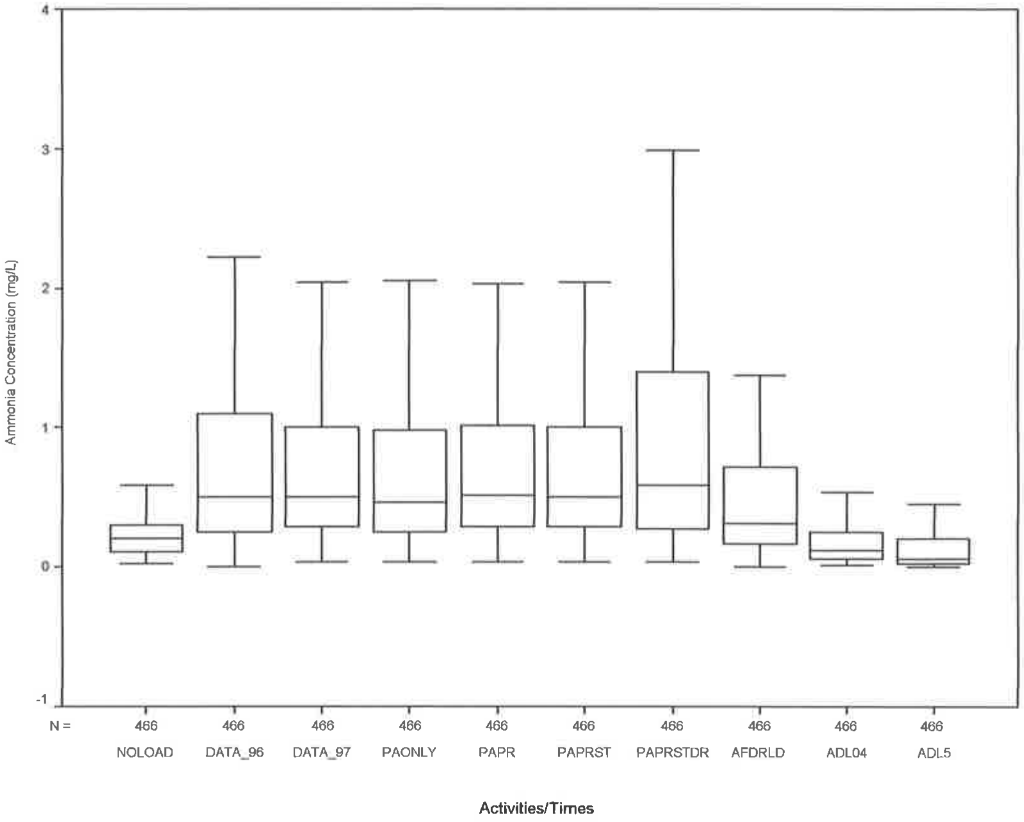
NOLOAD = no nutrient load entering the estuary
DATA_96 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1996 Data Set
DATA_97 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1997 Data Set
PAONLY = Nutrient loads from only port Adelaide
PAPR = Nutrient loads from Port Adelaide and Penrice Soda
PAPRST = Nutrient loads from Port Adelaide Sewage Treatment, Penrice Soda Product, Stormwater
PAPRSTDR = Nutrient loads from Port Adelaide Sewage Treatment Work, Penrice Soda Products, stormwater and when dredging
AFDRLD = after dredging nutrient loads like DATA_97
ADL04 = after dredging and no nutrient loads
ADL5 = After dredging and increasing nutrient loads predicted from population projection

Figure 7.20 Box and whisker plots summarising the concentration of Phosphorus Total



NOLOAD = no nutrient load entering the estuary
DATA_96 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1996 Data Set
DATA_97 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1997 Data Set
PAONLY = Nutrient loads from only port Adelaide
PAPR = Nutrient loads from Port Adelaide and Penrice Soda
PAPRST = Nutrient loads from Port Adelaide Sewage Treatment, Penrice Soda Product, Stormwater
PAPRSTDR = Nutrient loads from Port Adelaide Sewage Treatment Work, Penrice Soda Products, stormwater and when dredging
AFDRLD = after dredging nutrient loads like DATA_97
ADL04 = after dredging and no nutrient loads
ADL5 = After dredging and increasing nutrient loads predicted from population projection

Figure 7.21 Box and whisker plots summarising the concentration of TKN



NOLOAD = no nutrient load entering the estuary
DATA_96 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1996 Data Set
DATA_97 = Nutrient loads from Bolivar Sewage Treatment, Port Adelaide Sewage Treatment, Stormwater and Penrice Soda Product Using 1997 Data Set
PAONLY = Nutrient loads from only port Adelaide
PAPR = Nutrient loads from Port Adelaide and Penrice Soda
PAPRST = Nutrient loads from Port Adelaide Sewage Treatment, Penrice Soda Product, Stormwater
PAPRSTDR = Nutrient loads from Port Adelaide Sewage Treatment Work, Penrice Soda Products, stormwater and when dredging
AFDRLD = after dredging nutrient loads like DATA_97
ADL04 = after dredging and no nutrient loads
ADL5 = After dredging and increasing nutrient loads predicted from population projection

Figure 7.22 Box and whisker plots of the concentration of Ammonia

Analysis of Variance (ANOVA) was used in this study to differentiate the effects of different treatments (scenarios). The results of ANOVA (Analysis of Variance) show that what has been explained from Box-Plot apparent in the ANOVA results, as can be seen in Appendix 36. The ANOVA results as shown in Appendix 36 show that in comparison with the scenarion of "NOLOAD", every activity and their combination have different degree of significance.

The results of the analysis of synergistic cumulative effects show that the alteration of physical condition of the estuary through dredging in combination with other activities can produce synergistic effects. It is also apparent that after dredging, the effects of nutrient loading into the estuary become insignificant. As the above figures show (see ADLO4 in figures), further improvement of water quality condition will also be achieved if no nutrients at all are input into the estuary. The results of the analysis of synergistic type of effects show that the combination of activities resulted in more significant effects than that in single activity, although the effects are different for different water quality parameters.

These results indicate that for cumulative effects to become synergistic, the triggering mechanism must exist. In this regard, dredging would likely to be the activity triggering synergistic type of cumulative effects to occur by referring to the results of ANOVA , whisker and box plots. The mechanism that causes synergistic type of cumulative effects is likely to be the disruption of the physical condition of the estuary, due to dredging. This may be evidence that although the focus on analysing cumulative effects in this study is on the nutrient loading, some changes in the physical conditions need to be considered.

The procedure used, as shown in Figure 7.7, for determining synergistic type of effects in this study can be misleading when the order of activity is considered as "trigger mechanism" to synergistic effects. It can be argued that the order of activity will not affect the determination of trigger activity causing synergistic effects. The only considerations to determine the synergistic type of effects were the ANOVA results, whisker and box plots. Therefore, it can be stated that whatever the order of the activity included, this would not affect the determination of the activity which trigger the synergistic effects.

Figure 7.23 shows the significance of synergistic type cumulative effects. As can be seen from Figure 7.23, the distribution of classes of synergistic type of cumulative effects can be explained as follow.

(1) All segments in Port River estuary and the segments which connect Port River and Barker Inlet show the "Very Significant" class (Class III) of index of synergistic type of cumulative effects.

(2) Most segments in Barker Inlet estuary show "Not Significant" class (class I), except for those segments which are close to the 'parting" which show the "Significant" class (Class II).

These results show that by using the statistical technique, scaling and weighting in GIS, synergistic effects can be identified and predicted. In this regard, the synergistic effects of the interaction between nutrient loadings and the physical alteration of estuary through dredging can result in a different pattern quantitatively or qualitatively compared to the effects of each of activity and this can be seen in Figure 7.20 and 7.22 for Phosphorus Total and Ammonia concentration respectively. It is also clear that the effects of this combination are different for different location, time and water quality parameters.

From the analysis of synergistic type of cumulative effects, it is clear that synergistic effects can be analysed in light of direct (first order) effects, in this case the effects of nutrient loadings on water quality in the estuary. Synergistic effects can also be analysed in different levels (hierarchies) of effects. For example, further analysis of this type of effect can be conducted by analysing the synergistic effects of different nutrient component on seagrass and mangroves communities. This kind of analysis will be in different level, namely the level of indirect or second order effects.

If the data are available, this second order synergistic effects can be analysed by using the methods used in this study (statistical analysis, GIS, scaling and weighting). The first and second order of synergistic effects can than be aggregated to result in the synergistic index total. Therefore, the methodology for analysing synergistic type of cumulative effects in this study contains flexibility in the sense that another form of information can be added if necessary and if data are available by using similar methods. This is likely to provide simplification for analysing this type of cumulative effects.

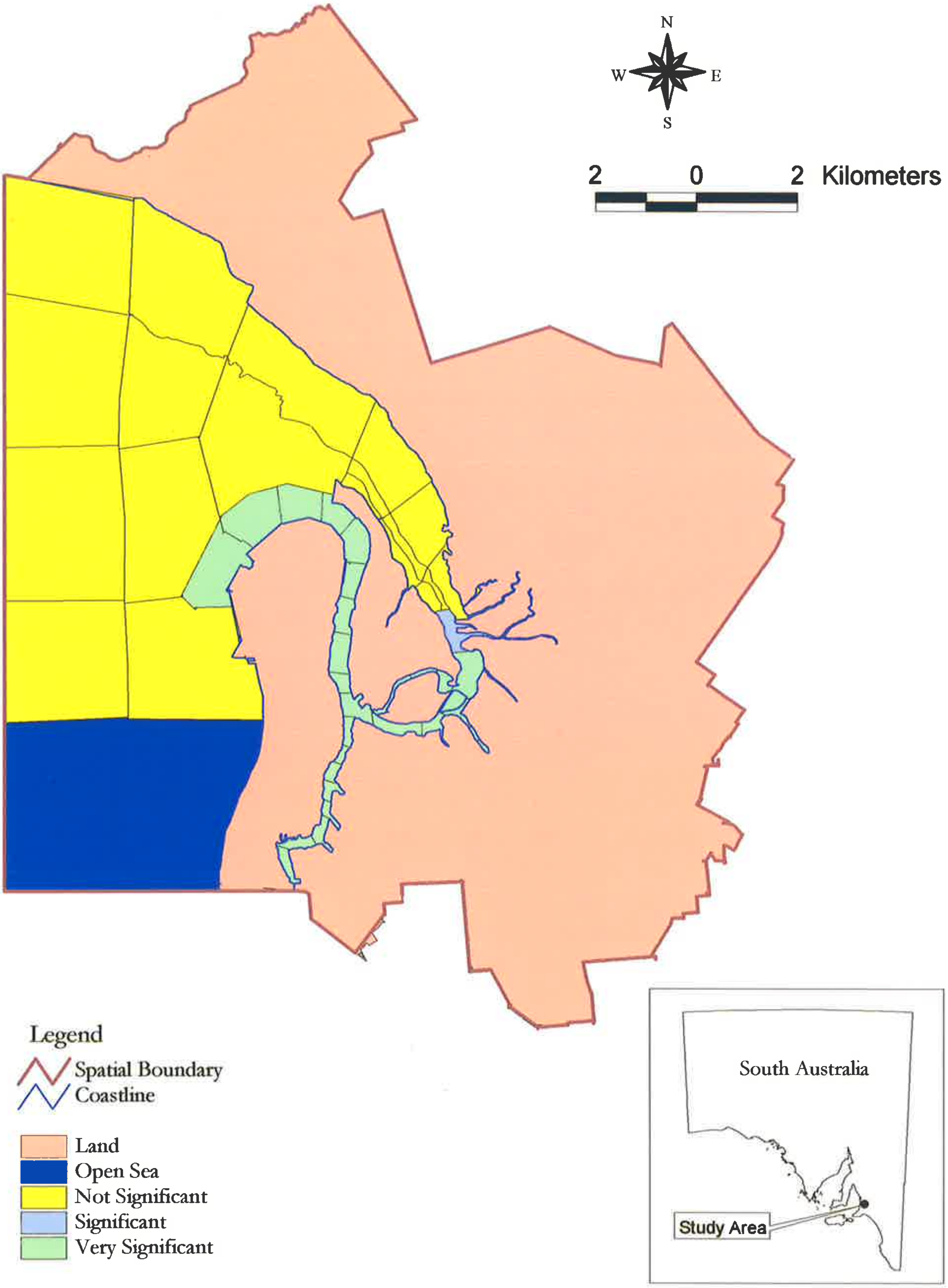
Cocklin, Parker and Hay (1992a:35) define compounding as "synergistic effects arising from multiple sources on a single environmental component". With regard to the results of synergistic types of cumulative effects in this study, it is meant the synergistic effects of nutrient loadings and alteration of physical condition of estuary (multiple sources) to water quality (the main Valued Environmental Component from scooping), as a single environmental component.

The definition of synergistic effects by Cocklin, Parker and Hay (1992a:35) above is only one of those listed before. The various definition of synergistic type of effects seem not to limit the creativity in building the methodology, rather these varying definitions seems to encourage more creative development of the methodology for identifying and predicting type of cumulative effects for a particular purpose. The methodology used in this study may be one of them.

7.5 Comparison of Space and Temporal Crowding, Threshold and Synergistic Types of Cumulative Effects

From the previous figures (7.16, 7.18 and 7.23, it would appear that the occurrence of the very significance and significance classes of the three types of effects are different. Comparing only two figures (Figure 7.16 and 7.23), it is apparent that there is a significant differences in the locations of their occurrence. Most of the study area having significant class of space and temporal crowding type of effects (almost all parts of estuarine water, except in the area where the water from Port River and Barker Inlet meet each other). The areas where the water from Barker Inlet and Port River estuaries meet are having "very significant class". This pattern is different to the synergistic type of effects in which "very significance" class occurs in overall Port River estuary and the

Figure 7.23 The Significance of Synergistic Cumulative Effects



segments connecting both estuaries. These results indicate that tides and depth are likely to be the main factors which determine the significance of effects.

The pattern of the occurrence of space and temporal crowding type of effects is interesting because most of the estuaries show the classes of "significant" and "very significant" (see Figure 7.16). This seems to agree with the results of Moran indices as explained before. This pattern of space and temporal effects is likely to relate to tide activities in the study area which means that the effects of three major activities (Port Adelaide Sewage Treatment Works, Bolivar Sewage Treatment Works and Penrice Soda Products) have spread over segments of both estuaries.

This pattern of occurrence can be related to the tide activities in the study area. Considering Figure 7.23 and comparing this figure with Figure 3.4 and Figure 3.5 (Chapter III), it would appear that the tides especially the tide velocity, is considered as a the major component which determine the pattern of synergistic effects, (see Figure 3.4 and the explanation in section 6.3.2 about the data required for WASAP5, especially that which explain tide velocity in both estuaries). This explanation above would be appear, especially if the pattern of "significant" class of synergistic effects which occur in the area where "parting" exist. Upper part areas of Barker Inlet does not show the classes of "significant" and "very significant" which strongly relates to the high velocities of tides. On the other hand, all segments in Port River estuary shows the "very significant" class which are likely to relate to the low velocity of tides and this condition triggers the occurrence of synergistic type of cumulative effects.

For the purpose of managing the estuary, threshold type of effects can be the major basis. As can be seen in Figure 7.18 and comparing this figure with two previous discussed figures (Figure 7.16 and Figure 7.23), it would appear that most of the main body of both estuaries show "very significant" class, which indicate that they have been experiencing the water quality conditions exceeding threshold values. Figure 7.18 indicates that if the future activities (see Chapter V) went ahead, the effects on water quality would be significant. The management implication of this would be that selection of future activities must be conducted in order to maintain the condition of water quality.

7.6 Comments on the Results of the Analysis of Types of Cumulative Effects

The proposed methodology in this study is mainly aimed at improving existing methodologies for CEA using types of cumulative effects as the basis for the analysis. This study has used expert opinion, statistical analysis, GIS and water quality modelling for analysing and synthesising information pertinent to CEA. The advantages of using these methods for CEA have been explained with regard to the processes of CEA, from scoping to the evaluation. The proposed methodology developed is intended to be simple and practical. The main component to be considered was to identify and use types of cumulative effects for the determination of total cumulative effects.

From the analysis of types of cumulative effects, it would appear that the combination of expert knowledge, statistical analysis, Geographical Information Systems (GIS) and a water quality modelling was valuable for analysing types of cumulative effects. The benefit of using water quality modelling in this study is that the model integrates spatial and temporal components, two crucial dimensions in Cumulative Effects Assessment (CEA). Therefore, the results provide detailed information about values of modelled phenomena of water quality spatially and temporally.

By incorporating the results of water quality modeling into GIS, the processes of aggregation can be conducted. Raster GIS has proved to be useful for combining the quantitative and qualitative (weights) values for combining effects to result in the total cumulative effects.

From the results, it would appear that by analysing types of cumulative effects, significant amounts of information can be generated. The following are the information that can be gained if types of cumulative effects are analysed.

(1) The mechanism of effects to accumulate can be gained, either local cumulative effects, i.e. in particular segments, or global cumulative effects, which occur in the overall estuarine areas. The local characteristics can determine the particular type of cumulative effects to occurs.

(2) The possible processes responsible for the impacts to accumulate can be gained.

(3) The spatial structure of effects can be identified by using GIS analysis.

(4) The information about the pathways leading to cumulative effects can be obtained. It has been clear from the results of the analysis of the types of cumulative effects that different pathways can occur over different times.

From the above, it is clear that types of cumulative effects assisted in identifying and determining the total cumulative effects. From the above discussion, it is clear that by analysing different types of cumulative effects, important information regarding CEA can be gained. CEA that considers the types of cumulative effects can have two major benefits: scientifically impact prediction can be gained, the integration of spatial and temporal dimensions can be achieved and the uses of the combination of qualitative and quantitative methodology can be strengthened.

VIII. Evaluation of the Proposed Methodology Used in this Study

Assumptions and simplifications are the main components which determine the success of any impact assessment methodology (Irving and Bain, 1993:369). With regard to simplification, there are three main components of simplifications in this study:

(1) Simplification in spatial organisation of the estuary used for this study by dividing estuarine area into segments.
(2) Simplification in the analysis of water quality using water quality modeling.
(3) Simplification in the aggregation of effects to result in the significance of each type of cumulative effects and the total cumulative effects.

For the purposes of clarification, the following assumptions used in this study are intentionally repeated from Chapter IV (Theoretical Framework). These assumptions are:

(1) Scoping has been conducted so that the most important Valued Environmental Component(s)/VEC(s) has been selected. In this case, water quality is the most important VEC selected from scoping stage (see Chapter V).
(2) Cumulative effects exist locally over time. There is also the interaction of effects from one location to the other locations. Every part of the estuary has experienced the accumulation of effects due to both direct effects from the activity close to this location and the effects of other activities.
(3) Cumulative effects can occur in every location (part) of estuary and this can spill over to the neighborhood areas.
(4) The system is assumed to be highly dynamic and the density of activities included in CEA is changing along the continuum.
(5) The issues of impact aggregation and impact interaction must be bound to the smallest particular spatial unit (particular location) so that the presence of local cumulative effects can be identified. This can then be used to identify regional cumulative effects. It is assumed that within a particular location, there have been effects due to the presence of activity(s) in that location. Using this concept, analysis of cumulative effect can be conducted hierarchically by mainly

using the pre-determined smallest spatial unit towards the larger spatial units. Therefore, cumulative effects can be local and regional. The local pattern will determine the regional pattern.

(6) Despite the complexity of the estuarine environment, there is spatial and temporal pattern of effects that can direct CEA in estuary.

There are five main achievements from this study by using these assumptions and simplifications:

(1) The main achievement of this study was the development of procedures for the identification of types of cumulative effects and the determination of their significances.
(2) Another achievement was the procedures which can incorporate the qualitative and quantitative information for the determination of the significance of types of effects through scaling and weighting.
(3) The combination of spatial and temporal dimensions through water quality modeling and the analysis of the combination of effects using Geographical Information Systems (GIS) are also an attainment from this study.
(4) The procedures for establishing the spatial boundary for CEA is also the attainment of this study.
(5) The procedure for determining future activities to be included in CEA is also the achievement of this study.

These five achievements have differentiated this study to other existing studies on CEA. Section 8.2 and Section 8.3 will explain the distinctive characteristics of the proposed methodology used in this study.

8.1 Evaluation of the Concepts Used for the Analysis of Cumulative Effects

Estuarine environments are dynamic and complex systems. Waldichuk (1983:93) claims that

> The estuary is a very complex system physically, chemically and biologically. A sort of dynamic equilibrium exist here, where the combined action of runoff, tides, waves, currents, winds and atmospheric heating and cooling maintain a steadily changing condition diurnally and seasonally, but not necessarily altering the situation greatly from year to year

This statement underscores the significant challenges for Cumulative Effects Assessment (CEA) in an estuary due to the complexity of physical, chemical and biological conditions and these conditions vary diurnally and seasonally. Therefore, focusing the study on particular problem of cumulative effects in an estuary is necessary. This study focused on water quality in an estuary due to nutrient loadings.

The estuary itself could potentially be the source of pollutants within the estuary. For example, Waldichuk (1983: 94) claims that sediment in an estuary has an important role as a source of pollutants, however, these pollutants are not likely to be mobilised unless they are disturbed by an activity, such as dredging. The intensity of processes will determine the presence or the absence of cumulative effects. Chapter IV (Theoretical Framework) provided information about processes occurring in estuary. Therefore, in order to obtain information about potential cumulative effects, understanding the processes occurring in the estuary is fundamental. The reason for this is that it relates not only to the determination of the areas where parts of the estuary have been experiencing the accumulation of effects, but also the identification and the prediction of cumulative effects. The methodology used in this study regards the processes occurring in the estuary as the main component of the analysis.

In this study, particular emphasis was on the potential for accumulative effects to occur, and not the actual cumulative effects. The reason for this is that past data are lacking. This condition precluded a complete analysis of CEA which ideally require the availability of long term data. However, monitoring data of water quality parameters at nine sites do exist in the study area. The presence of monitoring data makes it possible to conduct CEA in the estuary. Available monitoring data can also be used in the validation process in the future.

In order to gain information about the potential of cumulative effects, the dynamics of an estuary must be considered. The consideration of the dynamics of an estuary must refer to the processes occurring in an estuary, and the types of cumulative effects have been useful components for integrating the components of variability of processes and the various effects on an estuary. Because of this, types of cumulative effects could provide the organising framework. Consequently, the determination of types of cumulative effects must be conducted at the beginning of CEA. The strengths of CEA, if types of cumulative effects are considered at the beginning, are:

(1) The methodology used in this study was based on the main assumption that there is variability of the activities, effects and, the responses of the different parts of the estuary. Another assumption was that this variation would lead to the occurrence of the different types of cumulative effects. If these types of cumulative effects and their characteristics are known, the aggregation of these types of cumulative effects could result in the values of the magnitude and significance of cumulative effects.

(2) Spaling and Smit (1993:590) claim that spatial accumulation may be characterized by some scales at local, regional, global. Although the conceptual framework of this type of effects exists, the methodology for determining space-crowding type of effects is still lacking and need to be developed. As the results of the analysis of space-crowding type of effects in this study, Moran indices can be used as the tool for the identification of this type of effects.

(3) As the results and discussion have shown, the consideration of types of cumulative effects could provide information about the sources of accumulation. By displaying the results of each type of cumulative effects through GIS, more knowledge on the factors responsible for the impacts accumulation can be gained. As shows in this study, predictive capability relates to the uses of water quality modelling. Integrating the results of water quality modelling with GIS resulted in the improvement of explanatory capabilities. Prediction and explanation are two main prerequisites for CEA methodology (Vlachos, 1985:65) and should be able to adjust to the data.

(4) Using the procedures for analysing cumulative effects as used in this study underscores the fact that types of cumulative effects can assist in the exploration of spatial and temporal dimensions of effects.

As explained, types of cumulative effects can provide a significant amount of information if they are used in CEA. The methodology used in this study has the potential to be applied on different areas, especially the estuarine environment or other land-based cumulative effects assessment.

8.2 Evaluation of Components Included in the Methodology in This Study

Irving, et al. (1986) in Morgan (1998:213) claims that there are some prerequisites of the methodology for Cumulative Effects Assessment. These prerequisites are:

(1) Enable multiple activities to be addressed.
(2) Be a practical method and produce information of use to a decision-maker.
(3) Be able to cope with many possible site-resource-impact combinations.
(4) Be able to cope with different spatial and temporal boundaries.
(5) Allow individual and interactive impacts to be aggregated to produce an estimate of the overall impact on an environmental component.
(6) Allow analysis to be conducted at different scales and level of detail.

From these prerequisites, it is clear that spatial and temporal dimensions must be included in building methodology for CEA which consider individual and interactive effects of multiple activities. It is also clear from prerequisite (2) that the methodology should be capable of producing useful information to the decision maker. The following will explain the capacities of the methodology used in this study in comparison with these six prerequisites.

(1) Enable multiple activities to be addressed

CEA methodology in this study can deal with more than one activity. Scoping is the main activity which was used for selecting activities to be included in CEA. Scoping as part of overall CEA assisted in the selection of past, present and future activities to be included in CEA. In terms of predicting the magnitude and significance of cumulative effects, the methodology proposed in this study can be used to analyse the effects of multiple activities on the Valued Environmental Component, that is water quality. It is also clear that the main issue addressed in this study related only to nutrient loadings.

(2) Be a practical method and produce information of use to a decision-maker.

Water quality modelling used in this study may be the only component which could preclude the practicality of this proposed methodology. The reason for this is that obtaining the data for input into the model and the calibration of the model needs a significant amount of time and effort. However, if the results of water quality modelling are input into Geographical Information Systems, and aggregated, the information from modeling results is likely to be useful for the decision makers. In fact, every local council contacted has been using Geographical Information Systems.

(3) Be able to cope with many possible site-resource-impact combinations.

This may be the fundamental strength of the proposed methodology used in this study. The capability of water quality modelling used in this study to combine spatial and temporal variability of physical, chemical and biological processes proved that the model used was able to cope with many possible site, resources and impact combinations. The capability however is limited to such relationships that are embedded in the model. The use of GIS has also made it possible to combine many different impacts of nutrient loadings on water quality in the estuary by using scaling and weighting techniques into the values of total cumulative effects per segment.

(4) Be able to cope with different spatial and temporal boundaries.

The proposed methodology shows that spatial and temporal boundaries are the main components that must be included in CEA. The proposed methodology recognises the fact that CEA is a dynamic process. Because of this, the spatial and temporal dynamics of estuarine environment, the effects associated with activities, the spatial and temporal boundaries of the assessment and the activities included in the assessment of cumulative effects must be considered. This has implication in that CEA in estuarine environment should adapt to changes and spatial and temporal boundaries should also change accordingly. This can be conducted, for instances by considering the spatial and temporal distribution of activities, effects and their interactions. Water quality modelling used in this study is likely to be capable of analysing the different spatial and temporal configurations. As shown, GIS could be used to determine the spatial boundary for CEA.

(5) Allow individual and interactive impacts to be aggregated to produce an estimate of the overall impact on an environmental component.

The proposed methodology provides the technique for aggregating effects to produce an estimate of cumulative effects by using index. The proposed methodology regards types of cumulative effects as an important component for use in aggregating effects. In addition, the proposed methodology provided the strength of the combination of quantitative and qualitative methodologies for aggregating effects. If the quantitative data do not exist, the quantification of qualitative values can be used in CEA. As demonstrated in the results and discussion, GIS was the main method used for aggregating effects. This capability of GIS has been underscored by Contant and Wiggins (1993:336) who state that "Clearly, GIS technology allows easier spatial aggregation and dis-aggregation of mapped information over a variety of non-coincident boundary*"*.

(6) Allow analysis to be conducted at different scales and level of detail.

The proposed methodology shows that using segments used for water quality modelling, the aggregation of effects for the overall estuary could be conducted. Therefore, the analysis was conducted by using a spatial hierarchy from the segments to the overall estuary. The analysis can be extended to include larger areas, for example, by including parts of the open sea.

As explained, the proposed methodology used in this study cover most prerequisites of ideal methodology as proposed by Irving, et al. (1986) in Morgan (1998). This study however was not aimed at producing accurate information about cumulative effects. This study mainly focuses on how CEA can be conducted in structured way by considering spatial and temporal variability of activities and their associated environmental effects using Geographical Information Systems (GIS) and water quality modeling as the methods of analysis.

8.3 Comparisons of Proposed and Existing Methodologies for CEA

In terms of the procedures for combining effects, this proposed methodology is similar to that in the study by Abbruzzese and Leibowitz (1997). However, the proposed methodology used objective measures, namely the results of water quality modelling, whereas the study by Abbruzzese and Leibowitz (1997) used the qualitative information.

In conjunction with the methods, this study is similar to that of McAllister, Overton and Brill (1996) in the sense that these two studies used water quality modelling (Water Quality Analysis Simulation Program). The difference is on the procedures for aggregating effects. This proposed methodology used Geographical Information Systems (GIS) for combining effects to result in total cumulative effects. The study by McAllister, Overton and Brill (1996), on the other hand used management planning and management model. By using GIS, the distribution of significance classes can be identified. Therefore, the results of the analysis using this proposed methodology could provide information on the different levels of the significance of cumulative effects for each location (segment used for water quality modelling).

The crucial component that differentiates this proposed methodology to other studies is that this study identifies and determines the significance of each type of cumulative effects and then aggregates the significance of each to produce cumulative effects total. This is considered as the most fundamental contribution of this proposed methodology to the development of the methodology for Cumulative Effects Assessment (CEA). In fact, Morgan (1998:201-202) claims that

> There is a bewildering range of impacts that can be considered 'cumulative'. Many overlap, and several (such as indirect effects) are impacts that one would expect to be considered in any EIA. The cumulative effects most assessors would probably be interested in are the space and time crowding. The next problem is how to deal with these aspects in prediction.

Morgan's statement highlights the potential of the bewildering meaning of cumulative effects. However, as this study on CEA has shown, types of cumulative effects could provide organising framework for dealing with the complexity embedded in CEA. The main reason for this is that there is the component of variability of the environmental conditions and the environmental responses so that the use of types of cumulative effects could possibly identify total environmental effects. In relation to this, Stull, La Gory and Vinikour (1987:50) state that

> Temporal change in the severity and type of impacts also add considerable complexity to cumulative assessment because the interactions among projects cannot be estimated unless important temporal effects are identified and incorporated. In some instances, impacts will be most severe during the first several years or decades following project construction and then will level off to some stable value. In other cases, impacts may be temporary and have initial effects only or have a complex pattern of temporal expression. Temporal changes are important for a variety of impacts, including sedimentation, water quality and habitat disturbance.

Spaling, Smit and Kreuwitzwer (1993) give emphasis to the importance of spatial and temporal variability in environmental impact assessment. Considering this, the use of types of cumulative effects for CEA is likely to resolve problems embedded in CEA, especially those deals with the component of spatial and temporal variability of disturbances and effects. Environmental components have spatial and temporal attributes. In additions, interactions amongst environmental components are also complex, as evidenced in the analysis of types of cumulative effects in this study. Types of cumulative effects are the major analytical tools for analysing cumulative effects because these will include the spatial and temporal attributes of effects.

Another distinct component which differentiates the proposed methodology from those used in other studies is the fact that this study used GIS for different purposes: the analytical tool for analysing input data into water quality model, for combining effects and the display of the results. Previous studies, such as those conducted by Spaling (1995), Green, et al. (1995), Walker, et al. (1986) and Spaling (1995) used GIS only for the purpose of displaying information and analysing changes of areas without employing a variety of analytical capabilities of GIS. This study has shown that the analysis of cumulative effects could be conducted with GIS by employing techniques available in raster data structure available in ARC/INFO 8.1 GIS. The capability of GIS to interpolate data is likely to provide significant contribution to CEA in the future, especially when data are limited. Although the procedure for aggregating effects in this study is basically the development of conventional overlay technique (McHarg, 1969 and Wathern, 1988) in terms of techniques used, the use of GIS in this study is far more advanced. This is due to the capabilities of current GIS software for dealing with both qualitative and quantitative information. It is important to note the statement of João and Fonseca (1996:383) who claim that

> However, the full power of these systems (GIS) has not yet been fully explored due to the difficulties associated with the lack of GIS modelling tool specific for EIA, the non-variability of digital data that can be used 'off-the-shelf', and the time and money necessary to invest in GIS.

It is clear from the above that the use of full analytical capability of GIS for EIA needs to be investigated. The results of this study using GIS for CEA in estuarine environment indicate that GIS provide substantial merits for determining the spatial boundary, for the aggregation of effects, for the analysis of input data into the model and for displaying CEA related information.

"Predicting cumulative effects can be quite complex or very simple depending on the project, the environment and the other human activities" (Ross, 1998:274). CEA on dynamic system, such as estuarine environment is likely to be more complex than that in simple system. For this reason, Risser (1988:587) claims that

> Given the inherent complexity of ecosystems and landscapes, and the multitude of ways in which these systems response to disturbance, various methods to reduce this complexity to manageable level must be attempted.

The methodology in this thesis was an attempt to reduce the complexity of CEA in estuarine environments into manageable manner by using types of cumulative effects as the main frameworks.

IX. Conclusion

Since the Council on Environmental Quality promulgated the regulation on cumulative effects in 1976, Cumulative Effects Assessment (CEA) has been one of main concerns in the assessment of environmental effects. Since then, there has been development of theoretical and practical frameworks of cumulative effects. However, it is apparent that the main concern in the development of cumulative effects is its methodology. The methodologies for CEA have also improved over ten years as evidenced by the literature. This is especially the case for land/watershed based CEA. Despite this development, the methodology for CEA in spatially unconstrained areas, such as estuarine environment has been limited. The dynamics of the estuarine environments are likely to require CEA that has a different approach to the land based CEA.

The most obvious requirement of the methodology for CEA relates to how to cover the spatial and temporal variability of artificial and natural processes and activities and how to use this variability to produce reliable estimates of cumulative effects. Embedding the components of variability for CEA in the estuarine environment requires methodologies which are capable of analysing the spatial and temporal dynamics of processes and their consequences. Geographical Information Systems (GIS) and water quality modeling are considered as two methods for CEA which can be the main components of methodology.

In this study, the proposed methodology for CEA consists of a number of stages. Figure 9.1 below shows the CEA used in this study. The stages used in this proposed methodology are:

(1) Scoping, consisting of the following stages: determination of spatial and temporal boundaries for CEA, determining the significant issue in the study area, the selection of the Valued Environmental Component (VEC), the selection of past, present and future activities included in the assessment. Due to the complexity of the interrelationship of the environmental components, this stage was conducted by using expert knowledge as the main method of data acquisition. Interviews in combination with other sources were used to identify

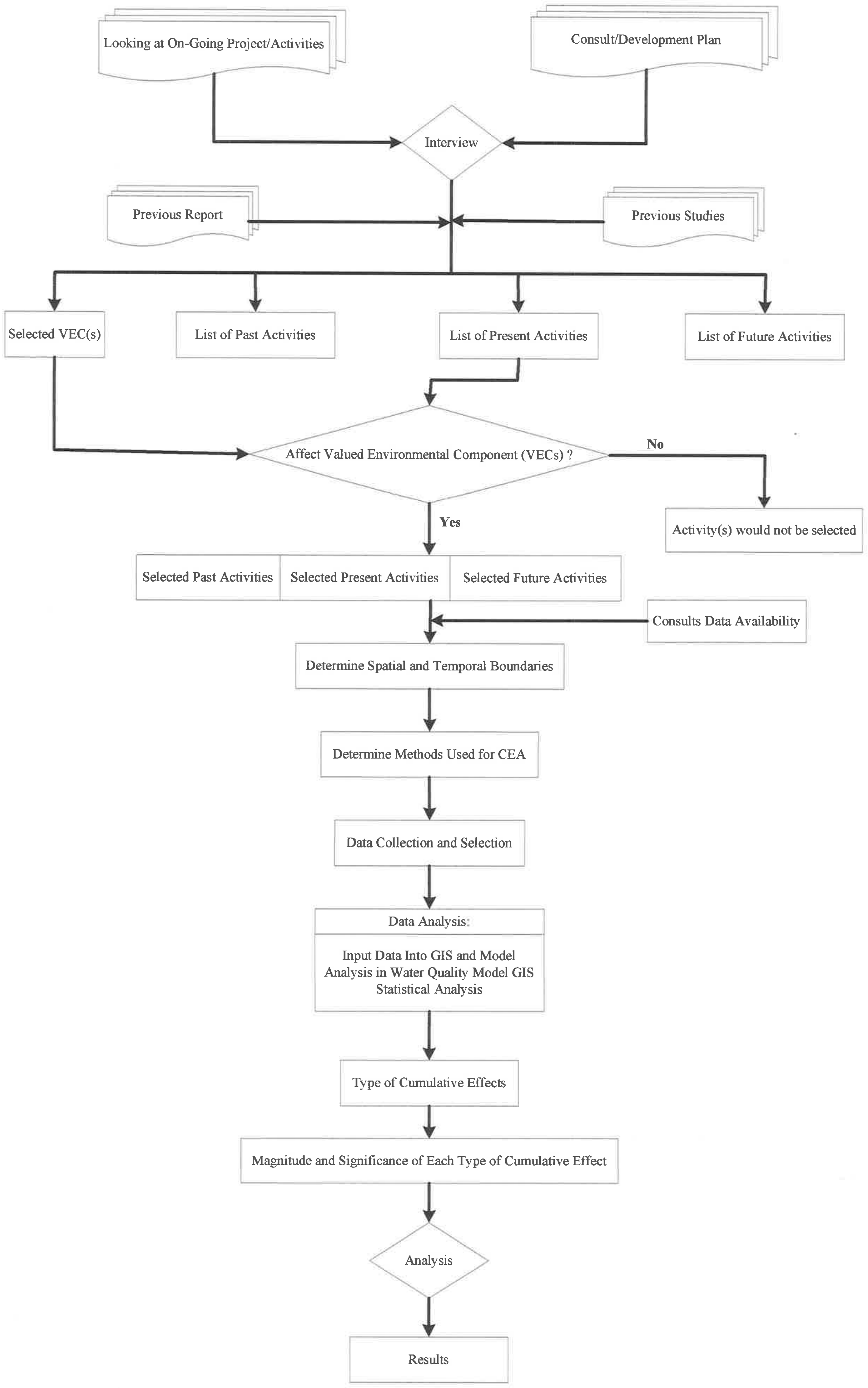


Figure 9.1 Stages Used in Cumulative Effects Assessment in this Study

the selected components. As demonstrated in Chapter V, the selected VEC was water quality.

(2) Trend analysis of selected Valued Environmental Components (VEC) was conducted after identifying the significant issue in the study area.

(3) Modelling was then undertaken. At this stage, GIS as one method of analyzing cumulative effects was used to process spatially related data for input into the water quality model. For example, GIS was used to derive data for input into model, such as the configuration of segments and channels, area of segments, length of channels and width of channels.

(4) Analysis of types of cumulative effects was then conducted. At this stage, GIS was the main tool for analysing types of cumulative effects and aggregating effects. Statistical techniques, such as box and whiskers plots and Anova were also employed with the main aim at obtaining the information of synergistic type of cumulative effects.

(5) Further aggregation of each type of cumulative effects was conducted to produce the significance for types and for total cumulative effects. The main technique used was scaling and weighting.

The variability of the stressors and responses in the estuary can only be analysed if there is a basis for identifying, predicting and aggregating effects. As the results of this study have shown, types of cumulative effects can facilitate the identification, prediction and aggregation to result in the significance of total cumulative effects. Therefore, it is clear from this study that the recognition and the analysis of the types of effects at the beginning of cumulative effects analysis, assist not only in the identification of the presence of the absence of cumulative effects, but also support the aggregation of effects to determine the magnitude and significance.

As shown in the results and discussion, some types of effects, such as space crowded, temporal crowded, and synergistic effects can be identified by using the existing methods. Geographical Information Systems (GIS), modeling (e.g. WASP5 water quality model), statistical analysis and expert knowledge have assisted in the analysis of types of cumulative effects, and total cumulative effects. It is clear from results and discussion that although the objective measures can be applied to the magnitude of cumulative effects, the determination of significance of cumulative effects requires the subjective judgment, especially in the processes of scaling and weighting. Consequently, information loss was unavoidable.

Solving environmental problems requires more holistic and comprehensive views of activities and their associated effects. Cumulative Effect Assessment (CEA) must be conducted for this reason. Methodologies should exist which can cover the variability of activities, the environment and their interaction spatially and temporally. The proposed methodology is one of a number of methodologies, which can potentially be employed, especially for estuarine environment. Some strengths of this methodology are:

(1) The ability to identify and predict cumulative effects at the local level, that is part of the estuary, and the global level, that is overall estuary.
(2) Capability of representing the variability of the presence and the absence of different types of cumulative effects.
(3) The use of the integration of GIS, water quality modelling, expert knowledge and statistical analysis, the aggregation of effects and the display the results of cumulative effects.

According to Contant and Wiggins (1993) and Ross (1998:269), there are a number of components that need to be addressed in CEA. Contant and Wiggins (1993) claim that there are three main components that need to be developed in CEA. These components are:

(1) Improving monitoring and prediction of actions and impacts over space and time.
(2) Increasing the knowledge of the responses of environmental systems to development perturbations, including synergistic and indirect effects.
(3) Developing management systems that provide the appropriate responses to actions that produce significant cumulative effects.

In addition, Ross (1998:269) states that for any CEA there are four key requirements. These are:

(1) To identify Valued Ecosystem Components (VECs) affected by the proposed project (scoping).
(2) To determine what other past, present and future human activities have affected or will affect these VECs.
(3) To predict the impact on VECs of the project in combination with the other human activities and determine the significance of impacts.
(4) To suggest how to manage the cumulative effects.

These two studies identify similar components, however those outlined by Ross (1998) are more detailed than that by these of Contant and Wiggins (1993). The evaluation of the proposed methodology from this thesis can be evaluated against Ross's components.

The methodology used in this thesis has addressed most of the components as follows. The first component relates to the identification of Valued Ecosystem Components or (VECs). As explained in the Chapter V, the identification of VECs is a fundamental stage in scoping. This study demonstrated that the determination of VECs could be conducted by using expert knowledge and other information from previous studies and reports. Structured interviews used in this study assisted in the selection of VECs.

Another component that relates to VECs is the determination of the spatial boundary. The first and second components from both studies by Contant and Wiggins (1993) and Ross (1998) relate to the determination of the spatial boundary. As demonstrated in this thesis, GIS analysis from the spatial distribution of VECs, the boundary of local councils and the boundary of development plans have provided a reliable boundary for CEA. In this study, it was assumed that there is no fixed boundary for CEA. This means that the spatial boundary for CEA is flexible and can be adjusted if there is new information. This provides a new element in the methodology for CEA, especially that which relates to the determination of spatial boundaries.

The second component relates to the determination of other past, present and future human activities that have affected or will affect the selected VECs. This requirement considers the importance of the temporal dimension in CEA. McCold and Saulsbury (1996), for example show that past and present impacts should also be included in CEA because they can affect the determination of the significance of cumulative effects. The past, present and future activities in this study were determined by using a simplification of that proposed by Rumrill and Canter (1998). Some components included in the proposed methodology for determination of past, present and future activities included were

(1) Expert knowledge.
(2) Development Plan.
(3) On-going Development.
(4) Unpublished planning form the results of interviewing key people dealing with proposed activity, such as dredging.
(5) The effects on VECs.

From the determination of VECs and activities included in CEA, it would appear that expert knowledge can assist in determining VECs and past, present and future activities that must be included in CEA

The third component is the most fundamental in CEA. This component relates to the prediction of effects from the combination of activities. In this study, types of cumulative effects have a crucial role in determining total cumulative effects. This study shows that by using types of effects, the prediction of cumulative effects in an estuary over space and time can be conducted in an organised manner. This means that types of cumulative effects provide organising framework for analysing cumulative effects in the sense that calculating total cumulative effects can be simplified. Types of cumulative effects not only provide the framework for aggregating effects, but can also incorporate the spatial and temporal variability. Using types of cumulative effects and available methods for CEA, such as Geographical Information Systems (GIS), water quality modeling, statistical analysis and expert knowledge, the complex phenomena occurring in the estuary can be simplified for analysing CEA. Using these methods, the identification of types of cumulative effects can be conducted and their associated significance can be determined. Then, the total aggregated effects can be calculated by summing the significance of each type of cumulative effects.

The combination of qualitative and quantitative methodology was used to determine the significance of each type of cumulative effects and the total cumulative effects. In this study, water quality modelling was used to provide the more objective values of environmental effects than previous studies that used quantification from the qualitative values, while GIS was the main method for aggregating effects. In this regard, the roles of GIS as method for aggregating effects have been demonstrated in this study. Explanation above relates to the first and second components of Contant and Wiggins (1993) and third component of Ross (1998:275).

The fourth component relates to the management of cumulative effects. This thesis was not aimed at providing recommendations for managing cumulative effects. This study focus was on building the procedure for CEA in estuarine environments.

Uncertainty in the predicted impacts is an unavoidable component in any environmental impact assessment. For this reason, follow up studies (monitoring, evaluation and management) need to be conducted. Evaluation and management are two main factors that relate to monitoring. The results of monitoring can be used to evaluate the predicted impacts.

From the above, it is clear that this study has provided a significant contribution to the methodology of CEA because:

(1) It incorporates spatial and temporal dimensions.
(2) It has the ability to combine quantitative and qualitative methodologies for CEA.
(3) It provides the testable evidence of cumulative effects.

Further research is required to improve the proposed methodology, which may include the combination of other VEC(s). In this regard, the proposed methodology for aggregating effects can potentially be used to aggregate effects from other VEC(s), as long as the scaling and weighting procedures have been established. The application of the proposed methodology to other spatially unconstrained areas or spatially constrained areas, such as watersheds/catchments will provide information about its applicability. Further studies are also required which emphasises the integrations of the methodology used in this study to the management model.

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Appendix 1

Appendix 1a. Summary of daily average Concentrations, flows and loads
(Source: D.A. Lords and Associates, Pty Ltd, 1996 : 14)

Flow		35.4ML
Total Nitrogen	-Concentration -load	40mg/L 1.4 tonnes
Total Phosphorus	-Concentration -load	8.2 mg/L 0.29 tonnes
Salinity	-Concentration -load	4, 425mg/L 157 tonnes
Faecal Colliform	-with Disinfection -no disinfection	<50cfu/100ml 50,000 cfu/100ml

Appendix 1b. Average Daily flows, Concentrations and Loads of Nitrogen, Phosphorus and Suspended Solids (Source: D.A. Lords and Associates, Pty Ltd, 1996 : 15)

Month	Flow (Mega Liter/ML)	Total N		Total P		Suspended Solids (mg/L)
		Conc. (mg/l)	Load (tonnes)	Conc. (mg/L)	Load (tonnes)	
January	86.7	29.1	2.5	6.6	0.6	111
February	103.7	24.7	2.6	6.9	0.7	112
March	98.7	27.2	2.7	7.4	0.7	117
April	96.0	36.7	3.5	7.4	0.7	108
May	102.7	49.4	5.1	7.9	0.8	99
June	108.0	61.7	6.7	8.1	0.9	81
July	120.3	68.7	8.3	8.1	1.0	61
August	118.8	70.6	8.4	8.3	1.0	56
September	123.5	64.7	8.0	7.1	0.9	64
October	105.3	51.5	5.4	7.0	0.7	69
November	118.3	41.1	4.9	6.1	0.7	85
December	120.5	32.4	3.9	6.6	0.8	91

Appendix 1c. Concentrations and Loads for Discharges to the Port Adelaide River
(Source: D.A. Lords and Associates, Pty Ltd, 1996 : 16)

Parameter	Concentration (mg/L)	Daily Load (tonnes)	Annual Load (tonnes)
Temperature	41 – 47 °Celcius	-	-
$Ca(OH)_2$	74	6	2,000
Settleable solids	3,700	278	100,000
NO_3-N	0.5	0.04	14
NH_4-N	18	1.4	490
Total N	20	1.5	540
Total P	<0.001-3.5	<0.0001-0.2	0.3-3

Appendix 1d. Modelled Mean Monthly Stormwater Flows (Sources: D.A Lords and Associates, 1996:18)

Stormwater Sources	Catchment Area (km^2)	Runoff Coefficient (%)	Monthly Average Stormwater Flows (ML/d)												Annual Average (ML/d)	Annual total (ML/l)
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOP	DEC		
Jenkins Street drain	5.4	0.36	1.3	1.3	1.6	2.9	3.3	3.6	3.9	3.6	2.9	2.6	2.0	1.6	2.6	934
Eastern Parade drain	7.1	0.39	1.9	1.9	2.3	4.2	4.7	5.2	5.6	5.2	4.2	3.7	2.8	2.3	3.7	1339
Magazine Creek drain	5.4	0.5	1.8	1.8	2.3	4.1	4.5	5.0	5.4	5.0	4.1	3.6	2.7	2.3	3.5	1287
North Arms East drain	17.0	0.46	5.2	5.2	6.5	11.7	13.0	14.3	15.6	14.3	11.7	10.4	7.8	6.5	10.2	3717
HEP drain	12.5	0.47	4.0	4.0	5.0	8.9	9.9	10.9	11.9	10.9	8.9	7.9	5.9	5.0	7.8	2831
South Road drain	8.7	0.5	2.9	2.9	3.6	6.5	7.2	8.0	8.7	8.0	6.5	5.8	4.4	3.6	5.7	2073
Dustan Road Drain	2.3	0.5	0.8	0.8	1.0	1.7	1.9	2.1	2.3	2.1	1.7	1.5	1.2	1.0	1.5	548
North Arm drain	3.9	0.67	1.7	1.7	2.2	3.9	4.4	4.8	5.2	4.8	3.9	3.5	2.6	2.2	3.4	1249
Dry Creek	98.8	0.3	19.7	19.7	24.7	44.4	49.3	54.3	59.2	54.3	44.4	39.5	29.6	24.7	38.6	14105
Little Para River	40.6	0.25	6.7	6.7	8.3	15.0	16.7	18.3	20.0	18.3	15.0	13.3	10.0	8.3	13.1	4765
West Lakes (combined)	32.9	0.29	6.4	6.4	8.0	14.3	15.9	17.5	19.1	17.5	14.3	12.7	9.5	8.0	12.5	4547
Helps Road drain	69.7	0.30	13.8	13.8	17.1	30.9	34.4	37.7	41.2	37.7	30.9	27.4	20.6	17.1	28.0	10236
Munno Para drain	24.2	0.25	4.0	4.0	4.9	8.9	10.0	10.9	11.9	10.9	8.9	7.9	6.0	4.9	8.4	3017
TOTAL	**328.5**	**0.32**	**70.2**	**70.2**	**87.5**	**157.4**	**175.2**	**192.6**	**210.0**	**192.6**	**157.4**	**139.4**	**105.1**	**87.5**	**139.0**	**50702**

Appendix2

Appendix 2 Consists of Nine Sub_Appendices, according to Nine Sites of Water Quality Sampling Locations.

Appendix 2a. Water Quality Data Used for Modelling at Site 1
(Source : Environmental Protection Authority)

Site 1	Ammonia (as N)	Phosphorus (total asP)	TKN (asN)	Chlorophyl a	Nitrate (asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.141	1.5	12	0.01
30/10/95	0.9	0.38	2.6	16	3.8
4/12/95	0.1	0.28	0.1	3.8	16
8/1/96	0.1	0.37	0.1	39	1
29/1/96	0.5	0.07	1.4	27	1
8/3/96	0.5	0.32	0.5	9.9	4
16/5/96	1.1	0.1	0.5	5	4
21/6/96	0.1	0.01	0.8	17	0.01
31/7/96	0.81	0.09	1.2	6	0.3016
30/8/96	0.76	0.065	1.1	n/a	n/a
27/9/96	0.52	0.071	1	1	n/a
31/10/96	0.465	0.074	0.83	0.005	n/a
26/11/96	0.64	0.064	1	3	n/a
19/12/96	0.455	0.12	1.2	7	n/a
27/1/97	0.59	0.042	0.94	2	n/a
25/2/97	0.8	0.065	1.1	6	n/a
18/3/97	0.48	0.051	0.86	8	n/a
29/4/97	0.74	0.076	1.2	1	n/a
24/6/97	0.97	0.074	1.1	1	n/a
24/7/97	1.7	0.12	2.55	7.3	n/a
21/8/97	0.76	0.12	1.05	33	n/a
18/9/97	1.1	0.115	1.5	2.7	n/a
16/10/97	0.4	0.09	1.1	16	n/a
20/11/97	n/a	0	0	16.7	n/a
26/11/97	0.16	0.08	0.7	0	n/a
19/12/97	0.55	0.08	0.9	13	n/a
12/2/98	0.4	0.108	1.1	58	n/a
5/3/98	n/a	0	0	0	n/a
30/4/1998	0.94	0.32	1.28	9	n/a
28/5/1998	0.87	0.154	0	2.9	n/a
2/7/98	0.74	0.065	0.88	2.9	n/a

Appendix 2a (continued)

(1)	(2)	(3)	(4)	(5)	(6)
12/8/98	1	0.13	1	12	n/a
3/9/98	0.89	0.076	1.1	7.6	n/a
12/11/98	1.1	0.099	1.3	11	n/a
7/1/99	1	0.083	1.5	38	n/a
4/2/99	0.89	0.082	0.98	44	n/a
11/3/99	1.5	0.14	2.1	24	n/a
28/4/99	2.2	0.164	2.4	6.2	n/a
13/5/99	1.5	0.15	1.7	8.8	n/a
10/6/99	1.4	0.086	1.6	1.7	n/a
5/8/99	n/a	0	0	2.9	n/a

Appendix 2b. Water Quality Data Used for Modelling at Site 2
(Source : Environmental Protection Authority)

Site2	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.078	0.1	3.1	0.01
30/10/95	0.6	0.25	2.4	8.5	2.7
12/12/95	0.1	0.24	0.1	14	13
8/1/1996	0.1	0.36	0.1	41	0.4
29/1/96	0.2	0.03	1.4	17	1
8/3/96	0.4	0.14	0.5	2.6	1
16/5/96	0.3	0.1	0.5	1	1
21/6/96	0.1	0.01	2.2	5.6	1
31/7/96	0.71	0.06	1	6	n/a
30/8/96	0.345	0.044	0.68	1	n/a
27/9/96	0.34	0.05	0.76	1	n/a
31/10/96	0.15	0.034	0.39	1	n/a
26/11/96	0.074	0.026	0.16	1	n/a
27/1/97	0.115	0.019	0.395	1	n/a
25/2/97	0.46	0.035	0.69	3	n/a
18/3/97	0.28	0.036	0.59	1	n/a
29/4/97	0.5	0.021	0.9	1	n/a
24/6/97	0.485	0.034	0.63	1	n/a
24/7/97	1.2	0.065	2.05	4.5	n/a
21/8/97	0.61	0.105	1.4	6.6	0.564
18/9/97	0.6	0.08	1.1	2.5	n/a
16/10/97	0.28	0.045	0.95	6.8	0.26
20/11/97	n/a	n/a	n/a	n/a	n/a
26/11/97	0.32	0.125	0.8	n/a	n/a
19/12/97	0.2	0.05	0.5	4.4	n/a
22/1/98	0.16	0.042	0.72	7.2	0.058
12/2/98	0.41	0.07	1	14	n/a
5/3/98	0.49	0.075	0.65	3	n/a
30/4/98	0.33	0.05	0.6	2.1	n/a
28/5/98	0.73	0.02	0.7	1.3	n/a
2/7/98	0.27	0.039	0.34	1.4	n/a
12/8/98	0.95	0.036	0.9	2.3	n/a

Appendix 2b (continued)

(1)	(2)	(3)	(4)	(5)	(6)
3/9/98	0.33	0.026	0.37	4	n/a
12/11/98	0.29	0.0032	0.4	1.3	n/a
7/1/99	0.44	0.041	0.64	13	n/a
4/2/99	0.41	0.032	0.35	2.1	n/a
11/3/99	0.68	0.042	0.85	4.3	n/a
28/4/99	1.5	0.068	1.3	3.6	n/a
13/5/99	0.54	0.04	0.62	2.7	n/a
10/6/99	0.67	0.043	0.83	1.3	n/a
5/8/99	n/a	n/a	n/a	6.9	n/a

Appendix 2c. Water Quality Data Used for Modelling at Site 3
(Source : Environmental Protection Authority)

Site 3	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.001	0.1	2.8	0.01
30/10/95	0.2	0.3	0.8	2.3	0.01
4/12/95	0.3	0.47	7	34	13
8/1/1996	0.1	0.26	0.1	15	0.4
8/3/96	0.1	0.04	0.5	2.5	1
16/5/96	0.1	0.07	0.5	1	1
21/6/96	0.1	0.01	0.5	2.9	1
31/7/96	0.005	0.2	0.63	8	0
30/8/96	0.055	0.022	0.265	n/a	0.047
27/9/96	0.11	0.05	0.52	n/a	n/a
31/10/96	0.041	0.008	0.255	n/a	n/a
26/11/96	0.043	0.017	0.215	1	n/a
19/12/96	0.04	0.032	0.365	n/a	n/a
27/1/97	0.038	0.014	0.26	1	n/a
25/2/97	0.058	0.018	0.255	1	n/a
29/4/97	0.105	0.019	0.275	n/a	n/a
24/6/97	0.13	0.02	0.335	4	n/a
24/7/97	0.3	0.035	0.95	3.1	n/a
21/8/97	0.24	0.05	0.6	4.4	n/a
18/9/97	0.47	0.09	1.5	2.4	n/a
16/10/97	0.061	0.07	1.35	3.2	n/a
26/11/97	0.21	0.03	0.75	n/a	n/a
19/12/97	0.075	0.03	0.3	n/a	n/a
22/1/98	0.1	0.03	0.52	2.3	n/a
12/2/98	0.125	0.03	0.4	6.6	n/a
5/3/98	0.14	0.043	0.35	1.7	n/a
30/4/98	0.12	0.1	0.2	1.5	n/a
28/5/98	0.37	0.02	0.62	1.6	n/a
2/7/98	0.07	0.02	0.14	2.7	n/a
12/8/98	0.26	0.021	0.32	2.1	n/a
3/9/98	0.18	0.02	0.34	2.8	n/a
12/11/98	0.13	0.026	0.29	1	n/a

Appendix 2c (continued)

(1)	(2)	(3)	(4)	(5)	(6)
7/1/99	0.14	0.025	0.22	2.9	n/a
4/2/99	0.41	0.12	2	1	n/a
11/3/99	0.22	0.02	0.28	2.2	n/a
28/4/99	0.15	0.024	0.36	1.9	n/a
29/4/99	0.14	0.024	0.34	1.9	n/a
13/5/99	0.14	0.023	0.19	1.6	n/a
7/6/99	0.34	0.027	0.44	1.3	n/a
10/6/99	0.4	0.026	0.4	1.3	n/a
5/8/99	n/a	n/a	n/a	6	n/a

Appendix 2d. Water Quality Data Used for Modelling at Site 4
(Source : Environmental Protection Authority)

Site 4	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
28/9/95	0.1	0.13	0.1	1.3	0.01
30/10/95	0.4	0.43	1.4	0.9	2.5
4/12/95	0.2	0.35	4.7	8.1	17
8/1/96	0.1	0.43	0.1	17	0.6
29/1/96	0.1	0.08	2	13	1
8/3/96	0.9	0.23	0.5	1.7	3
16/5/96	0.4	0.1	0.5	9.1	2
21/6/96	0.1	0.1	0.5	2.4	1
31/7/96	0.42	0.09	0.85	7	n/a
30/8/96	0.17	0.065	0.53	1	0.255
27/9/96	0.39	0.071	0.84	1	0.365
31/10/96	0.305	0.049	0.6	1	0.165
26/11/96	0.465	0.037	0.79	18	0.12
19/12/96	0.36	0.06	0.98	6	0.15
27/1/97	0.52	0.026	0.87	3	n/a
25/2/97	0.285	0.05	1.4	4	n/a
18/3/97	0.49	0.042	0.87	1	n/a
29/4/97	0.83	0.073	1.3	3	n/a
27/5/97	0.83	0.062	1.1	0	n/a
24/6/97	0.78	0.077	1	1	0.455
24/7/97	0.9	0.075	1.65	1.8	n/a
21/8/97	0.47	0.115	0.9	1.8	n/a
18/9/97	0.34	0.075	1	1.5	n/a
16/10/97	0.2	0.055	0.85	1.5	n/a
20/11/97	n/a	n/a	n/a	14	n/a
26/11/97	0.2	0.065	0.45	n/a	n/a
19/12/97	0.39	0.065	0.8	3.3	0.277
22/1/98	0.42	0.06	0.97	17	n/a
12/2/98	0.31	0.078	0.81	9.1	n/a
5/3/98	n/a	0.079	0.74	1.8	n/a
30/4/98	n/a	0.06	1	1.7	n/a
28/5/98	n/a	0.036	0.64	0.8	n/a

Appendix 2d (continued)

(1)	(2)	(3)	(4)	(5)	(6)
2/7/98	n/a	0.073	0.74	0.5	n/a
12/8/98	n/a	0.049	0.91	1.6	n/a
3/9/98	n/a	0.056	0.76	2.8	n/a
12/11/98	n/a	0.056	1.1	3.9	n/a
7/1/99	n/a	0.7	1.9	33	n/a
4/2/99	n/a	0.059	0.73	3.1	n/a
11/3/99	n/a	0.082	3	9.4	n/a
28/4/99	n/a	0.078	1.1	1.3	n/a
13/5/99	n/a	0.11	1.3	5	n/a
10/6/99	n/a	0.084	1.2	0.6	n/a
5/8/99	n/a	n/a	n/a	1.8	n/a

Appendix 2e. Water Quality Data Used for Modelling at Site 5
(Source : Environmental Protection Authority)

Site 5	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.56	0.1	0.8	
31/10/95	0.5	0.37	1.2	1	0.01
4/12/95	0.1	0.4	2.4	5.4	3.8
8/1/96	0.1	0.39	0.1	19	14
29/1/96	0.1	0.08	2	3.9	0.5
8/3/96	0.9	0.23	0.5	1.7	1
16/5/96	0.6	0.08	0.5	8.3	3
21/6/96	0.1	0.01	0.5	2.5	1
31/7/96	0.48	0.08	0.84	7	1
30/8/96	0.33	0.041	0.72	n/a	n/a
27/9/96	0.39	0.08	0.94	n/a	n/a
31/10/96	0.295	0.04	0.65	1	n/a
26/11/96	0.43	0.034	0.82	1	n/a
19/12/96	0.15	0.054	0.86	2	n/a
27/1/97	0.495	0.041	0.89	1	n/a
25/2/97	0.069	0.055	1.2	2	0.097
18/3/97	0.485	0.047	0.87	3	n/a
29/4/97	0.87	0.054	1.4	6	n/a
27/5/97	0.8	0.068	0.97	1	n/a
24/6/97	0.8	0.07	1.1	1	n/a
24/7/97	0.8	0.075	1.41	1.7	n/a
21/8/97	0.4	0.095	0.8	1.8	n/a
18/9/97	0.3	0.08	0.9	0.7	n/a
16/10/97	0.13	0.055	0.8	1.7	0.62
26/11/97	0.18	0.075	0.7	n/a	n/a
2/12/97	0.41	0.05	0.7	3.1	0.162
29/1/98	0.38	0.04	0.31	5.6	n/a
12/2/98	0.4	0.075	0.73	7.1	n/a
5/3/98	0.5	0.092	0.83	2.2	n/a
30/4/98	n/a	0.025	0.38	14	0.31
28/5/98	n/a	0.066	0.58	0.7	n/a
2/7/98	n/a	0.088	0.66	0.5	n/a

Appendix 2e (continued)

(1)	(2)	(3)	(4)	(5)	(6)
12/8/98	n/a	0.055	0.75	2.2	n/a
3/9/98	n/a	0.063	0.63	1.5	n/a
12/11/98	n/a	0.062	1.3	4.4	n/a
7/1/99	n/a	0.069	1.1	6.6	n/a
4/2/99	n/a	0.068	0.7	5.2	n/a
11/3/99	n/a	0.081	1.4	6	n/a
28/4/99	n/a	0.078	1	1.4	n/a
13/5/99	n/a	0.075	0.84	1.6	n/a
10/6/99	n/a	0.072	1	0.8	n/a
5/8/99	n/a	n/a	n/a	1.8	n/a

Appendix 2f. Water Quality Data Used for Modelling at Site 6
(Source : Environmental Protection Authority)

Site 6	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.125	0.1	0.8	0.01
30/10/95	0.5	0.33	1.4	1.6	3.4
4/12/95	0.2	0.41	0.1	0.1	11
8/1/96	0.1	0.34	0.1	17	0.4
29/1/96	0.3	0.09	2	4.2	1
8/3/96	0.3	0.1	0.5	5.8	3
16/5/96	0.6	0.1	0.5	0.8	1
21/6/96	0.1	0.1	0.5	1.5	1
31/7/96	0.71	0.07	1	11	n/a
3/8/96	0.375	0.07	0.73	1	n/a
27/9/96	0.445	0.067	0.92	1	n/a
31/10/96	0.31	0.048	0.68	1	n/a
26/11/96	0.44	0.057	1.1	1	n/a
19/12/96	0.22	0.047	0.79	9	n/a
27/1/97	0.44	0.063	0.98	3	n/a
25/2/97	0.01	0.066	1.2	4	n/a
18/3/97	0.42	0.044	0.83	2	n/a
29/4/97	0.64	0.051	1.2	1	n/a
27/5/97	0.67	0.089	0.88	1	n/a
24/6/97	1.35	0.27	1.9	2	n/a
24/7/97	0.8	0.105	1.85	2.2	n/a
21/8/97	0.47	0.115	1	3.8	n/a
18/9/97	0.47	0.09	0.95	1.3	n/a
16/10/97	0.12	0.055	1.15	1.5	n/a
26/11/97	0.26	0.065	0.8	n/a	n/a
19/12/97	0.4	0.05	0.75	5.9	n/a
22/1/98	0.39	0.05	0.82	4.9	n/a
12/2/98	0.315	0.049	0.66	17	n/a
5/3/98	0.69	0.104	1	3.3	n/a
30/4/98	0.26	0.02	n/a	3.6	n/a
28/5/98	0.74	0.06	n/a	1.1	n/a
2/7/98	0.28	0.052	n/a	1	n/a

Appendix 2f (Continued)

(1)	(2)	(3)	(4)	(5)	(6)
12/8/98	0.87	0.049	n/a	2.3	n/a
3/9/98	0.48	0.063	n/a	1.2	n/a
12/11/99	0.92	0.061	n/a	3.8	n/a
7/1/99	1	0.05	n/a	13	n/a
4/2/99	0.52	0.057	n/a	18	n/a
11/3/99	0.87	0.081	n/a	14	n/a
29/4/99	0.75	0.068	n/a	2.2	n/a
13/5/99	0.58	0.076	n/a	1.4	n/a
10/6/99	0.8	0.07	n/a	1.2	n/a
5/8/99	n/a	n/a	n/a	2.6	n/a

Appendix 2g. Water Quality Data Used for Modelling at Site 7
(Source : Environmental Protection Authority)

Site 7	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.104	0.1	1	0.01
30/10/95	0.4	0.18	1.4	2.1	2.5
4/12/95	0.1	0.42	0.1	3.8	8.5
8/1/96	0.1	0.53	0.1	8.2	0.2
29/1/96	0.3	0.1	2.4	2.4	1
8/3/96	0.6	0.11	0.5	2.8	3
16/5/96	0.2	0.09	0.5	0.6	1
21/6/96	0.1	0.1	0.5	2.4	1
31/7/96	0.38	0.08	0.74	1	n/a
30/8/96	0.285	0.265	1.5	20	n/a
27/9/96	0.27	0.087	0.9	1	n/a
31/10/96	0.24	0.036	0.68	1	n/a
26/11/96	0.24	0.022	0.67	1	n/a
19/12/96	0.105	0.071	0.76	1	n/a
27/1/97	0.185	0.072	0.71	1	n/a
25/2/97	0.8	0.087	1.3	6	n/a
18/3/97	0.285	0.059	0.82	1	n/a
29/4/97	0.255	0.003	0.75	1	n/a
27/5/97	0.295	0.046	0.64	1	n/a
24/6/97	1	0.125	1.3	1	n/a
24/7/97	0.8	0.105	1.8	4.2	n/a
21/8/97	0.31	0.09	0.62	2.5	n/a
18/9/97	0.057	0.102	0.9	2.3	n/a
16/10/97	0.052	0.07	0.9	2.8	n/a
20/11/97	n/a	n/a	n/a	13	n/a
26/11/97	0.18	0.065	0.9	n/a	n/a
19/12/97	0.15	0.09	0.7	7.9	n/a
22/1/98	0.2	0.03	0.61	14	n/a
12/2/98	0.015	0.064	0.55	13	n/a
5/3/98	0.465	0.102	0.93	4.7	n/a
30/4/98	0.26	0.02	1.24	2.2	n/a
28/5/98	0.57	0.05	0.66	1	n/a

Appendix 2g (Continued)

(1)	(2)	(3)	(4)	(5)	(6)
2/7/98	0.73	0.063	0.92	0.8	n/a
12/8/98	0.36	0.048	0.56	3.1	n/a
3/9/98	0.47	0.068	0.6	1.5	n/a
12/11/99	0.47	0.049	0.71	1.9	n/a
7/1/99	0.6	0.064	0.98	8.7	n/a
4/2/99	0.44	0.049	0.54	2.9	n/a
11/3/99	0.67	0.074	1.1	4.8	n/a
29/4/99	0.67	0.064	0.85	1.7	n/a
13/5/99	0.46	0.055	0.63	1.6	n/a
10/6/99	0.7	0.066	0.98	1.5	n/a
5/8/99	n/a	n/a	n/a	3.9	n/a

Appendix 2h. Water Quality Data Used for Modelling at Site 8
(Source : Environmental Protection Authority)

Site 8	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
28/9/95	0.1	0.115	0.1	1.6	0.01
30/10/95	0.2	0.1	0.8	2.3	1.1
4/12/95	0.1	0.36	0.1	3.9	13
29/1/96	0.01	0.04	2	1.2	1
8/3/96	0.1	0.39	0.1	9.7	1
16/5/96	0.1	0.06	0.5	1.2	1
21/6/96	0.1	0.2	0.5	1.9	1
31/7/96	0.51	0.05	0.83	9	n/a
30/8/96	0.09	0.032	0.4	1	n/a
27/9/96	0.145	0.047	0.59	1	n/a
31/10/96	0.036	0.032	0.315	1	n/a
26/11/96	0.029	0.019	0.275	1	n/a
19/12/96	0.033	0.027	0.415	1	n/a
27/1/97	0.16	0.026	0.33	1	n/a
25/2/97	0.245	0.033	0.63	7	n/a
18/3/97	0.073	0.029	0.475	1	0.008
29/4/97	0.125	0.013	0.335	1	n/a
27/5/97	0.215	0.025	1.3	3	0.205
24/6/97	0.61	0.053	0.86	1	n/a
24/7/97	0.3	0.06	1.15	5.8	n/a
21/8/97	0.19	0.055	0.7	2.8	n/a
18/9/97	0.11	0.035	0.7	2.3	n/a
16/10/97	0.057	0.065	0.8	3.8	n/a
20/11/97	0.13	0.04	1.3	n/a	n/a
26/11/97	0.13	0.04	0.6	n/a	n/a
19/12/97	0.05	0.03	0.3	2	n/a
22/1/98	0.04	0.02	0.32	2.7	n/a
12/2/98	0.055	0.027	0.31	4.5	0.075
5/3/98	0.11	0.077	0.86	8.6	0.19
30/4/98	0.13	0.02	0.32	1.6	0.1
28/5/98	0.34	0.026	0.6	1.5	0.33
2/7/98	0.04	0.019	0.19	7.8	0.01
12/8/98	0.27	0.027	0.34	2.6	n/a

Appendix 2h (continued)

(1)	(2)	(3)	(4)	(5)	(6)
3/9/98	0.08	0.031	0.32	5.5	n/a
12/11/99	0.1	0.031	0.33	2	n/a
7/1/99	0.1	0.022	0.23	4.2	n/a
4/2/99	0.08	0.02	0.11	0.8	n/a
11/3/99	1.1	0.17	1.6	22	n/a
29/4/99	2.6	0.202	2.8	2.6	n/a
13/5/99	1	0.072	1.1	3.1	n/a
10/6/99	1.9	0.1	2	3.5	n/a
5/8/99	n/a	n/a	n/a	6.8	n/a

Appendix 2i. Water Quality Data Used for Modelling at Site 9
(Source : Environmental Protection Authority)

Site 9	Ammonia(as N)	Phosphorus(total asP)	TKN(asN)	Chlorophyl a	Nitrate(asNO3)
(1)	(2)	(3)	(4)	(5)	(6)
31/7/96	0.78	0.09	1.2	n/a	n/a
30/8/96	1.5	0.255	2.2	1	n/a
27/9/96	0.64	0.11	0.99	1	n/a
31/10/96	0.86	0.135	1.2	n/a	n/a
26/11/96	1.65	0.252	2	1	n/a
19/12/96	0.55	0.11	1.4	1	n/a
27/1/97	0.89	0.13	1.4	16	n/a
25/2/97	1.65	0.165	1.8	10	n/a
18/3/97	0.66	0.125	1.4	23	n/a
29/4/97	1.15	0.2	1.9	1	n/a
27/5/97	1.62	0.185	1.8	n/a	n/a
24/6/97	0.185	0.03	0.96	1	n/a
24/7/97	1.9	0.22	3.1	8.9	n/a
21/8/97	1.1	0.185	1.45	5.2	n/a
18/9/97	0.9	0.055	1.5	3.7	n/a
16/10/97	0.7	0.12	1.35	9	n/a
20/11/97	n/a	n/a	n/a	n/a	n/a
26/11/97	0.41	0.115	1.3		n/a
19/12/97	0.73	0.175	1.25	54	n/a
22/1/98	1	0.24	1.8	92	n/a
12/2/98	0.79	0.239	1.47	80	n/a
5/3/98	0.52	0.22	1.47	10	n/a
30/4/98	0.19	0.056	0.7	1.6	n/a
28/5/98	1.4	0.388	1.9	130	n/a
2/7/98	0.63	0.1	0.78	7	n/a
12/8/98	1.4	0.22	1.6	10	0.197
3/9/98	1.1	0.069	0	14	n/a
12/11/99	1.1	0.14	1.5	14	n/a

Appendix 2i (continued)

(1)	(2)	(3)	(4)	(5)	(6)
7/1/99	0.86	0.065	1.2	9.2	n/a
4/2/99	0.7	0.27	1.8	240	n/a
11/3/99	0.02	0.02	0.21	1.6	n/a
29/4/99	1.3	0.024	0.31	1.3	n/a
13/5/99	1.2	0.18	1.8	34	n/a
10/6/99	0.22	0.023	0.34	2.1	n/a
5/8/99	n/a	n/a	n/a	3.7	n/a

Appendix 3

Appendix 3. Index of Agreement (IOA) and Average Error Calculation of Tide Heights

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
2.3	2.3254	0.00064516	0.781	0.719	0.781	0.719	2.250
2.4	2.2424	0.02483776	0.881	0.636	0.881	0.636	2.301
2.3	2.2243	0.00573049	0.781	0.618	0.781	0.618	1.957
2.2	2.1172	0.00685584	0.681	0.510	0.681	0.510	1.420
2.1	2.0331	0.00447561	0.581	0.426	0.581	0.426	1.015
1.7	1.9495	0.06225025	0.181	0.343	0.181	0.343	0.275
1.8	1.8639	0.00408321	0.281	0.257	0.281	0.257	0.290
1.2	1.386	0.034596	-0.319	-0.221	0.319	0.221	0.291
0.8	1.0924	0.08549776	-0.719	-0.514	0.719	0.514	1.521
0.7	0.951	0.063001	-0.819	-0.656	0.819	0.656	2.174
0.6	0.7624	0.02637376	-0.919	-0.844	0.919	0.844	3.109
0.4	0.6678	0.07171684	-1.119	-0.939	1.119	0.939	4.234
0.7	0.6277	0.00522729	-0.819	-0.979	0.819	0.979	3.232
0.6	0.625	0.000625	-0.919	-0.982	0.919	0.982	3.612
0.7	0.6359	0.00410881	-0.819	-0.971	0.819	0.971	3.203
0.6	0.6609	0.00370881	-0.919	-0.946	0.919	0.946	3.477
0.6	0.7166	0.01359556	-0.919	-0.890	0.919	0.890	3.272
0.71	0.7623	0.00273529	-0.809	-0.844	0.809	0.844	2.733
0.51	0.8701	0.12967201	-1.009	-0.737	1.009	0.737	3.046
0.9	1.0283	0.01646089	-0.619	-0.578	0.619	0.578	1.433
0.8	1.2518	0.20412324	-0.719	-0.355	0.719	0.355	1.153
1.2	1.5112	0.09684544	-0.319	-0.096	0.319	0.096	0.172
1.6	1.7481	0.02193361	0.081	0.141	0.081	0.141	0.050
1.3	2.0802	0.60871204	-0.219	0.473	0.219	0.473	0.479
2.3	2.2498	0.00252004	0.781	0.643	0.781	0.643	2.029
2.2	2.3412	0.01993744	0.681	0.734	0.681	0.734	2.004
2.2	2.3917	0.03674889	0.681	0.785	0.681	0.785	2.150
2.4	2.4106	0.00011236	0.881	0.804	0.881	0.804	2.839
2	2.4165	0.17347225	0.481	0.810	0.481	0.810	1.667
2.3	2.4167	0.01361889	0.781	0.810	0.781	0.810	2.532
2.3	2.4137	0.01292769	0.781	0.807	0.781	0.807	2.522
2.3	2.3931	0.00866761	0.781	0.786	0.781	0.786	2.457
2.3	2.3848	0.00719104	0.781	0.778	0.781	0.778	2.431
2.3	2.3533	0.00284089	0.781	0.747	0.781	0.747	2.334
2.4	2.2798	0.01444804	0.881	0.673	0.881	0.673	2.416
2.3	2.1739	0.01590121	0.781	0.567	0.781	0.567	1.818
2.3	2.1824	0.01382976	0.781	0.576	0.781	0.576	1.841
2.5	2.1782	0.10355524	0.981	0.571	0.981	0.571	2.411
1.3	2.1093	0.65496649	-0.219	0.503	0.219	0.503	0.520
1.4	1.9768	0.33269824	-0.119	0.370	0.119	0.370	0.239
1.6	1.6843	0.00710649	0.081	0.078	0.081	0.078	0.025
1.3	1.5586	0.06687396	-0.219	-0.048	0.219	0.048	0.071
2.2	1.341	0.737881	0.681	-0.266	0.681	0.266	0.897

Appendix 3 (Continued)

1.1	1.2381	0.01907161	-0.419	-0.369	0.419	0.369	0.620
2	1.0459	0.91030681	0.481	-0.561	0.481	0.561	1.086
0.7	0.9109	0.04447881	-0.819	-0.696	0.819	0.696	2.294
0.7	0.7949	0.00900601	-0.819	-0.812	0.819	0.812	2.659
0.6	0.7049	0.01100401	-0.919	-0.902	0.919	0.902	3.315
0.7	0.6466	0.00285156	-0.819	-0.960	0.819	0.960	3.165
Average = 1.51	Average = 1.60	Sum = 4.7198		IOA for Tide height = 0.992			Sum = 93.04
			Average Error = 0.1049				

Appendix 4

Appendix 4. IoA Calculation for Chlorophyll a Concentration for all nine Sites for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
39	39.00	0.00	31.33226	31.3	31.3	31.3	3920
9.9	3.66	38.90	2.232258	-4.03	2.23	4.03	39.2
5	1.58	11.70	-2.66774	-6.11	2.67	6.11	77
17	2.00	225.00	9.332258	-5.69	9.33	5.69	226
6	5.04	0.92	-1.66774	-2.65	1.67	2.65	18.6
3	6.16	9.99	-4.66774	-1.53	4.67	1.53	38.4
3	2.41	0.35	-4.66774	-5.28	4.67	5.28	99
7	9.27	5.15	-0.66774	1.58	0.668	1.58	5.05
41	41.00	0.00	33.33226	33.3	33.3	33.3	4440
2.6	3.60	1.00	-5.06774	-4.09	5.07	4.09	83.9
5.6	3.33	5.15	-2.06774	-4.36	2.07	4.36	41.3
1	8.23	52.30	-6.66774	0.54	6.67	0.54	52
1	8.09	50.30	-6.66774	0.4	6.67	0.4	50
1	4.39	11.50	-6.66774	-3.3	6.67	3.3	99.4
1	1.60	0.36	-6.66774	-6.09	6.67	6.09	163
15	15.00	0.00	7.332258	7.31	7.33	7.31	214
2.5	4.13	2.66	-5.16774	-3.56	5.17	3.56	76.2
1	1.46	0.21	-6.66774	-6.23	6.67	6.23	166
2.9	4.16	1.59	-4.76774	-3.53	4.77	3.53	68.9
8	11.30	10.90	0.332258	3.61	0.332	3.61	15.5
1	1.50	0.25	-6.66774	-6.19	6.67	6.19	165
17	17.00	0.00	9.332258	9.31	9.33	9.31	348
1.7	3.30	2.56	-5.96774	-4.39	5.97	4.39	107
9.1	1.07	64.50	1.432258	-6.62	1.43	6.62	64.8
2.4	1.71	0.48	-5.26774	-5.98	5.27	5.98	127
7	4.84	4.67	-0.66774	-2.85	0.668	2.85	12.4
1	5.29	18.40	-6.66774	-2.4	6.67	2.4	82.2
1	6.73	32.80	-6.66774	-0.96	6.67	0.96	58.2
1	12.80	139.00	-6.66774	5.11	6.67	5.11	139
18	2.59	237.00	10.33226	-5.1	10.3	5.1	238
6	6.00	0.00	-1.66774	-1.69	1.67	1.69	11.3
19	19.00	0.00	13.943	10.4	13.9	10.4	594
1.7	8.55	46.90	-3.357	-0.02	3.36	0.02	11.4
8.3	3.99	18.60	3.243	-4.58	3.24	4.58	61.2
2.5	4.00	2.25	-2.557	-4.57	2.56	4.57	50.8
7	6.11	0.79	1.943	-2.46	1.94	2.46	19.4
1	15.20	202.00	-4.057	6.63	4.06	6.63	114
1	5.05	16.40	-4.057	-3.52	4.06	3.52	57.4
2	12.50	110.00	-3.057	3.93	3.06	3.93	48.8
17	19.20	4.84	11.943	10.6	11.9	10.6	510
5.8	11.60	33.60	0.743	3.03	0.743	3.03	14.2
0.8	4.30	12.30	-4.257	-4.27	4.26	4.27	72.7
1.5	4.30	7.84	-3.557	-4.27	3.56	4.27	61.3
11	5.40	31.40	5.943	-3.17	5.94	3.17	83
1	8.55	57.00	-4.057	-0.02	4.06	0.02	16.6
1	8.01	49.10	-4.057	-0.56	4.06	0.56	21.3
13	21.90	79.20	7.943	13.3	7.94	13.3	453
4	5.34	1.80	-1.057	-3.23	1.06	3.23	18.4

Appendix 4 (Continued)

9	11.20	4.84	3.943	2.63	3.94	2.63	43.2
8.2	19.20	121.00	3.143	10.6	3.14	10.6	190
2.8	10.40	57.80	-2.257	1.83	2.26	1.83	16.7
0.6	3.89	10.80	-4.457	-4.68	4.46	4.68	83.5
2.4	3.48	1.17	-2.657	-5.09	2.66	5.09	60
1	1.08	0.01	-4.057	-7.49	4.06	7.49	133
3	2.72	0.08	-2.057	-5.85	2.06	5.85	62.5
1	1.47	0.22	-4.057	-7.1	4.06	7.1	124
12	22.20	104.00	6.943	13.6	6.94	13.6	423
3	4.12	1.25	-2.057	-4.45	2.06	4.45	42.3
1	1.25	0.06	-4.057	-7.32	4.06	7.32	129
Average= 6.428	Average = 8.17	Sum = 1,900.00	IOA for Tide height = 0.873				Sum = 14800

Appendix5

Appendix 5. IoA Calculation for Chlorophyll a for 1996 Data for Port River Estuary only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
39	39	0	31.332	31.3	31.3	31.3	3920
9.9	3.66	38.9	2.232	-4.03	2.23	4.03	39.2
5	1.58	11.7	-2.668	-6.11	2.67	6.11	77
17	2	225	9.332	-5.69	9.33	5.69	226
6	5.04	0.922	-1.668	-2.65	1.67	2.65	18.6
3	6.16	9.99	-4.668	-1.53	4.67	1.53	38.4
3	2.41	0.348	-4.668	-5.28	4.67	5.28	99
7	9.27	5.15	-0.668	1.58	0.668	1.58	5.05
41	41	0	33.332	33.3	33.3	33.3	4440
2.6	3.6	1	-5.068	-4.09	5.07	4.09	83.9
5.6	3.33	5.15	-2.068	-4.36	2.07	4.36	41.3
1	8.23	52.3	-6.668	0.54	6.67	0.54	52
1	8.09	50.3	-6.668	0.4	6.67	0.4	50
1	4.39	11.5	-6.668	-3.3	6.67	3.3	99.4
1	1.6	0.36	-6.668	-6.09	6.67	6.09	163
15	15	0	7.332	7.31	7.33	7.31	214
2.5	4.13	2.66	-5.168	-3.56	5.17	3.56	76.2
1	1.46	0.212	-6.668	-6.23	6.67	6.23	166
2.9	4.16	1.59	-4.768	-3.53	4.77	3.53	68.9
8	11.3	10.9	0.332	3.61	0.332	3.61	15.5
1	1.5	0.25	-6.668	-6.19	6.67	6.19	165
17	17	0	9.332	9.31	9.33	9.31	348
1.7	3.3	2.56	-5.968	-4.39	5.97	4.39	107
9.1	1.07	64.5	1.432	-6.62	1.43	6.62	64.8
2.4	1.71	0.476	-5.268	-5.98	5.27	5.98	127
7	4.84	4.67	-0.668	-2.85	0.668	2.85	12.4
1	5.29	18.4	-6.668	-2.4	6.67	2.4	82.2
1	6.73	32.8	-6.668	-0.96	6.67	0.96	58.2
1	12.8	139	-6.668	5.11	6.67	5.11	139
18	2.59	237	10.332	-5.1	10.3	5.1	238
6	6	0	-1.668	-1.69	1.67	1.69	11.3
Average = 7.667	Average = 7.69	Sum = 928	IOA for Tide height = 0.917				Sum = 11300

Appendix 6

Appendix 6. IoA Calculation for Chlorophyll a for 1996 Data for Barker Inlet Only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
19	19	0	13.94	10.4	13.9	10.4	594
1.7	8.55	46.9	-3.36	-0.02	3.36	0.02	11.4
8.3	3.99	18.6	3.24	-4.58	3.24	4.58	61.2
2.5	4	2.25	-2.56	-4.57	2.56	4.57	50.8
7	6.11	0.792	1.94	-2.46	1.94	2.46	19.4
1	15.2	202	-4.06	6.63	4.06	6.63	114
1	5.05	16.4	-4.06	-3.52	4.06	3.52	57.4
2	12.5	110	-3.06	3.93	3.06	3.93	48.8
17	19.2	4.84	11.94	10.6	11.9	10.6	510
5.8	11.6	33.6	0.74	3.03	0.743	3.03	14.2
0.8	4.3	12.3	-4.26	-4.27	4.26	4.27	72.7
1.5	4.3	7.84	-3.56	-4.27	3.56	4.27	61.3
11	5.4	31.4	5.94	-3.17	5.94	3.17	83
1	8.55	57	-4.06	-0.02	4.06	0.02	16.6
1	8.01	49.1	-4.06	-0.56	4.06	0.56	21.3
13	21.9	79.2	7.94	13.3	7.94	13.3	453
4	5.34	1.8	-1.06	-3.23	1.06	3.23	18.4
9	11.2	4.84	3.94	2.63	3.94	2.63	43.2
8.2	19.2	121	3.14	10.6	3.14	10.6	190
2.8	10.4	57.8	-2.26	1.83	2.26	1.83	16.7
0.6	3.89	10.8	-4.46	-4.68	4.46	4.68	83.5
2.4	3.48	1.17	-2.66	-5.09	2.66	5.09	60
1	1.08	0.0064	-4.06	-7.49	4.06	7.49	133
3	2.72	0.0784	-2.06	-5.85	2.06	5.85	62.5
1	1.47	0.221	-4.06	-7.1	4.06	7.1	124
12	22.2	104	6.94	13.6	6.94	13.6	423
3	4.12	1.25	-2.06	-4.45	2.06	4.45	42.3
1	1.25	0.0625	-4.06	-7.32	4.06	7.32	129
5.057	8.71	975	IOA Barker Inlet = 0.723				Sum = 3520

Appendix7

Appendix 7. Average Error Calculation for 1996 Chlorophyll a Data

Observed (Obsr)	Predicted (Pred)	(Obsr-Pred)
39.00	39.00	0.00
9.90	3.66	6.24
5.00	1.58	3.42
17.00	2.00	15.00
6.00	5.04	0.96
3.00	6.16	-3.16
3.00	2.41	0.59
7.00	9.27	-2.27
41.00	41.00	0.00
2.60	3.60	-1.00
5.60	3.33	2.27
1.00	8.23	-7.23
1.00	8.09	-7.09
1.00	4.39	-3.39
1.00	1.60	-0.60
15.00	15.00	0.00
2.50	4.13	-1.63
1.00	1.46	-0.46
2.90	4.16	-1.26
8.00	11.30	-3.30
1.00	1.50	-0.50
17.00	17.00	0.00
1.70	3.30	-1.60
9.10	1.07	8.03
2.40	1.71	0.69
7.00	4.84	2.16
1.00	5.29	-4.29
1.00	6.73	-5.73
1.00	12.80	-11.80
18.00	2.59	15.40
6.00	6.00	0.00
19.00	19.00	0.00
1.70	8.55	-6.85
8.30	3.99	4.31
2.50	4.00	-1.50
7.00	6.11	0.89
1.00	15.20	-14.20
1.00	5.05	-4.05
2.00	12.50	-10.50
17.00	19.20	-2.20
5.80	11.60	-5.80

Appendix7. (Continued)

Observed (Obsr)	Predicted (Pred)	(Obsr-Pred)
0.80	4.30	-3.50
1.50	4.30	-2.80
11.00	5.40	5.60
1.00	8.55	-7.55
1.00	8.01	-7.01
13.00	21.90	-8.90
4.00	5.34	-1.34
9.00	11.20	-2.20
8.20	19.20	-11.00
2.80	10.40	-7.60
0.60	3.89	-3.29
2.40	3.48	-1.08
1.00	1.08	-0.08
3.00	2.72	0.28
1.00	1.47	-0.47
12.00	22.20	-10.20
3.00	4.12	-1.12
1.00	1.25	-0.25
6.43	8.17	-103.00
		Sum = -1.75

Appendix 8

Appendix 8. IoA Calculation for Ammonia Concentration for overall Estuaries for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.50	0.76	0.07	0.19	0.37	0.19	0.37	0.31
1.10	0.66	0.19	0.79	0.27	0.79	0.27	1.10
0.10	0.54	0.19	-0.21	0.14	0.21	0.14	0.13
0.81	0.66	0.02	0.50	0.27	0.50	0.27	0.58
0.47	0.98	0.26	0.15	0.58	0.15	0.58	0.54
0.64	0.79	0.02	0.33	0.40	0.33	0.40	0.52
0.46	0.64	0.04	0.14	0.25	0.14	0.25	0.15
0.20	0.20	0.00	-0.11	-0.19	0.11	0.19	0.09
0.30	0.21	0.01	-0.01	-0.19	0.01	0.19	0.04
0.10	0.20	0.01	-0.21	-0.19	0.21	0.19	0.16
0.35	0.25	0.01	0.03	-0.14	0.03	0.14	0.03
0.34	0.27	0.00	0.03	-0.12	0.03	0.12	0.02
0.15	0.19	0.00	-0.16	-0.20	0.16	0.20	0.13
0.07	0.16	0.01	-0.24	-0.23	0.24	0.23	0.22
0.10	0.12	0.00	-0.21	-0.27	0.21	0.27	0.24
0.10	0.30	0.04	-0.21	-0.09	0.21	0.09	0.09
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.01	0.11	0.01	-0.31	-0.29	0.31	0.29	0.35
0.04	0.07	0.00	-0.27	-0.32	0.27	0.32	0.35
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.90	0.41	0.24	0.59	0.01	0.59	0.01	0.36
0.40	0.42	0.00	0.09	0.02	0.09	0.02	0.01
0.10	0.42	0.10	-0.21	0.03	0.21	0.03	0.06
0.42	0.57	0.02	0.11	0.17	0.11	0.17	0.08
0.17	0.55	0.14	-0.14	0.16	0.14	0.16	0.09
-1.00	-2.00	-3.00	-4.00	-5.00	-6.00	-7.00	-8.00
0.39	0.74	0.12	0.08	0.34	0.08	0.34	0.17
0.31	0.81	0.26	-0.01	0.42	0.01	0.42	0.18
0.47	0.52	0.00	0.15	0.12	0.15	0.12	0.07
0.36	0.27	0.01	0.05	-0.12	0.05	0.12	0.03
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.90	1.12	0.05	-0.07	0.00	0.07	0.00	0.01
0.60	1.49	0.79	-0.37	0.37	0.38	0.37	0.55
0.10	1.22	1.25	-0.87	0.10	0.88	0.10	0.95
0.48	1.01	0.28	-0.49	-0.11	0.50	0.11	0.37
0.30	1.17	0.77	-0.68	0.05	0.68	0.05	0.53
0.43	1.12	0.48	-0.54	0.00	0.55	0.00	0.30
0.15	1.11	0.92	-0.82	-0.01	0.83	0.01	0.70
0.10	0.10	0.00	-0.87	-1.02	0.88	1.02	3.59
0.30	0.80	0.25	-0.67	-0.32	0.68	0.32	0.99
0.60	1.09	0.24	-0.37	-0.03	0.38	0.03	0.16
0.10	0.73	0.39	-0.87	-0.39	0.88	0.39	1.60
0.71	0.67	0.00	-0.26	-0.45	0.27	0.45	0.51
0.38	0.92	0.29	-0.60	-0.20	0.60	0.20	0.64
0.45	0.93	0.23	-0.53	-0.19	0.53	0.19	0.52
0.31	0.93	0.38	-0.66	-0.19	0.67	0.19	0.74
0.44	0.86	0.18	-0.53	-0.26	0.54	0.26	0.63

Appendix 8 (Continue)

0.22	0.81	0.34	-0.75	-0.31	0.76	0.31	1.14
0.10	0.10	0.00	-0.87	-1.02	0.88	1.02	3.59
0.60	0.13	0.23	-0.37	-0.99	0.38	0.99	1.87
0.20	0.58	0.15	-0.77	-0.54	0.78	0.54	1.72
0.10	0.27	0.03	-0.87	-0.85	0.88	0.85	2.98
0.38	0.13	0.06	-0.59	-0.99	0.60	0.99	2.50
-1.00	-2.00	-3.00	-4.00	-5.00	-6.00	-7.00	-8.00
0.29	0.37	0.01	-0.69	-0.76	0.69	0.76	2.09
0.27	0.32	0.00	-0.70	-0.80	0.71	0.80	2.27
0.24	0.31	0.00	-0.73	-0.82	0.74	0.82	2.40
0.24	0.27	0.00	-0.73	-0.85	0.74	0.85	2.52
0.11	0.26	0.02	-0.87	-0.86	0.87	0.86	2.99
18.21	12.70	30.50	17.24	11.60	17.20	11.60	830.00
Average =0.63	Average = 0.74	Sum = 39.70	IOA = 0.96				Sum = 876.00

Appendix 9

Appendix 9. Index of Agreement (IOA) Calculation for Ammonia Concentration at Port River Estuary for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.50	0.76	0.07	0.19	0.37	0.19	0.37	0.31
1.10	0.66	0.19	0.79	0.27	0.79	0.27	1.10
0.10	0.54	0.19	-0.21	0.14	0.21	0.14	0.13
0.81	0.66	0.02	0.50	0.27	0.50	0.27	0.58
0.47	0.98	0.26	0.15	0.58	0.15	0.58	0.54
0.64	0.79	0.02	0.33	0.40	0.33	0.40	0.52
0.46	0.64	0.04	0.14	0.25	0.14	0.25	0.15
0.20	0.20	0.00	-0.11	-0.19	0.11	0.19	0.09
0.30	0.21	0.01	-0.01	-0.19	0.01	0.19	0.04
0.10	0.20	0.01	-0.21	-0.19	0.21	0.19	0.16
0.35	0.25	0.01	0.03	-0.14	0.03	0.14	0.03
0.34	0.27	0.00	0.03	-0.12	0.03	0.12	0.02
0.15	0.19	0.00	-0.16	-0.20	0.16	0.20	0.13
0.07	0.16	0.01	-0.24	-0.23	0.24	0.23	0.22
0.10	0.12	0.00	-0.21	-0.27	0.21	0.27	0.24
0.10	0.30	0.04	-0.21	-0.09	0.21	0.09	0.09
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.01	0.11	0.01	-0.31	-0.29	0.31	0.29	0.35
0.04	0.07	0.00	-0.27	-0.32	0.27	0.32	0.35
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
0.90	0.41	0.24	0.59	0.01	0.59	0.01	0.36
0.40	0.42	0.00	0.09	0.02	0.09	0.02	0.01
0.10	0.42	0.10	-0.21	0.03	0.21	0.03	0.06
0.42	0.57	0.02	0.11	0.17	0.11	0.17	0.08
0.17	0.55	0.14	-0.14	0.16	0.14	0.16	0.09
0.39	0.74	0.12	0.08	0.34	0.08	0.34	0.17
0.31	0.81	0.26	-0.01	0.42	0.01	0.42	0.18
0.47	0.52	0.00	0.15	0.12	0.15	0.12	0.07
0.36	0.27	0.01	0.05	-0.12	0.05	0.12	0.03
0.10	0.10	0.00	-0.21	-0.29	0.21	0.29	0.26
Average =0.31	Average = 0.39	Sum =1.79			**IOA for ammonia = 0.75**		Sum = 7.16

Appendix 10

Appendix 10. Index of Agreement (IOA) Calculation for Ammonia Concentration at Barker Inlet on for 1996 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.90	1.12	0.05	-0.07	0.00	0.07	0.00	0.01
0.60	1.49	0.79	-0.37	0.37	0.38	0.37	0.55
0.10	1.22	1.25	-0.87	0.10	0.88	0.10	0.95
0.48	1.01	0.28	-0.49	-0.11	0.50	0.11	0.37
0.30	1.17	0.77	-0.68	0.05	0.68	0.05	0.53
0.43	1.12	0.48	-0.54	0.00	0.55	0.00	0.30
0.15	1.11	0.92	-0.82	-0.01	0.83	0.01	0.70
0.10	0.10	0.00	-0.87	-1.02	0.88	1.02	3.59
0.30	0.80	0.25	-0.67	-0.32	0.68	0.32	0.99
0.60	1.09	0.24	-0.37	-0.03	0.38	0.03	0.16
0.10	0.73	0.39	-0.87	-0.39	0.88	0.39	1.60
0.71	0.67	0.00	-0.26	-0.45	0.27	0.45	0.51
0.38	0.92	0.29	-0.60	-0.20	0.60	0.20	0.64
0.45	0.93	0.23	-0.53	-0.19	0.53	0.19	0.52
0.31	0.93	0.38	-0.66	-0.19	0.67	0.19	0.74
0.44	0.86	0.18	-0.53	-0.26	0.54	0.26	0.63
0.22	0.81	0.34	-0.75	-0.31	0.76	0.31	1.14
0.10	0.10	0.00	-0.87	-1.02	0.88	1.02	3.59
0.60	0.13	0.23	-0.37	-0.99	0.38	0.99	1.87
0.20	0.58	0.15	-0.77	-0.54	0.78	0.54	1.72
0.10	0.27	0.03	-0.87	-0.85	0.88	0.85	2.98
0.38	0.13	0.06	-0.59	-0.99	0.60	0.99	2.50
0.29	0.37	0.01	-0.69	-0.76	0.69	0.76	2.09
0.27	0.32	0.00	-0.70	-0.80	0.71	0.80	2.27
0.24	0.31	0.00	-0.73	-0.82	0.74	0.82	2.40
0.24	0.27	0.00	-0.73	-0.85	0.74	0.85	2.52
0.11	0.26	0.02	-0.87	-0.86	0.87	0.86	2.99
18.21	12.70	30.50	17.24	11.60	17.20	11.60	830.00
Average =0.97	Average = 1.12	Sum = 37.90			**IOA = 0.96**		Sum = 868.00

Appendix 11

Appendix 11. Average Error of Ammonia Concentration for 1996 Data

Observed	Predicted	(Observation - Prediction)
0.10	0.10	0.00
0.50	0.76	-0.26
1.10	0.66	0.44
0.10	0.54	-0.44
0.81	0.66	0.15
0.47	0.98	-0.51
0.64	0.79	-0.15
0.46	0.64	-0.19
0.20	0.20	0.00
0.30	0.21	0.09
0.10	0.20	-0.10
0.35	0.25	0.09
0.34	0.27	0.07
0.15	0.19	-0.04
0.07	0.16	-0.09
0.10	0.12	-0.02
0.10	0.30	-0.20
0.10	0.10	0.00
0.01	0.11	-0.10
0.04	0.07	-0.03
0.10	0.10	0.00
0.90	0.41	0.49
0.40	0.42	-0.02
0.10	0.42	-0.32
0.42	0.57	-0.15
0.17	0.55	-0.38
0.39	0.74	-0.35
0.31	0.81	-0.51
0.47	0.52	-0.05
0.36	0.27	0.09
0.10	0.10	0.00
0.90	1.12	-0.22
0.60	1.49	-0.89
0.10	1.22	-1.12
0.48	1.01	-0.53
0.30	1.17	-0.88
0.43	1.12	-0.69
0.15	1.11	-0.96
0.10	0.10	0.00
0.30	0.80	-0.50
0.60	1.09	-0.49
0.10	0.73	-0.63
0.71	0.67	0.04
0.38	0.92	-0.54

Appendix 11 (Continue)

0.45	0.93	-0.48
0.31	0.93	-0.62
0.44	0.86	-0.42
0.22	0.81	-0.59
0.10	0.10	0.00
0.60	0.13	0.47
0.20	0.58	-0.38
0.10	0.27	-0.17
0.38	0.13	0.25
0.29	0.37	-0.08
0.27	0.32	-0.05
0.24	0.31	-0.07
0.24	0.27	-0.03
0.11	0.26	-0.15
18.21	12.70	5.53
Average = 0.63	Average = 0.74	Sum = -6.67
	Average Error = -0.11	

Appendix 12

Appendix 12. Index of Agreement (IoA) Calculation for TKN Concentration for 1997 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O' + Absolute P')^2
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.27	0.05	-0.13	-0.54	0.13	0.54	0.44
0.50	0.56	0.00	-0.13	-0.24	0.13	0.24	0.14
0.80	1.32	0.27	0.17	0.52	0.17	0.52	0.47
1.20	2.38	1.39	0.57	1.58	0.57	1.58	4.61
0.83	0.51	0.10	0.20	-0.29	0.20	0.29	0.24
1.00	0.39	0.37	0.37	-0.41	0.37	0.41	0.61
1.20	0.35	0.72	0.57	-0.45	0.57	0.45	1.04
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.40	0.01	-0.13	-0.40	0.13	0.40	0.28
2.20	2.12	0.01	1.57	1.32	1.57	1.32	8.33
0.68	0.65	0.00	0.05	-0.15	0.05	0.15	0.04
0.76	0.43	0.11	0.13	-0.37	0.13	0.37	0.25
0.39	0.30	0.01	-0.24	-0.51	0.24	0.51	0.56
0.16	0.23	0.01	-0.47	-0.57	0.47	0.57	1.08
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.48	0.00	-0.13	-0.33	0.13	0.33	0.21
0.50	0.50	0.00	-0.13	-0.30	0.13	0.30	0.19
0.50	2.49	3.96	-0.13	1.69	0.13	1.69	3.30
0.63	3.58	8.70	0.00	2.78	0.00	2.78	7.72
0.22	0.22	0.00	-0.42	-0.58	0.42	0.58	1.00
0.10	0.15	0.00	-0.53	-0.65	0.53	0.65	1.40
0.50	0.22	0.08	-0.13	-0.58	0.13	0.58	0.51
0.50	0.38	0.02	-0.13	-0.43	0.13	0.43	0.31
0.50	1.12	0.38	-0.13	0.32	0.13	0.32	0.20
0.85	2.29	2.07	0.22	1.49	0.22	1.49	2.91
0.53	0.99	0.21	-0.10	0.18	0.10	0.18	0.08
0.84	0.66	0.03	0.21	-0.14	0.21	0.14	0.12
0.60	0.95	0.12	-0.03	0.14	0.03	0.14	0.03
0.79	0.45	0.12	0.16	-0.36	0.16	0.36	0.26
0.98	0.21	0.60	0.35	-0.60	0.35	0.60	0.90
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.42	0.01	-0.16	-0.70	0.16	0.70	0.73
0.50	1.60	1.21	-0.16	0.48	0.16	0.48	0.41
0.50	2.29	3.20	-0.16	1.17	0.16	1.17	1.77
0.84	3.15	5.34	0.18	2.03	0.18	2.03	4.89
0.65	1.17	0.27	-0.01	0.05	0.01	0.05	0.00
0.82	0.90	0.01	0.16	-0.22	0.16	0.22	0.15
0.86	0.78	0.01	0.20	-0.34	0.20	0.34	0.29
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.40	0.01	-0.16	-0.72	0.16	0.72	0.77
0.50	2.10	2.56	-0.16	0.98	0.16	0.98	1.30
0.50	1.69	1.42	-0.16	0.57	0.16	0.57	0.53
1.00	2.74	3.03	0.34	1.62	0.34	1.62	3.85
0.73	1.66	0.87	0.07	0.54	0.07	0.54	0.37
0.92	0.96	0.00	0.26	-0.16	0.26	0.16	0.18
0.68	1.49	0.66	0.02	0.37	0.02	0.37	0.15
1.10	1.10	0.00	0.44	-0.02	0.44	0.02	0.21

Appendix 12 (Continued)

0.79	0.90	0.01	0.13	-0.22	0.13	0.22	0.12
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.10	0.16	-0.16	-1.02	0.16	1.02	1.39
0.50	2.11	2.59	-0.16	0.99	0.16	0.99	1.32
0.50	0.73	0.05	-0.16	-0.39	0.16	0.39	0.30
0.74	0.50	0.06	0.08	-0.62	0.08	0.62	0.49
1.50	0.50	1.00	0.84	-0.62	0.84	0.62	2.14
0.90	0.71	0.04	0.24	-0.41	0.24	0.41	0.43
0.68	1.40	0.52	0.02	0.28	0.02	0.28	0.09
0.67	0.98	0.09	0.01	-0.15	0.01	0.15	0.02
0.76	0.71	0.00	0.10	-0.41	0.10	0.41	0.26
Average = 0.64	Average = 0.95	Sum = 42.40	IOA for TKN = 0.406				Sum = 71.45
			Average errror = 0.310				

Appendix 13

Appendix 13. Index of Agreement (IoA) Calculation for TKN for Port River Only for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.27	0.05	-0.13	-0.54	0.13	0.54	0.44
0.50	0.56	0.00	-0.13	-0.24	0.13	0.24	0.14
0.80	1.32	0.27	0.17	0.52	0.17	0.52	0.47
1.20	2.38	1.39	0.57	1.58	0.57	1.58	4.61
0.83	0.51	0.10	0.20	-0.29	0.20	0.29	0.24
1.00	0.39	0.37	0.37	-0.41	0.37	0.41	0.61
1.20	0.35	0.72	0.57	-0.45	0.57	0.45	1.04
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.40	0.01	-0.13	-0.40	0.13	0.40	0.28
2.20	2.12	0.01	1.57	1.32	1.57	1.32	8.33
0.68	0.65	0.00	0.05	-0.15	0.05	0.15	0.04
0.76	0.43	0.11	0.13	-0.37	0.13	0.37	0.25
0.39	0.30	0.01	-0.24	-0.51	0.24	0.51	0.56
0.16	0.23	0.01	-0.47	-0.57	0.47	0.57	1.08
0.10	0.10	0.00	-0.53	-0.70	0.53	0.70	1.52
0.50	0.48	0.00	-0.13	-0.33	0.13	0.33	0.21
0.50	0.50	0.00	-0.13	-0.30	0.13	0.30	0.19
0.50	2.49	3.96	-0.13	1.69	0.13	1.69	3.30
0.63	3.58	8.70	0.00	2.78	0.00	2.78	7.72
0.22	0.22	0.00	-0.42	-0.58	0.42	0.58	1.00
0.10	0.15	0.00	-0.53	-0.65	0.53	0.65	1.40
0.50	0.22	0.08	-0.13	-0.58	0.13	0.58	0.51
0.50	0.38	0.02	-0.13	-0.43	0.13	0.43	0.31
0.50	1.12	0.38	-0.13	0.32	0.13	0.32	0.20
0.85	2.29	2.07	0.22	1.49	0.22	1.49	2.91
0.53	0.99	0.21	-0.10	0.18	0.10	0.18	0.08
0.84	0.66	0.03	0.21	-0.14	0.21	0.14	0.12
0.60	0.95	0.12	-0.03	0.14	0.03	0.14	0.03
0.79	0.45	0.12	0.16	-0.36	0.16	0.36	0.26
0.98	0.21	0.60	0.35	-0.60	0.35	0.60	0.90
Average = 0.63	Average = 0.80	Sum = 19.30	IOA = 0.537				Sum = 41.81

Appendix 14

Appendix 14. Index of Agreement (IOA) Calculation for TKN for Barker Inlet only for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.42	0.01	-0.16	-0.70	0.16	0.70	0.73
0.50	1.60	1.21	-0.16	0.48	0.16	0.48	0.41
0.50	2.29	3.20	-0.16	1.17	0.16	1.17	1.77
0.84	3.15	5.34	0.18	2.03	0.18	2.03	4.89
0.65	1.17	0.27	-0.01	0.05	0.01	0.05	0.00
0.82	0.90	0.01	0.16	-0.22	0.16	0.22	0.15
0.86	0.78	0.01	0.20	-0.34	0.20	0.34	0.29
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.40	0.01	-0.16	-0.72	0.16	0.72	0.77
0.50	2.10	2.56	-0.16	0.98	0.16	0.98	1.30
0.50	1.69	1.42	-0.16	0.57	0.16	0.57	0.53
1.00	2.74	3.03	0.34	1.62	0.34	1.62	3.85
0.73	1.66	0.87	0.07	0.54	0.07	0.54	0.37
0.92	0.96	0.00	0.26	-0.16	0.26	0.16	0.18
0.68	1.49	0.66	0.02	0.37	0.02	0.37	0.15
1.10	1.10	0.00	0.44	-0.02	0.44	0.02	0.21
0.79	0.90	0.01	0.13	-0.22	0.13	0.22	0.12
0.10	0.10	0.00	-0.56	-1.02	0.56	1.02	2.49
0.50	0.10	0.16	-0.16	-1.02	0.16	1.02	1.39
0.50	2.11	2.59	-0.16	0.99	0.16	0.99	1.32
0.50	0.73	0.05	-0.16	-0.39	0.16	0.39	0.30
0.74	0.50	0.06	0.08	-0.62	0.08	0.62	0.49
1.50	0.50	1.00	0.84	-0.62	0.84	0.62	2.14
0.90	0.71	0.04	0.24	-0.41	0.24	0.41	0.43
0.68	1.40	0.52	0.02	0.28	0.02	0.28	0.09
0.67	0.98	0.09	0.01	-0.15	0.01	0.15	0.02
0.76	0.71	0.00	0.10	-0.41	0.10	0.41	0.26
Average = 0.66	Average = 1.12	Sum = 23.10	IOA = 0.221				Sum = 29.64

Appendix 15

Appendix 15. Average Error for TKN for 1996 Data

Observed	Predicted	(Observed - Predicted)
0.10	0.10	0.00
0.50	0.27	0.23
0.50	0.56	-0.06
0.80	1.32	-0.52
1.20	2.38	-1.18
0.83	0.51	0.32
1.00	0.39	0.61
1.20	0.35	0.85
0.10	0.10	0.00
0.50	0.40	0.10
2.20	2.12	0.08
0.68	0.65	0.03
0.76	0.43	0.33
0.39	0.30	0.09
0.16	0.23	-0.07
0.10	0.10	0.00
0.50	0.48	0.03
0.50	0.50	0.00
0.50	2.49	-1.99
0.63	3.58	-2.95
0.22	0.22	-0.01
0.10	0.15	-0.05
0.50	0.22	0.28
0.50	0.38	0.12
0.50	1.12	-0.62
0.85	2.29	-1.44
0.53	0.99	-0.46
0.84	0.66	0.18
0.60	0.95	-0.35
0.79	0.45	0.34
0.98	0.21	0.77
0.10	0.10	0.00
0.50	0.42	0.08
0.50	1.60	-1.10
0.50	2.29	-1.79
0.84	3.15	-2.31
0.65	1.17	-0.52
0.82	0.90	-0.08
0.86	0.78	0.08
0.10	0.10	0.00
0.50	0.40	0.10
0.50	2.10	-1.60
0.50	1.69	-1.19
1.00	2.74	-1.74
0.73	1.66	-0.93

Appendix 15 (Continued)

0.92	0.96	-0.04
0.68	1.49	-0.81
1.10	1.10	0.00
0.79	0.90	-0.11
0.10	0.10	0.00
0.50	0.10	0.40
0.50	2.11	-1.61
0.50	0.73	-0.23
0.74	0.50	0.24
1.50	0.50	1.00
0.90	0.71	0.19
0.68	1.40	-0.72
0.67	0.98	-0.31
0.76	0.71	0.05
Average = 0.64	Average = 0.95	Sum = -18.30
	Average Error = -0.31	

Appendix 16

Appendix 16. Average Error for TKN 1996 Data for Port River only

Observed	Predicted	(Observed-Predicted)
0.10	0.10	0.00
0.50	0.27	0.23
0.50	0.56	-0.06
0.80	1.32	-0.52
1.20	2.38	-1.18
0.83	0.51	0.32
1.00	0.39	0.61
1.20	0.35	0.85
0.10	0.10	0.00
0.50	0.40	0.10
2.20	2.12	0.08
0.68	0.65	0.03
0.76	0.43	0.33
0.39	0.30	0.09
0.16	0.23	-0.07
0.10	0.10	0.00
0.50	0.48	0.03
0.50	0.50	0.00
0.50	2.49	-1.99
0.63	3.58	-2.95
0.22	0.22	-0.01
0.10	0.15	-0.05
0.50	0.22	0.28
0.50	0.38	0.12
0.50	1.12	-0.62
0.85	2.29	-1.44
0.53	0.99	-0.46
0.84	0.66	0.18
0.60	0.95	-0.35
0.79	0.45	0.34
0.98	0.21	0.77
Average = 0.6308	Average = 0.803	Sum = -5.33
	Average Error = -0.18	

Appendix 17

Appendix 17. Average Error for TKN Concentration for 1996 Data for Barker Inlet only

Observed	Predicted	(Observed - Predicted)
0.10	0.10	0.00
0.50	0.42	0.08
0.50	1.60	-1.10
0.50	2.29	-1.79
0.84	3.15	-2.31
0.65	1.17	-0.52
0.82	0.90	-0.08
0.86	0.78	0.08
0.10	0.10	0.00
0.50	0.40	0.10
0.50	2.10	-1.60
0.50	1.69	-1.19
1.00	2.74	-1.74
0.73	1.66	-0.93
0.92	0.96	-0.04
0.68	1.49	-0.81
1.10	1.10	0.00
0.79	0.90	-0.11
0.10	0.10	0.00
0.50	0.10	0.40
0.50	2.11	-1.61
0.50	0.73	-0.23
0.74	0.50	0.24
1.50	0.50	1.00
0.90	0.71	0.19
0.68	1.40	-0.72
0.67	0.98	-0.31
0.76	0.71	0.05
Average = 0.6585714	Average = 1.12E+00	Sum = -1.29E+01
	Average Error = -0.48	

Appendix 18

Appendix 18 Index of Agreement (IOA) Calculation for Phosphate Concentration for 1996 Data Set for Overall Estuaries

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.37	0.37	0.00	0.25	0.26	0.25	0.26	0.26
0.32	0.28	0.00	0.16	0.21	0.16	0.21	0.14
0.10	0.10	0.00	-0.02	-0.01	0.02	0.01	0.00
0.01	0.06	0.00	-0.07	-0.10	0.07	0.10	0.03
0.09	0.04	0.00	-0.08	-0.02	0.08	0.02	0.01
0.07	0.13	0.00	0.01	-0.04	0.01	0.04	0.00
0.07	0.09	0.00	-0.04	-0.04	0.04	0.04	0.01
0.07	0.08	0.00	-0.05	-0.03	0.05	0.03	0.01
0.06	0.05	0.00	-0.08	-0.04	0.08	0.04	0.01
0.12	0.09	0.00	-0.04	0.01	0.04	0.01	0.00
0.10	0.37	0.07	0.24	-0.01	0.24	0.01	0.06
0.40	0.25	0.02	0.12	0.29	0.12	0.29	0.17
0.30	0.25	0.00	0.12	0.19	0.12	0.19	0.10
0.10	0.06	0.00	-0.06	-0.01	0.06	0.01	0.00
0.01	0.06	0.00	-0.06	-0.10	0.06	0.10	0.03
0.06	0.02	0.00	-0.11	-0.05	0.11	0.05	0.02
0.04	0.15	0.01	0.02	-0.06	0.02	0.06	0.01
0.05	0.04	0.00	-0.08	-0.06	0.08	0.06	0.02
0.03	0.05	0.00	-0.08	-0.07	0.08	0.07	0.02
0.03	0.02	0.00	-0.11	-0.08	0.11	0.08	0.04
0.26	0.26	0.00	0.14	0.15	0.14	0.15	0.08
0.04	0.26	0.05	0.13	-0.07	0.13	0.07	0.04
0.07	0.04	0.00	-0.08	-0.04	0.08	0.04	0.01
0.01	0.07	0.00	-0.06	-0.10	0.06	0.10	0.02
0.20	0.01	0.04	-0.11	0.09	0.11	0.09	0.04
0.02	0.18	0.03	0.06	-0.09	0.06	0.09	0.02
0.05	0.03	0.00	-0.09	-0.06	0.09	0.06	0.02
0.01	0.05	0.00	-0.08	-0.10	0.08	0.10	0.03
0.02	0.01	0.00	-0.11	-0.09	0.11	0.09	0.04
0.03	0.16	0.02	0.04	-0.08	0.04	0.08	0.01
0.43	0.43	0.00	0.31	0.32	0.31	0.32	0.39
0.23	0.24	0.00	0.11	0.12	0.11	0.12	0.05
0.10	0.07	0.00	-0.06	-0.01	0.06	0.01	0.00
0.10	0.05	0.00	-0.08	-0.01	0.08	0.01	0.01
0.09	0.05	0.00	-0.08	-0.02	0.08	0.02	0.01
0.07	0.11	0.00	-0.02	-0.04	0.02	0.04	0.00
0.07	0.15	0.01	0.03	-0.04	0.03	0.04	0.00
0.05	0.15	0.01	0.02	-0.06	0.02	0.06	0.01
0.04	0.05	0.00	-0.07	-0.07	0.07	0.07	0.02
0.06	0.06	0.00	-0.07	-0.05	0.07	0.05	0.01
0.39	0.39	0.00	0.31	0.05	0.31	0.05	0.13
0.08	0.60	0.27	0.52	-0.26	0.52	0.26	0.62
0.23	0.26	0.00	0.18	-0.11	0.18	0.11	0.09
0.01	0.14	0.02	0.06	-0.33	0.06	0.33	0.15
0.08	0.10	0.00	0.02	-0.26	0.02	0.26	0.08
0.04	0.19	0.02	0.11	-0.30	0.11	0.30	0.17
0.08	0.14	0.00	0.06	-0.26	0.06	0.26	0.10
0.03	0.19	0.02	0.11	-0.31	0.11	0.31	0.18

Appendix 18 (Continued)

0.05	0.12	0.00	0.04	-0.29	0.04	0.29	0.11
0.04	0.15	0.01	0.07	-0.30	0.07	0.30	0.14
0.34	0.34	0.00	0.26	0.00	0.26	0.00	0.07
0.10	0.71	0.37	0.63	-0.24	0.63	0.24	0.75
0.10	0.65	0.31	0.57	-0.24	0.57	0.24	0.66
0.10	0.22	0.01	0.14	-0.24	0.14	0.24	0.15
0.07	0.13	0.00	0.05	-0.27	0.05	0.27	0.11
0.07	0.10	0.00	0.02	-0.27	0.02	0.27	0.09
0.07	0.19	0.01	0.11	-0.27	0.11	0.27	0.15
0.05	0.14	0.01	0.06	-0.29	0.06	0.29	0.13
0.06	0.24	0.03	0.16	-0.28	0.16	0.28	0.20
0.05	0.13	0.01	0.05	-0.29	0.05	0.29	0.12
0.06	0.13	0.01	0.05	-0.28	0.05	0.28	0.11
0.53	0.34	0.04	0.26	0.19	0.26	0.19	0.20
0.11	0.53	0.18	0.45	-0.23	0.45	0.23	0.46
0.09	0.53	0.19	0.45	-0.25	0.45	0.25	0.49
0.10	0.15	0.00	0.07	-0.24	0.07	0.24	0.10
0.08	0.11	0.00	0.03	-0.26	0.03	0.26	0.08
0.27	0.09	0.03	0.01	-0.08	0.01	0.08	0.01
0.09	0.10	0.00	0.02	-0.25	0.02	0.25	0.07
0.04	0.08	0.00	0.00	-0.31	0.00	0.31	0.10
0.02	0.25	0.05	0.17	-0.32	0.17	0.32	0.23
0.07	0.12	0.00	0.04	-0.27	0.04	0.27	0.10
0.07	0.04	0.00	-0.04	-0.27	0.04	0.27	0.09
0.04	0.04	0.00	-0.04	-0.30	0.04	0.30	0.11
0.07	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
0.05	0.13	0.01	0.05	-0.29	0.05	0.29	0.11
0.08	0.18	0.01	0.10	-0.27	0.10	0.27	0.13
0.07	0.17	0.01	0.09	-0.27	0.09	0.27	0.13
0.12	0.17	0.00	0.09	-0.22	0.09	0.22	0.10
0.12	0.18	0.00	0.10	-0.22	0.10	0.22	0.10
0.12	0.24	0.02	0.16	-0.23	0.16	0.23	0.15
0.09	0.59	0.25	0.51	-0.25	0.51	0.25	0.58
0.08	0.15	0.01	0.07	-0.26	0.07	0.26	0.11
0.11	0.11	0.00	0.03	-0.23	0.03	0.23	0.07
0.02	0.01	0.00	-0.07	-0.32	0.07	0.32	0.15
0.04	0.19	0.02	0.11	-0.31	0.11	0.31	0.17
0.04	0.23	0.04	0.15	-0.31	0.15	0.31	0.21
0.02	0.23	0.05	0.16	-0.32	0.15	0.32	0.23
0.03	0.25	0.05	0.17	-0.31	0.17	0.31	0.23
0.07	0.25	0.04	0.18	-0.28	0.17	0.28	0.20
0.11	0.29	0.03	0.21	-0.24	0.21	0.24	0.20
0.08	0.71	0.39	0.63	-0.26	0.63	0.26	0.79
0.05	0.53	0.24	0.45	-0.30	0.45	0.30	0.56
0.13	1.19	1.13	1.11	-0.22	1.11	0.22	1.76
0.05	0.72	0.45	0.65	-0.29	0.64	0.29	0.88
0.01	0.03	0.00	-0.05	-0.33	0.05	0.33	0.14
0.02	0.23	0.05	0.15	-0.32	0.15	0.32	0.23
0.02	0.25	0.05	0.17	-0.32	0.17	0.32	0.25
0.02	0.26	0.06	0.18	-0.32	0.18	0.32	0.25

Appendix 18 (Continued)

0.02	0.28	0.07	0.20	-0.32	0.20	0.32	0.27
0.05	0.28	0.05	0.20	-0.29	0.20	0.29	0.24
0.09	0.34	0.06	0.26	-0.25	0.26	0.25	0.26
0.07	0.88	0.66	0.80	-0.27	0.80	0.27	1.15
0.03	0.59	0.31	0.51	-0.31	0.51	0.31	0.67
0.03	1.39	1.85	1.31	-0.31	1.31	0.31	2.63
0.03	1.31	1.64	1.23	-0.31	1.23	0.31	2.38
0.03	0.75	0.52	0.67	-0.31	0.67	0.31	0.97
0.03	0.04	0.00	-0.04	-0.32	0.04	0.32	0.12
0.05	0.17	0.02	0.09	-0.29	0.09	0.29	0.15
0.04	0.14	0.01	0.06	-0.30	0.06	0.30	0.13
0.07	0.10	0.00	0.02	-0.27	0.02	0.27	0.08
0.06	0.12	0.00	0.04	-0.28	0.04	0.28	0.10
0.08	0.15	0.01	0.07	-0.26	0.07	0.26	0.11
0.08	0.23	0.02	0.15	-0.27	0.15	0.27	0.17
0.12	0.45	0.11	0.37	-0.23	0.37	0.23	0.35
0.08	0.57	0.25	0.49	-0.27	0.49	0.27	0.58
0.06	1.14	1.18	1.06	-0.29	1.06	0.29	1.81
0.07	0.37	0.09	0.29	-0.28	0.29	0.28	0.32
0.04	0.39	0.12	0.31	-0.30	0.31	0.30	0.37
0.06	0.20	0.02	0.12	-0.29	0.12	0.29	0.16
0.05	0.29	0.06	0.21	-0.29	0.21	0.29	0.25
0.05	0.28	0.05	0.20	-0.29	0.20	0.29	0.24
0.07	0.30	0.05	0.22	-0.27	0.22	0.27	0.24
0.07	0.31	0.06	0.23	-0.27	0.23	0.27	0.25
0.08	0.33	0.07	0.25	-0.27	0.25	0.27	0.27
0.10	0.71	0.38	0.63	-0.25	0.63	0.25	0.77
0.08	0.76	0.46	0.68	-0.26	0.68	0.26	0.88
0.06	1.19	1.29	1.11	-0.29	1.11	0.29	1.95
0.08	1.43	1.84	1.35	-0.27	1.35	0.27	2.61
0.05	1.02	0.94	0.94	-0.29	0.94	0.29	1.52
0.06	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
0.04	0.18	0.02	0.11	-0.30	0.10	0.30	0.16
0.05	0.25	0.04	0.17	-0.29	0.17	0.29	0.21
0.09	0.20	0.01	0.12	-0.25	0.12	0.25	0.14
0.27	0.20	0.01	0.12	-0.07	0.12	0.07	0.04
0.11	0.21	0.01	0.13	-0.24	0.13	0.24	0.14
0.12	0.28	0.03	0.20	-0.23	0.20	0.23	0.18
0.09	0.66	0.33	0.58	-0.25	0.58	0.25	0.69
0.06	0.67	0.38	0.59	-0.29	0.59	0.29	0.77
0.07	1.14	1.16	1.06	-0.28	1.06	0.28	1.79
0.05	1.29	1.54	1.21	-0.29	1.21	0.29	2.25
0.05	0.83	0.61	0.75	-0.29	0.75	0.29	1.09
0.07	0.34	0.07	0.26	-0.27	0.26	0.27	0.28
0.09	0.03	0.00	-0.05	-0.25	0.05	0.25	0.09
0.06	0.03	0.00	-0.05	-0.28	0.05	0.28	0.11
0.00	0.02	0.00	-0.06	-0.34	0.06	0.34	0.16
0.05	0.03	0.00	-0.05	-0.30	0.05	0.30	0.12
0.13	0.05	0.01	-0.03	-0.22	0.03	0.22	0.06
0.11	0.06	0.00	-0.02	-0.24	0.02	0.24	0.07

Appendix 18 (Continued)

0.09	0.06	0.00	-0.02	-0.25	0.02	0.25	0.07
0.10	0.04	0.00	-0.04	-0.24	0.04	0.24	0.08
0.07	0.07	0.00	-0.01	-0.27	0.01	0.27	0.08
0.07	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
Average = 0.09	Average = 0.28	Sum = 21.20	IOA = 0.547				Sum = 46.74
			Average Error = -0.48				

Appendix 19

Appendix 19. Index of Aggrement (IoA) Calculation for Phospahet Concentration for Port River only for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.37	0.37	0.00	0.25	0.26	0.25	0.26	0.26
0.32	0.28	0.00	0.16	0.21	0.16	0.21	0.14
0.10	0.10	0.00	-0.02	-0.01	0.02	0.01	0.00
0.01	0.06	0.00	-0.07	-0.10	0.07	0.10	0.03
0.09	0.04	0.00	-0.08	-0.02	0.08	0.02	0.01
0.07	0.13	0.00	0.01	-0.04	0.01	0.04	0.00
0.07	0.09	0.00	-0.04	-0.04	0.04	0.04	0.01
0.07	0.08	0.00	-0.05	-0.03	0.05	0.03	0.01
0.06	0.05	0.00	-0.08	-0.04	0.08	0.04	0.01
0.12	0.09	0.00	-0.04	0.01	0.04	0.01	0.00
0.10	0.37	0.07	0.24	-0.01	0.24	0.01	0.06
0.40	0.25	0.02	0.12	0.29	0.12	0.29	0.17
0.30	0.25	0.00	0.12	0.19	0.12	0.19	0.10
0.10	0.06	0.00	-0.06	-0.01	0.06	0.01	0.00
0.01	0.06	0.00	-0.06	-0.10	0.06	0.10	0.03
0.06	0.02	0.00	-0.11	-0.05	0.11	0.05	0.02
0.04	0.15	0.01	0.02	-0.06	0.02	0.06	0.01
0.05	0.04	0.00	-0.08	-0.06	0.08	0.06	0.02
0.03	0.05	0.00	-0.08	-0.07	0.08	0.07	0.02
0.03	0.02	0.00	-0.11	-0.08	0.11	0.08	0.04
0.26	0.26	0.00	0.14	0.15	0.14	0.15	0.08
0.04	0.26	0.05	0.13	-0.07	0.13	0.07	0.04
0.07	0.04	0.00	-0.08	-0.04	0.08	0.04	0.01
0.01	0.07	0.00	-0.06	-0.10	0.06	0.10	0.02
0.20	0.01	0.04	-0.11	0.09	0.11	0.09	0.04
0.02	0.18	0.03	0.06	-0.09	0.06	0.09	0.02
0.05	0.03	0.00	-0.09	-0.06	0.09	0.06	0.02
0.01	0.05	0.00	-0.08	-0.10	0.08	0.10	0.03
0.02	0.01	0.00	-0.11	-0.09	0.11	0.09	0.04
0.03	0.16	0.02	0.04	-0.08	0.04	0.08	0.01
0.43	0.43	0.00	0.31	0.32	0.31	0.32	0.39
0.23	0.24	0.00	0.11	0.12	0.11	0.12	0.05
0.10	0.07	0.00	-0.06	-0.01	0.06	0.01	0.00
0.10	0.05	0.00	-0.08	-0.01	0.08	0.01	0.01
0.09	0.05	0.00	-0.08	-0.02	0.08	0.02	0.01
0.07	0.11	0.00	-0.02	-0.04	0.02	0.04	0.00
0.07	0.15	0.01	0.03	-0.04	0.03	0.04	0.00
0.05	0.15	0.01	0.02	-0.06	0.02	0.06	0.01
0.04	0.05	0.00	-0.07	-0.07	0.07	0.07	0.02
0.06	0.06	0.00	-0.07	-0.05	0.07	0.05	0.01
Average = 0.11	Average = 0.13	Average = 0.29	IoA = 0.841				Sum = 1.79

Appendix 20. Index of Agreement (IoA) Calculation for Phosphate Concentration for Barker Inlet for 1996 Data

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.39	0.39	0.00	0.31	0.05	0.31	0.05	0.13
0.08	0.60	0.27	0.52	-0.26	0.52	0.26	0.62
0.23	0.26	0.00	0.18	-0.11	0.18	0.11	0.09
0.01	0.14	0.02	0.06	-0.33	0.06	0.33	0.15
0.08	0.10	0.00	0.02	-0.26	0.02	0.26	0.08
0.04	0.19	0.02	0.11	-0.30	0.11	0.30	0.17
0.08	0.14	0.00	0.06	-0.26	0.06	0.26	0.10
0.03	0.19	0.02	0.11	-0.31	0.11	0.31	0.18
0.05	0.12	0.00	0.04	-0.29	0.04	0.29	0.11
0.04	0.15	0.01	0.07	-0.30	0.07	0.30	0.14
0.34	0.34	0.00	0.26	0.00	0.26	0.00	0.07
0.10	0.71	0.37	0.63	-0.24	0.63	0.24	0.75
0.10	0.65	0.31	0.57	-0.24	0.57	0.24	0.66
0.10	0.22	0.01	0.14	-0.24	0.14	0.24	0.15
0.07	0.13	0.00	0.05	-0.27	0.05	0.27	0.11
0.07	0.10	0.00	0.02	-0.27	0.02	0.27	0.09
0.07	0.19	0.01	0.11	-0.27	0.11	0.27	0.15
0.05	0.14	0.01	0.06	-0.29	0.06	0.29	0.13
0.06	0.24	0.03	0.16	-0.28	0.16	0.28	0.20
0.05	0.13	0.01	0.05	-0.29	0.05	0.29	0.12
0.06	0.13	0.01	0.05	-0.28	0.05	0.28	0.11
0.53	0.34	0.04	0.26	0.19	0.26	0.19	0.20
0.11	0.53	0.18	0.45	-0.23	0.45	0.23	0.46
0.09	0.53	0.19	0.45	-0.25	0.45	0.25	0.49
0.10	0.15	0.00	0.07	-0.24	0.07	0.24	0.10
0.08	0.11	0.00	0.03	-0.26	0.03	0.26	0.08
0.27	0.09	0.03	0.01	-0.08	0.01	0.08	0.01
0.09	0.10	0.00	0.02	-0.25	0.02	0.25	0.07
0.04	0.08	0.00	0.00	-0.31	0.00	0.31	0.10
0.02	0.25	0.05	0.17	-0.32	0.17	0.32	0.23
0.07	0.12	0.00	0.04	-0.27	0.04	0.27	0.10
0.07	0.04	0.00	-0.04	-0.27	0.04	0.27	0.09
0.04	0.04	0.00	-0.04	-0.30	0.04	0.30	0.11
0.07	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
0.05	0.13	0.01	0.05	-0.29	0.05	0.29	0.11
0.08	0.18	0.01	0.10	-0.27	0.10	0.27	0.13
0.07	0.17	0.01	0.09	-0.27	0.09	0.27	0.13
0.12	0.17	0.00	0.09	-0.22	0.09	0.22	0.10
0.12	0.18	0.00	0.10	-0.22	0.10	0.22	0.10
0.12	0.24	0.02	0.16	-0.23	0.16	0.23	0.15
0.09	0.59	0.25	0.51	-0.25	0.51	0.25	0.58
0.08	0.15	0.01	0.07	-0.26	0.07	0.26	0.11
0.11	0.11	0.00	0.03	-0.23	0.03	0.23	0.07
0.02	0.01	0.00	-0.07	-0.32	0.07	0.32	0.15
0.04	0.19	0.02	0.11	-0.31	0.11	0.31	0.17
0.04	0.23	0.04	0.15	-0.31	0.15	0.31	0.21
0.02	0.23	0.05	0.16	-0.32	0.15	0.32	0.23
0.03	0.25	0.05	0.17	-0.31	0.17	0.31	0.23

Appendix 20 (Continued)

0.07	0.25	0.04	0.18	-0.28	0.17	0.28	0.20
0.11	0.29	0.03	0.21	-0.24	0.21	0.24	0.20
0.08	0.71	0.39	0.63	-0.26	0.63	0.26	0.79
0.05	0.53	0.24	0.45	-0.30	0.45	0.30	0.56
0.13	1.19	1.13	1.11	-0.22	1.11	0.22	1.76
0.05	0.72	0.45	0.65	-0.29	0.64	0.29	0.88
0.01	0.03	0.00	-0.05	-0.33	0.05	0.33	0.14
0.02	0.23	0.05	0.15	-0.32	0.15	0.32	0.23
0.02	0.25	0.05	0.17	-0.32	0.17	0.32	0.25
0.02	0.26	0.06	0.18	-0.32	0.18	0.32	0.25
0.02	0.28	0.07	0.20	-0.32	0.20	0.32	0.27
0.05	0.28	0.05	0.20	-0.29	0.20	0.29	0.24
0.09	0.34	0.06	0.26	-0.25	0.26	0.25	0.26
0.07	0.88	0.66	0.80	-0.27	0.80	0.27	1.15
0.03	0.59	0.31	0.51	-0.31	0.51	0.31	0.67
0.03	1.39	1.85	1.31	-0.31	1.31	0.31	2.63
0.03	1.31	1.64	1.23	-0.31	1.23	0.31	2.38
0.03	0.75	0.52	0.67	-0.31	0.67	0.31	0.97
0.03	0.04	0.00	-0.04	-0.32	0.04	0.32	0.12
0.05	0.17	0.02	0.09	-0.29	0.09	0.29	0.15
0.04	0.14	0.01	0.06	-0.30	0.06	0.30	0.13
0.07	0.10	0.00	0.02	-0.27	0.02	0.27	0.08
0.06	0.12	0.00	0.04	-0.28	0.04	0.28	0.10
0.08	0.15	0.01	0.07	-0.26	0.07	0.26	0.11
0.08	0.23	0.02	0.15	-0.27	0.15	0.27	0.17
0.12	0.45	0.11	0.37	-0.23	0.37	0.23	0.35
0.08	0.57	0.25	0.49	-0.27	0.49	0.27	0.58
0.06	1.14	1.18	1.06	-0.29	1.06	0.29	1.81
0.07	0.37	0.09	0.29	-0.28	0.29	0.28	0.32
0.04	0.39	0.12	0.31	-0.30	0.31	0.30	0.37
0.06	0.20	0.02	0.12	-0.29	0.12	0.29	0.16
0.05	0.29	0.06	0.21	-0.29	0.21	0.29	0.25
0.05	0.28	0.05	0.20	-0.29	0.20	0.29	0.24
0.07	0.30	0.05	0.22	-0.27	0.22	0.27	0.24
0.07	0.31	0.06	0.23	-0.27	0.23	0.27	0.25
0.08	0.33	0.07	0.25	-0.27	0.25	0.27	0.27
0.10	0.71	0.38	0.63	-0.25	0.63	0.25	0.77
0.08	0.76	0.46	0.68	-0.26	0.68	0.26	0.88
0.06	1.19	1.29	1.11	-0.29	1.11	0.29	1.95
0.08	1.43	1.84	1.35	-0.27	1.35	0.27	2.61
0.05	1.02	0.94	0.94	-0.29	0.94	0.29	1.52
0.06	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
0.04	0.18	0.02	0.11	-0.30	0.10	0.30	0.16
0.05	0.25	0.04	0.17	-0.29	0.17	0.29	0.21
0.09	0.20	0.01	0.12	-0.25	0.12	0.25	0.14
0.27	0.20	0.01	0.12	-0.07	0.12	0.07	0.04
0.11	0.21	0.01	0.13	-0.24	0.13	0.24	0.14
0.12	0.28	0.03	0.20	-0.23	0.20	0.23	0.18
0.09	0.66	0.33	0.58	-0.25	0.58	0.25	0.69
0.06	0.67	0.38	0.59	-0.29	0.59	0.29	0.77

Appendix 20 (Continued)

0.07	1.14	1.16	1.06	-0.28	1.06	0.28	1.79
0.05	1.29	1.54	1.21	-0.29	1.21	0.29	2.25
0.05	0.83	0.61	0.75	-0.29	0.75	0.29	1.09
0.07	0.34	0.07	0.26	-0.27	0.26	0.27	0.28
0.09	0.03	0.00	-0.05	-0.25	0.05	0.25	0.09
0.06	0.03	0.00	-0.05	-0.28	0.05	0.28	0.11
0.00	0.02	0.00	-0.06	-0.34	0.06	0.34	0.16
0.05	0.03	0.00	-0.05	-0.30	0.05	0.30	0.12
0.13	0.05	0.01	-0.03	-0.22	0.03	0.22	0.06
0.11	0.06	0.00	-0.02	-0.24	0.02	0.24	0.07
0.09	0.06	0.00	-0.02	-0.25	0.02	0.25	0.07
0.10	0.04	0.00	-0.04	-0.24	0.04	0.24	0.08
0.07	0.07	0.00	-0.01	-0.27	0.01	0.27	0.08
0.07	0.04	0.00	-0.04	-0.28	0.04	0.28	0.10
Average = 0.08	Average = 0.34	Sum = 20.90	IOA = 0.535				Sum = 44.96

Appendix 21

Appendix 21. Average Error for Phosphate Concentration for 1996 Data

Observed	Predicted	(Observed -Predicted)
0.37	0.37	0.00
0.32	0.28	0.04
0.10	0.10	0.00
0.01	0.06	-0.05
0.09	0.04	0.05
0.07	0.13	-0.07
0.07	0.09	-0.01
0.07	0.08	0.00
0.06	0.05	0.02
0.12	0.09	0.03
0.10	0.37	-0.27
0.40	0.25	0.15
0.30	0.25	0.05
0.10	0.06	0.04
0.01	0.06	-0.05
0.06	0.02	0.04
0.04	0.15	-0.10
0.05	0.04	0.01
0.03	0.05	-0.01
0.03	0.02	0.01
0.26	0.26	0.00
0.04	0.26	-0.22
0.07	0.04	0.03
0.01	0.07	-0.06
0.20	0.01	0.19
0.02	0.18	-0.16
0.05	0.03	0.02
0.01	0.05	-0.04
0.02	0.01	0.01
0.03	0.16	-0.13
0.43	0.43	0.00
0.23	0.24	-0.01
0.10	0.07	0.03
0.10	0.05	0.05
0.09	0.05	0.04
0.07	0.11	-0.05
0.07	0.15	-0.08
0.05	0.15	-0.10
0.04	0.05	-0.02
0.06	0.06	0.00
0.39	0.39	0.00
0.08	0.60	-0.52
0.23	0.26	-0.03
0.01	0.14	-0.13
0.08	0.10	-0.02

Appendix 21 (Continued)

0.04	0.19	-0.15
0.08	0.14	-0.06
0.03	0.19	-0.16
0.05	0.12	-0.07
0.04	0.15	-0.11
0.34	0.34	0.00
0.10	0.71	-0.61
0.10	0.65	-0.55
0.10	0.22	-0.12
0.07	0.13	-0.06
0.07	0.10	-0.03
0.07	0.19	-0.12
0.05	0.14	-0.09
0.06	0.24	-0.19
0.05	0.13	-0.08
0.06	0.13	-0.07
0.53	0.34	0.19
0.11	0.53	-0.42
0.09	0.53	-0.44
0.10	0.15	-0.05
0.08	0.11	-0.03
0.27	0.09	0.17
0.09	0.10	-0.01
0.04	0.08	-0.05
0.02	0.25	-0.22
0.07	0.12	-0.05
0.07	0.04	0.03
0.04	0.04	0.00
0.07	0.04	0.02
0.05	0.13	-0.08
0.08	0.18	-0.10
0.07	0.17	-0.10
0.12	0.17	-0.05
0.12	0.18	-0.06
0.12	0.24	-0.12
0.09	0.59	-0.50
0.08	0.15	-0.07
0.11	0.11	0.00
0.02	0.01	0.01
0.04	0.19	-0.15
0.04	0.23	-0.19
0.02	0.23	-0.21
0.03	0.25	-0.22
0.07	0.25	-0.19
0.11	0.29	-0.19
0.08	0.71	-0.63
0.05	0.53	-0.49

Appendix 21 (Continued)

0.13	1.19	-1.07
0.05	0.72	-0.67
0.01	0.03	-0.01
0.02	0.23	-0.21
0.02	0.25	-0.23
0.02	0.26	-0.24
0.02	0.28	-0.26
0.05	0.28	-0.23
0.09	0.34	-0.25
0.07	0.88	-0.81
0.03	0.59	-0.56
0.03	1.39	-1.36
0.03	1.31	-1.28
0.03	0.75	-0.72
0.03	0.04	-0.02
0.05	0.17	-0.12
0.04	0.14	-0.10
0.07	0.10	-0.03
0.06	0.12	-0.06
0.08	0.15	-0.07
0.08	0.23	-0.16
0.12	0.45	-0.33
0.08	0.57	-0.50
0.06	1.14	-1.09
0.07	0.37	-0.30
0.04	0.39	-0.35
0.06	0.20	-0.14
0.05	0.29	-0.24
0.05	0.28	-0.23
0.07	0.30	-0.23
0.07	0.31	-0.24
0.08	0.33	-0.26
0.10	0.71	-0.62
0.08	0.76	-0.68
0.06	1.19	-1.14
0.08	1.43	-1.36
0.05	1.02	-0.97
0.06	0.04	0.02
0.04	0.18	-0.14
0.05	0.25	-0.20
0.09	0.20	-0.11
0.27	0.20	0.07
0.11	0.21	-0.11
0.12	0.28	-0.17
0.09	0.66	-0.57
0.06	0.67	-0.62
0.07	1.14	-1.08

Appendix 21 (Continued)

0.05	1.29	-1.24
0.05	0.83	-0.78
0.07	0.34	-0.27
0.09	0.03	0.06
0.06	0.03	0.03
0.00	0.02	-0.01
0.05	0.03	0.02
0.13	0.05	0.08
0.11	0.06	0.05
0.09	0.06	0.03
0.10	0.04	0.06
0.07	0.07	0.00
0.07	0.04	0.02
Average = 0.09	Average = 0.28	Sum = -30.00
	Average Error = -0.197	

Appendix 22

Appendix 22. IoA Calculation for Chlorophyll a Concentration for Overall Estuary for 1997 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
2.00	2.00	0.00	-2.01	-1.55	2.01	1.55	12.70
6.00	4.04	3.84	1.99	0.49	1.99	0.49	6.13
8.00	1.88	37.45	3.99	-1.67	3.99	1.67	32.00
1.00	1.83	0.69	-3.01	-1.72	3.01	1.72	22.41
1.00	1.19	0.04	-3.01	-2.36	3.01	2.36	28.87
7.30	2.33	24.70	3.29	-1.22	3.29	1.22	20.31
33.00	2.57	925.98	28.99	-0.98	28.99	0.98	897.99
2.70	1.71	0.98	-1.31	-1.84	1.31	1.84	9.94
16.00	1.82	201.07	11.99	-1.73	11.99	1.73	188.14
16.70	7.67	81.54	12.69	4.12	12.69	4.12	282.46
13.00	6.74	39.19	8.99	3.19	8.99	3.19	148.27
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	30.95
3.00	4.68	2.82	-1.01	1.13	1.01	1.13	4.59
1.00	1.60	0.36	-3.01	-1.95	3.01	1.95	24.64
1.00	3.34	5.48	-3.01	-0.21	3.01	0.21	10.39
1.00	1.41	0.17	-3.01	-2.14	3.01	2.14	26.56
4.50	2.26	5.02	0.49	-1.29	0.49	1.29	3.16
6.60	2.23	19.10	2.59	-1.32	2.59	1.32	15.26
2.50	1.70	0.64	-1.51	-1.85	1.51	1.85	11.31
6.80	1.74	25.60	2.79	-1.81	2.79	1.81	21.13
4.40	9.83	29.48	0.39	6.28	0.39	6.28	44.44
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	30.95
1.00	5.73	22.37	-3.01	2.18	3.01	2.18	26.97
4.00	1.45	6.50	-0.01	-2.10	0.01	2.10	4.47
3.10	2.84	0.07	-0.91	-0.71	0.91	0.71	2.64
4.40	2.68	2.96	0.39	-0.87	0.39	0.87	1.58
2.40	1.98	0.18	-1.61	-1.57	1.61	1.57	10.13
3.20	2.01	1.42	-0.81	-1.54	0.81	1.54	5.54
3.00	3.00	0.00	-1.01	-0.55	1.01	0.55	2.44
4.00	6.88	8.29	-0.01	3.33	0.01	3.33	11.18
1.00	1.51	0.26	-3.01	-2.04	3.01	2.04	25.54
3.00	1.11	3.57	-1.01	-2.44	1.01	2.44	11.93
9.10	1.66	55.35	5.09	-1.89	5.09	1.89	48.67
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	30.95
1.80	2.46	0.44	-2.21	-1.09	2.21	1.09	10.91
1.80	2.35	0.30	-2.21	-1.20	2.21	1.20	11.65
1.50	2.45	0.90	-2.51	-1.10	2.51	1.10	13.06
1.50	3.43	3.72	-2.51	-0.12	2.51	0.12	6.94
14.00	7.92	36.97	9.99	4.37	9.99	4.37	206.11
3.30	4.10	0.64	-0.71	0.55	0.71	0.55	1.60
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	30.95
2.00	7.85	34.22	-2.01	4.30	2.01	4.30	39.86
3.00	3.63	0.40	-1.01	0.08	1.01	0.08	1.20
6.00	2.94	9.36	1.99	-0.61	1.99	0.61	6.74
1.00	4.58	12.82	-3.01	1.03	3.01	1.03	16.35
1.00	2.52	2.31	-3.01	-1.03	3.01	1.03	16.35
1.70	4.54	8.07	-2.31	0.99	2.31	0.99	10.91
1.80	4.06	5.11	-2.21	0.51	2.21	0.51	7.42
0.70	3.26	6.55	-3.31	-0.29	3.31	0.29	12.99

Appendix 22 (Continued)

1.70	3.99	5.24	-2.31	0.44	2.31	0.44	7.58
3.10	10.40	53.29	-0.91	6.85	0.91	6.85	60.27
3.00	3.00	0.00	-1.01	-0.55	1.01	0.55	2.44
4.00	9.69	32.38	-0.01	6.14	0.01	6.14	37.87
2.00	3.77	3.13	-2.01	0.22	2.01	0.22	4.99
1.00	2.74	3.03	-3.01	-0.81	3.01	0.81	14.62
1.00	4.80	14.44	-3.01	1.25	3.01	1.25	18.18
2.00	2.27	0.07	-2.01	-1.28	2.01	1.28	10.85
2.20	6.57	19.10	-1.81	3.02	1.81	3.02	23.36
3.80	4.69	0.79	-0.21	1.14	0.21	1.14	1.83
1.30	3.68	5.66	-2.71	0.13	2.71	0.13	8.09
1.50	5.30	14.44	-2.51	1.75	2.51	1.75	18.18
5.90	9.10	10.24	1.89	5.55	1.89	5.55	55.30
1.00	1.20	0.04	-3.01	-2.35	3.01	2.35	28.77
6.00	7.80	3.24	1.99	4.25	1.99	4.25	38.89
1.00	2.15	1.32	-3.01	-1.40	3.01	1.40	19.48
1.00	1.26	0.07	-3.01	-2.29	3.01	2.29	28.13
1.00	3.48	6.15	-3.01	-0.07	3.01	0.07	9.51
1.00	1.55	0.30	-3.01	-2.00	3.01	2.00	25.14
4.20	6.78	6.66	0.19	3.23	0.19	3.23	11.67
2.50	3.98	2.19	-1.51	0.43	1.51	0.43	3.78
2.30	2.95	0.42	-1.71	-0.60	1.71	0.60	5.35
2.80	4.74	3.76	-1.21	1.19	1.21	1.19	5.78
13.00	1.70	127.69	8.99	-1.85	8.99	1.85	117.43
7.90	1.25	44.22	3.89	-2.30	3.89	2.30	38.27
Average = 4.01	Average = 3.55	Sum = 1984.82	IOA = 3.48E-01				Sum = 3043.42

Appendix 23. IoA Calculation for Chlorophyll a for Port River Estuary only.

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
2.00	2.00	0.00	-2.01	-1.55	2.01	1.55	9.74
6.00	4.04	3.84	1.99	0.49	1.99	0.49	0.95
8.00	1.88	37.45	3.99	-1.67	3.99	1.67	44.32
1.00	1.83	0.69	-3.01	-1.72	3.01	1.72	26.87
1.00	1.19	0.04	-3.01	-2.36	3.01	2.36	50.58
7.30	2.33	24.70	3.29	-1.22	3.29	1.22	16.08
33.00	2.57	925.98	28.99	-0.98	28.99	0.98	806.94
2.70	1.71	0.98	-1.31	-1.84	1.31	1.84	5.84
16.00	1.82	201.07	11.99	-1.73	11.99	1.73	430.01
16.70	7.67	81.54	12.69	4.12	12.69	4.12	2731.98
13.00	6.74	39.19	8.99	3.19	8.99	3.19	821.79
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	59.05
3.00	4.68	2.82	-1.01	1.13	1.01	1.13	1.31
1.00	1.60	0.36	-3.01	-1.95	3.01	1.95	34.53
1.00	3.34	5.48	-3.01	-0.21	3.01	0.21	0.40
1.00	1.41	0.17	-3.01	-2.14	3.01	2.14	41.59
4.50	2.26	5.02	0.49	-1.29	0.49	1.29	0.39
6.60	2.23	19.10	2.59	-1.32	2.59	1.32	11.66
2.50	1.70	0.64	-1.51	-1.85	1.51	1.85	7.84
6.80	1.74	25.60	2.79	-1.81	2.79	1.81	25.44
4.40	9.83	29.48	0.39	6.28	0.39	6.28	5.89
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	59.05
1.00	5.73	22.37	-3.01	2.18	3.01	2.18	43.16
4.00	1.45	6.50	-0.01	-2.10	0.01	2.10	0.00
3.10	2.84	0.07	-0.91	-0.71	0.91	0.71	0.42
4.40	2.68	2.96	0.39	-0.87	0.39	0.87	0.11
2.40	1.98	0.18	-1.61	-1.57	1.61	1.57	6.42
3.20	2.01	1.42	-0.81	-1.54	0.81	1.54	1.57
3.00	3.00	0.00	-1.01	-0.55	1.01	0.55	0.31
4.00	6.88	8.29	-0.01	3.33	0.01	3.33	0.00
1.00	1.51	0.26	-3.01	-2.04	3.01	2.04	37.79
3.00	1.11	3.57	-1.01	-2.44	1.01	2.44	6.12
9.10	1.66	55.35	5.09	-1.89	5.09	1.89	92.42
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	59.05
1.80	2.46	0.44	-2.21	-1.09	2.21	1.09	5.82
1.80	2.35	0.30	-2.21	-1.20	2.21	1.20	7.06
1.50	2.45	0.90	-2.51	-1.10	2.51	1.10	7.64
1.50	3.43	3.72	-2.51	-0.12	2.51	0.12	0.09
14.00	7.92	36.97	9.99	4.37	9.99	4.37	1904.54
3.30	4.10	0.64	-0.71	0.55	0.71	0.55	0.15
Average = 5.07	Average = 2.98	Sum = 1548.10	IOA = 0.790				Sum = 7364.92

Appendix 24

Appendix 24. IoA Calculation for Chlorophyll a Concentration for Barker Inlet only for 1997 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
1.00	1.00	0.00	-3.01	-2.55	3.01	2.55	59.05
2.00	7.85	34.22	-2.01	4.30	2.01	4.30	74.96
3.00	3.63	0.40	-1.01	0.08	1.01	0.08	0.01
6.00	2.94	9.36	1.99	-0.61	1.99	0.61	1.47
1.00	4.58	12.82	-3.01	1.03	3.01	1.03	9.63
1.00	2.52	2.31	-3.01	-1.03	3.01	1.03	9.63
1.70	4.54	8.07	-2.31	0.99	2.31	0.99	5.25
1.80	4.06	5.11	-2.21	0.51	2.21	0.51	1.27
0.70	3.26	6.55	-3.31	-0.29	3.31	0.29	0.92
1.70	3.99	5.24	-2.31	0.44	2.31	0.44	1.04
3.10	10.40	53.29	-0.91	6.85	0.91	6.85	39.16
3.00	3.00	0.00	-1.01	-0.55	1.01	0.55	0.31
4.00	9.69	32.38	-0.01	6.14	0.01	6.14	0.01
2.00	3.77	3.13	-2.01	0.22	2.01	0.22	0.20
1.00	2.74	3.03	-3.01	-0.81	3.01	0.81	5.96
1.00	4.80	14.44	-3.01	1.25	3.01	1.25	14.19
2.00	2.27	0.07	-2.01	-1.28	2.01	1.28	6.64
2.20	6.57	19.10	-1.81	3.02	1.81	3.02	30.00
3.80	4.69	0.79	-0.21	1.14	0.21	1.14	0.06
1.30	3.68	5.66	-2.71	0.13	2.71	0.13	0.12
1.50	5.30	14.44	-2.51	1.75	2.51	1.75	19.35
5.90	9.10	10.24	1.89	5.55	1.89	5.55	109.62
1.00	1.20	0.04	-3.01	-2.35	3.01	2.35	50.15
6.00	7.80	3.24	1.99	4.25	1.99	4.25	71.28
1.00	2.15	1.32	-3.01	-1.40	3.01	1.40	17.80
1.00	1.26	0.07	-3.01	-2.29	3.01	2.29	47.62
1.00	3.48	6.15	-3.01	-0.07	3.01	0.07	0.04
1.00	1.55	0.30	-3.01	-2.00	3.01	2.00	36.32
4.20	6.78	6.66	0.19	3.23	0.19	3.23	0.36
2.50	3.98	2.19	-1.51	0.43	1.51	0.43	0.42
2.30	2.95	0.42	-1.71	-0.60	1.71	0.60	1.06
2.80	4.74	3.76	-1.21	1.19	1.21	1.19	2.09
13.00	1.70	127.69	8.99	-1.85	8.99	1.85	276.39
7.90	1.25	44.22	3.89	-2.30	3.89	2.30	79.90
Average = 2.78	Average = 4.21	Sum = 436.72	IoA = 0.551				Sum = 972.29

Appendix 25. IoA Calculation for Ammonia for 1997 Data Set for Overall Estuary

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.59	0.59	0.00	0.12	0.02	0.12	0.02	0.02
0.80	1.02	0.05	0.33	0.45	0.33	0.45	0.61
0.48	0.73	0.06	0.01	0.15	0.01	0.15	0.03
0.74	0.53	0.05	0.27	-0.05	0.27	0.05	0.10
0.97	0.49	0.23	0.50	-0.08	0.50	0.08	0.34
1.70	0.75	0.90	1.23	0.18	1.23	0.18	1.99
0.76	1.20	0.19	0.29	0.63	0.29	0.63	0.84
1.10	1.28	0.03	0.63	0.71	0.63	0.71	1.79
0.16	0.87	0.50	-0.31	0.29	0.31	0.29	0.36
0.55	0.70	0.02	0.08	0.13	0.08	0.13	0.04
0.12	0.12	0.00	-0.35	-0.46	0.35	0.46	0.66
0.46	0.19	0.07	-0.01	-0.38	0.01	0.38	0.15
0.28	0.17	0.01	-0.19	-0.41	0.19	0.41	0.35
0.50	0.15	0.12	0.03	-0.42	0.03	0.42	0.21
0.49	0.21	0.08	0.02	-0.37	0.02	0.37	0.15
1.20	0.24	0.91	0.73	-0.33	0.73	0.33	1.13
0.61	0.40	0.04	0.14	-0.17	0.14	0.17	0.10
0.60	0.38	0.05	0.13	-0.20	0.13	0.20	0.11
0.28	0.51	0.05	-0.19	-0.06	0.19	0.06	0.06
0.32	0.22	0.01	-0.15	-0.35	0.15	0.35	0.25
0.20	0.28	0.01	-0.27	-0.29	0.27	0.29	0.32
0.04	0.04	0.00	-0.43	-0.54	0.43	0.54	0.93
0.06	0.09	0.00	-0.41	-0.48	0.41	0.48	0.80
0.11	0.07	0.00	-0.36	-0.50	0.36	0.50	0.75
0.13	0.13	0.00	-0.34	-0.44	0.34	0.44	0.61
0.30	0.14	0.03	-0.17	-0.44	0.17	0.44	0.36
0.24	0.32	0.01	-0.23	-0.25	0.23	0.25	0.23
0.47	0.29	0.03	0.00	-0.29	0.00	0.29	0.08
0.06	0.48	0.17	-0.41	-0.09	0.41	0.09	0.25
0.21	0.11	0.01	-0.26	-0.47	0.26	0.47	0.53
0.08	0.22	0.02	-0.39	-0.35	0.39	0.35	0.56
0.52	0.50	0.00	0.05	-0.07	0.05	0.07	0.02
0.29	0.69	0.17	-0.18	0.12	0.18	0.12	0.09
0.49	0.39	0.01	0.02	-0.18	0.02	0.18	0.04
0.83	0.24	0.35	0.36	-0.34	0.36	0.34	0.49
0.83	0.29	0.29	0.36	-0.28	0.36	0.28	0.41
0.78	0.39	0.16	0.31	-0.19	0.31	0.19	0.25
0.90	0.67	0.05	0.43	0.09	0.43	0.09	0.28
0.47	0.64	0.03	0.00	0.07	0.00	0.07	0.01
0.34	0.81	0.22	-0.13	0.23	0.13	0.23	0.13
0.20	1.03	0.69	-0.27	0.46	0.27	0.46	0.53
0.20	0.57	0.14	-0.27	-0.01	0.27	0.01	0.07
0.39	0.31	0.01	-0.08	-0.27	0.08	0.27	0.12
0.50	0.50	0.00	0.03	-0.07	0.03	0.07	0.01
0.07	1.06	0.98	-0.40	0.49	0.40	0.49	0.78
0.49	1.11	0.39	0.02	0.54	0.02	0.54	0.31
0.87	1.03	0.03	0.40	0.46	0.40	0.46	0.74
0.80	1.04	0.06	0.33	0.47	0.33	0.47	0.64
0.80	1.10	0.09	0.33	0.53	0.33	0.53	0.74

Appendix 25 (Continued)

0.80	1.24	0.19	0.33	0.67	0.33	0.67	1.00
0.40	1.35	0.90	-0.07	0.78	0.07	0.78	0.71
0.30	1.33	1.06	-0.17	0.76	0.17	0.76	0.86
0.13	1.38	1.56	-0.34	0.81	0.34	0.81	1.31
0.18	1.19	1.02	-0.29	0.62	0.29	0.62	0.82
0.41	1.15	0.55	-0.06	0.58	0.06	0.58	0.40
0.44	0.44	0.00	-0.03	-0.13	0.03	0.13	0.03
0.01	0.78	0.59	-0.46	0.21	0.46	0.21	0.44
0.42	0.84	0.18	-0.05	0.27	0.05	0.27	0.10
0.64	0.61	0.00	0.17	0.03	0.17	0.03	0.04
0.67	0.58	0.01	0.20	0.01	0.20	0.01	0.04
1.35	0.65	0.48	0.88	0.08	0.88	0.08	0.93
0.80	1.03	0.05	0.33	0.46	0.33	0.46	0.62
0.47	1.04	0.32	0.00	0.47	0.00	0.47	0.22
0.47	0.98	0.26	0.00	0.41	0.00	0.41	0.17
0.12	1.08	0.92	-0.35	0.51	0.35	0.51	0.73
0.26	0.86	0.36	-0.21	0.28	0.21	0.28	0.24
0.40	0.80	0.16	-0.07	0.22	0.07	0.22	0.08
0.19	0.19	0.00	-0.28	-0.39	0.28	0.39	0.45
0.80	0.23	0.33	0.33	-0.35	0.33	0.35	0.46
0.29	0.26	0.00	-0.18	-0.31	0.18	0.31	0.24
0.26	0.11	0.02	-0.21	-0.46	0.21	0.46	0.45
0.30	0.14	0.02	-0.17	-0.43	0.17	0.43	0.36
1.00	0.23	0.60	0.53	-0.35	0.53	0.35	0.77
0.80	0.58	0.05	0.33	0.01	0.33	0.01	0.12
0.31	0.36	0.00	-0.16	-0.21	0.16	0.21	0.13
0.06	0.23	0.03	-0.41	-0.35	0.41	0.35	0.57
0.05	0.14	0.01	-0.42	-0.43	0.42	0.43	0.72
0.18	0.09	0.01	-0.29	-0.49	0.29	0.49	0.60
0.15	0.14	0.00	-0.32	-0.43	0.32	0.43	0.56
Average =0.47	Average = 0.57	Sum = 17.02	IoA = 0.507				Sum = 34.54

Appendix 26

Appendix 26. IoA Calculation for Port River only for 1997 Data Set for Ammonia

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')²
0.59	0.59	0.00	0.12	0.02	0.12	0.02	0.02
0.80	1.02	0.05	0.33	0.45	0.33	0.45	0.61
0.48	0.73	0.06	0.01	0.15	0.01	0.15	0.03
0.74	0.53	0.05	0.27	-0.05	0.27	0.05	0.10
0.97	0.49	0.23	0.50	-0.08	0.50	0.08	0.34
1.70	0.75	0.90	1.23	0.18	1.23	0.18	1.99
0.76	1.20	0.19	0.29	0.63	0.29	0.63	0.84
1.10	1.28	0.03	0.63	0.71	0.63	0.71	1.79
0.16	0.87	0.50	-0.31	0.29	0.31	0.29	0.36
0.55	0.70	0.02	0.08	0.13	0.08	0.13	0.04
0.12	0.12	0.00	-0.35	-0.46	0.35	0.46	0.66
0.46	0.19	0.07	-0.01	-0.38	0.01	0.38	0.15
0.28	0.17	0.01	-0.19	-0.41	0.19	0.41	0.35
0.50	0.15	0.12	0.03	-0.42	0.03	0.42	0.21
0.49	0.21	0.08	0.02	-0.37	0.02	0.37	0.15
1.20	0.24	0.91	0.73	-0.33	0.73	0.33	1.13
0.61	0.40	0.04	0.14	-0.17	0.14	0.17	0.10
0.60	0.38	0.05	0.13	-0.20	0.13	0.20	0.11
0.28	0.51	0.05	-0.19	-0.06	0.19	0.06	0.06
0.32	0.22	0.01	-0.15	-0.35	0.15	0.35	0.25
0.20	0.28	0.01	-0.27	-0.29	0.27	0.29	0.32
0.04	0.04	0.00	-0.43	-0.54	0.43	0.54	0.93
0.06	0.09	0.00	-0.41	-0.48	0.41	0.48	0.80
0.11	0.07	0.00	-0.36	-0.50	0.36	0.50	0.75
0.13	0.13	0.00	-0.34	-0.44	0.34	0.44	0.61
0.30	0.14	0.03	-0.17	-0.44	0.17	0.44	0.36
0.24	0.32	0.01	-0.23	-0.25	0.23	0.25	0.23
0.47	0.29	0.03	0.00	-0.29	0.00	0.29	0.08
0.06	0.48	0.17	-0.41	-0.09	0.41	0.09	0.25
0.21	0.11	0.01	-0.26	-0.47	0.26	0.47	0.53
0.08	0.22	0.02	-0.39	-0.35	0.39	0.35	0.56
0.52	0.50	0.00	0.05	-0.07	0.05	0.07	0.02
0.29	0.69	0.17	-0.18	0.12	0.18	0.12	0.09
0.49	0.39	0.01	0.02	-0.18	0.02	0.18	0.04
0.83	0.24	0.35	0.36	-0.34	0.36	0.34	0.49
0.83	0.29	0.29	0.36	-0.28	0.36	0.28	0.41
0.78	0.39	0.16	0.31	-0.19	0.31	0.19	0.25
0.90	0.67	0.05	0.43	0.09	0.43	0.09	0.28
0.47	0.64	0.03	0.00	0.07	0.00	0.07	0.01
0.34	0.81	0.22	-0.13	0.23	0.13	0.23	0.13
Average = 0.50	Average = 0.44	Sum = 4.95	IoA = 0.69				Sum = 16.41

Appendix 27

Appendix 27. IoA Calculation for Ammonia for Barker Inlet for 1997 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')²
0.20	1.03	0.69	-0.27	0.46	0.27	0.46	0.53
0.20	0.57	0.14	-0.27	-0.01	0.27	0.01	0.07
0.39	0.31	0.01	-0.08	-0.27	0.08	0.27	0.12
0.50	0.50	0.00	0.03	-0.07	0.03	0.07	0.01
0.07	1.06	0.98	-0.40	0.49	0.40	0.49	0.78
0.49	1.11	0.39	0.02	0.54	0.02	0.54	0.31
0.87	1.03	0.03	0.40	0.46	0.40	0.46	0.74
0.80	1.04	0.06	0.33	0.47	0.33	0.47	0.64
0.80	1.10	0.09	0.33	0.53	0.33	0.53	0.74
0.80	1.24	0.19	0.33	0.67	0.33	0.67	1.00
0.40	1.35	0.90	-0.07	0.78	0.07	0.78	0.71
0.30	1.33	1.06	-0.17	0.76	0.17	0.76	0.86
0.13	1.38	1.56	-0.34	0.81	0.34	0.81	1.31
0.18	1.19	1.02	-0.29	0.62	0.29	0.62	0.82
0.41	1.15	0.55	-0.06	0.58	0.06	0.58	0.40
0.44	0.44	0.00	-0.03	-0.13	0.03	0.13	0.03
0.01	0.78	0.59	-0.46	0.21	0.46	0.21	0.44
0.42	0.84	0.18	-0.05	0.27	0.05	0.27	0.10
0.64	0.61	0.00	0.17	0.03	0.17	0.03	0.04
0.67	0.58	0.01	0.20	0.01	0.20	0.01	0.04
1.35	0.65	0.48	0.88	0.08	0.88	0.08	0.93
0.80	1.03	0.05	0.33	0.46	0.33	0.46	0.62
0.47	1.04	0.32	0.00	0.47	0.00	0.47	0.22
0.47	0.98	0.26	0.00	0.41	0.00	0.41	0.17
0.12	1.08	0.92	-0.35	0.51	0.35	0.51	0.73
0.26	0.86	0.36	-0.21	0.28	0.21	0.28	0.24
0.40	0.80	0.16	-0.07	0.22	0.07	0.22	0.08
0.19	0.19	0.00	-0.28	-0.39	0.28	0.39	0.45
0.80	0.23	0.33	0.33	-0.35	0.33	0.35	0.46
0.29	0.26	0.00	-0.18	-0.31	0.18	0.31	0.24
0.26	0.11	0.02	-0.21	-0.46	0.21	0.46	0.45
0.30	0.14	0.02	-0.17	-0.43	0.17	0.43	0.36
1.00	0.23	0.60	0.53	-0.35	0.53	0.35	0.77
0.80	0.58	0.05	0.33	0.01	0.33	0.01	0.12
0.31	0.36	0.00	-0.16	-0.21	0.16	0.21	0.13
0.06	0.23	0.03	-0.41	-0.35	0.41	0.35	0.57
0.05	0.14	0.01	-0.42	-0.43	0.42	0.43	0.72
0.18	0.09	0.01	-0.29	-0.49	0.29	0.49	0.60
0.15	0.14	0.00	-0.32	-0.43	0.32	0.43	0.56
Average = 0.43	Average = 0.71	Sum = 12.07		IoA = 0.33			Sum = 18.13

Appendix 28

Appendix 28. Average Error Calculation for Ammonia for 1997 Data Set

Observed	Predicted	(Observed -Predicted)
0.59	0.59	0.00
0.80	1.02	-0.22
0.48	0.73	-0.25
0.74	0.53	0.21
0.97	0.49	0.48
1.70	0.75	0.95
0.76	1.20	-0.44
1.10	1.28	-0.18
0.16	0.87	-0.71
0.55	0.70	-0.15
0.12	0.12	0.00
0.46	0.19	0.27
0.28	0.17	0.11
0.50	0.15	0.35
0.49	0.21	0.28
1.20	0.24	0.96
0.61	0.40	0.21
0.60	0.38	0.23
0.28	0.51	-0.23
0.32	0.22	0.10
0.20	0.28	-0.08
0.04	0.04	0.00
0.06	0.09	-0.03
0.11	0.07	0.03
0.13	0.13	0.00
0.30	0.14	0.16
0.24	0.32	-0.08
0.47	0.29	0.18
0.06	0.48	-0.42
0.21	0.11	0.11
0.08	0.22	-0.15
0.52	0.50	0.02
0.29	0.69	-0.41
0.49	0.39	0.10
0.83	0.24	0.59
0.83	0.29	0.54
0.78	0.39	0.40
0.90	0.67	0.23
0.47	0.64	-0.17
0.34	0.81	-0.47
0.20	1.03	-0.83
0.20	0.57	-0.37
0.39	0.31	0.08
0.50	0.50	-0.01
0.07	1.06	-0.99

Appendix 28 (Continued)

0.49	1.11	-0.63
0.87	1.03	-0.16
0.80	1.04	-0.24
0.80	1.10	-0.30
0.80	1.24	-0.44
0.40	1.35	-0.95
0.30	1.33	-1.03
0.13	1.38	-1.25
0.18	1.19	-1.01
0.41	1.15	-0.74
0.44	0.44	0.00
0.01	0.78	-0.77
0.42	0.84	-0.42
0.64	0.61	0.03
0.67	0.58	0.09
1.35	0.65	0.70
0.80	1.03	-0.23
0.47	1.04	-0.57
0.47	0.98	-0.51
0.12	1.08	-0.96
0.26	0.86	-0.60
0.40	0.80	-0.40
0.19	0.19	0.00
0.80	0.23	0.58
0.29	0.26	0.02
0.26	0.11	0.14
0.30	0.14	0.15
1.00	0.23	0.77
0.80	0.58	0.22
0.31	0.36	-0.05
0.06	0.23	-0.17
0.05	0.14	-0.09
0.18	0.09	0.09
0.15	0.14	0.01
0.47	0.57	-0.11
Average = 0.47	Average = 0.57	Sum = -8.41
	Average Error = -0.1185	

Appendix 29. IoA Calculation for TKN for 1997 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.94	1.45	0.26	-0.04	0.64	0.04	0.64	0.46
1.10	0.38	0.52	0.12	-0.43	0.12	0.43	0.30
0.86	0.31	0.30	-0.12	-0.50	0.12	0.50	0.38
1.20	0.25	0.91	0.22	-0.56	0.22	0.56	0.62
1.10	0.35	0.57	0.12	-0.46	0.12	0.46	0.34
2.55	0.76	3.21	1.57	-0.05	1.57	0.05	2.63
1.05	0.80	0.06	0.07	-0.01	0.07	0.01	0.01
1.50	0.99	0.26	0.52	0.18	0.52	0.18	0.49
1.10	1.14	0.00	0.12	0.33	0.12	0.33	0.20
0.70	0.89	0.04	-0.28	0.08	0.28	0.08	0.13
0.90	0.46	0.19	-0.08	-0.35	0.08	0.35	0.19
0.40	0.40	0.00	-0.58	-0.42	0.58	0.42	1.00
0.69	0.28	0.17	-0.29	-0.53	0.29	0.53	0.67
0.59	0.28	0.09	-0.39	-0.53	0.39	0.53	0.84
0.90	0.26	0.41	-0.08	-0.55	0.08	0.55	0.40
0.63	0.33	0.09	-0.35	-0.48	0.35	0.48	0.69
2.05	0.80	1.57	1.07	-0.01	1.07	0.01	1.18
1.40	0.58	0.68	0.42	-0.23	0.42	0.23	0.43
1.10	1.14	0.00	0.12	0.33	0.12	0.33	0.20
0.95	1.18	0.05	-0.03	0.37	0.03	0.37	0.16
0.80	0.76	0.00	-0.18	-0.06	0.18	0.06	0.06
0.50	0.34	0.03	-0.48	-0.47	0.48	0.47	0.90
0.26	0.26	0.00	-0.72	-0.55	0.72	0.55	1.61
0.26	0.29	0.00	-0.72	-0.52	0.72	0.52	1.54
0.28	0.27	0.00	-0.70	-0.54	0.70	0.54	1.54
0.34	0.34	0.00	-0.64	-0.47	0.64	0.47	1.24
0.95	0.94	0.00	-0.03	0.13	0.03	0.13	0.02
0.60	0.60	0.00	-0.38	-0.21	0.38	0.21	0.35
1.50	1.36	0.02	0.52	0.55	0.52	0.55	1.15
1.35	1.31	0.00	0.37	0.50	0.37	0.50	0.76
0.75	0.76	0.00	-0.23	-0.05	0.23	0.05	0.08
0.30	0.31	0.00	-0.68	-0.50	0.68	0.50	1.39
0.87	0.87	0.00	-0.11	0.06	0.11	0.06	0.03
1.40	0.58	0.68	0.42	-0.23	0.42	0.23	0.43
0.87	0.26	0.37	-0.11	-0.55	0.11	0.55	0.44
1.30	0.14	1.35	0.32	-0.67	0.32	0.67	0.99
1.10	0.22	0.78	0.12	-0.59	0.12	0.59	0.51
1.00	0.29	0.50	0.02	-0.52	0.02	0.52	0.29
1.65	0.76	0.79	0.67	-0.05	0.67	0.05	0.52
0.90	0.66	0.06	-0.08	-0.15	0.08	0.15	0.05
1.00	1.21	0.04	0.02	0.40	0.02	0.40	0.18
0.85	1.66	0.66	-0.13	0.85	0.13	0.85	0.96
0.45	0.95	0.25	-0.53	0.14	0.53	0.14	0.45
0.80	0.26	0.29	-0.18	-0.55	0.18	0.55	0.54
0.89	0.89	0.00	-0.09	0.08	0.09	0.08	0.03
1.20	0.70	0.25	0.22	-0.11	0.22	0.11	0.11

0.87	0.64	0.05	-0.11	-0.17	0.11	0.17	0.08
1.40	0.53	0.76	0.42	-0.28	0.42	0.28	0.50
0.97	0.93	0.00	-0.01	0.12	0.01	0.12	0.02
1.10	0.91	0.04	0.12	0.10	0.12	0.10	0.05
1.41	1.26	0.02	0.43	0.45	0.43	0.45	0.77
0.80	1.17	0.14	-0.18	0.36	0.18	0.36	0.29
0.90	1.58	0.46	-0.08	0.77	0.08	0.77	0.72
0.80	1.86	1.12	-0.18	1.05	0.18	1.05	1.51
0.70	1.71	1.02	-0.28	0.90	0.28	0.90	1.39
0.70	0.98	0.08	-0.28	0.17	0.28	0.17	0.20
0.98	0.44	0.29	0.00	-0.37	0.00	0.37	0.14
1.20	0.79	0.17	0.22	-0.02	0.22	0.02	0.06
0.83	0.72	0.01	-0.15	-0.09	0.15	0.09	0.06
1.20	0.52	0.46	0.22	-0.29	0.22	0.29	0.26
0.88	1.18	0.09	-0.10	0.37	0.10	0.37	0.22
1.90	0.98	0.85	0.92	0.17	0.92	0.17	1.19
1.85	1.43	0.18	0.87	0.62	0.87	0.62	2.22
1.00	1.21	0.04	0.02	0.40	0.02	0.40	0.18
0.95	1.58	0.40	-0.03	0.77	0.03	0.77	0.64
1.15	1.95	0.64	0.17	1.14	0.17	1.14	1.72
0.80	1.95	1.32	-0.18	1.14	0.18	1.14	1.74
0.75	1.03	0.08	-0.23	0.22	0.23	0.22	0.20
0.71	0.71	0.00	-0.27	-0.10	0.27	0.10	0.14
1.30	0.59	0.51	0.32	-0.22	0.32	0.22	0.30
0.82	0.50	0.10	-0.16	-0.31	0.16	0.31	0.22
0.75	0.36	0.15	-0.23	-0.45	0.23	0.45	0.46
0.64	1.18	0.29	-0.34	0.37	0.34	0.37	0.50
1.30	0.91	0.15	0.32	0.10	0.32	0.10	0.18
1.80	1.11	0.48	0.82	0.30	0.82	0.30	1.25
0.62	0.76	0.02	-0.36	-0.05	0.36	0.05	0.17
0.90	0.70	0.04	-0.08	-0.11	0.08	0.11	0.04
0.90	0.79	0.01	-0.08	-0.03	0.08	0.03	0.01
0.90	1.23	0.11	-0.08	0.42	0.08	0.42	0.25
0.70	0.69	0.00	-0.28	-0.12	0.28	0.12	0.16
Average = 0.98	Average = 0.81	Sum = 25.54		IoA = 0.44			Sum = 45.26

Appendix 30

Appendix 30. IoA Calculation for 1997 Data Set for TKN for Port River only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')²
0.94	1.45	0.26	-0.04	0.64	0.04	0.64	0.46
1.10	0.38	0.52	0.12	-0.43	0.12	0.43	0.30
0.86	0.31	0.30	-0.12	-0.50	0.12	0.50	0.38
1.20	0.25	0.91	0.22	-0.56	0.22	0.56	0.62
1.10	0.35	0.57	0.12	-0.46	0.12	0.46	0.34
2.55	0.76	3.21	1.57	-0.05	1.57	0.05	2.63
1.05	0.80	0.06	0.07	-0.01	0.07	0.01	0.01
1.50	0.99	0.26	0.52	0.18	0.52	0.18	0.49
1.10	1.14	0.00	0.12	0.33	0.12	0.33	0.20
0.70	0.89	0.04	-0.28	0.08	0.28	0.08	0.13
0.90	0.46	0.19	-0.08	-0.35	0.08	0.35	0.19
0.40	0.40	0.00	-0.58	-0.42	0.58	0.42	1.00
0.69	0.28	0.17	-0.29	-0.53	0.29	0.53	0.67
0.59	0.28	0.09	-0.39	-0.53	0.39	0.53	0.84
0.90	0.26	0.41	-0.08	-0.55	0.08	0.55	0.40
0.63	0.33	0.09	-0.35	-0.48	0.35	0.48	0.69
2.05	0.80	1.57	1.07	-0.01	1.07	0.01	1.18
1.40	0.58	0.68	0.42	-0.23	0.42	0.23	0.43
1.10	1.14	0.00	0.12	0.33	0.12	0.33	0.20
0.95	1.18	0.05	-0.03	0.37	0.03	0.37	0.16
0.80	0.76	0.00	-0.18	-0.06	0.18	0.06	0.06
0.50	0.34	0.03	-0.48	-0.47	0.48	0.47	0.90
0.26	0.26	0.00	-0.72	-0.55	0.72	0.55	1.61
0.26	0.29	0.00	-0.72	-0.52	0.72	0.52	1.54
0.28	0.27	0.00	-0.70	-0.54	0.70	0.54	1.54
0.34	0.34	0.00	-0.64	-0.47	0.64	0.47	1.24
0.95	0.94	0.00	-0.03	0.13	0.03	0.13	0.02
0.60	0.60	0.00	-0.38	-0.21	0.38	0.21	0.35
1.50	1.36	0.02	0.52	0.55	0.52	0.55	1.15
1.35	1.31	0.00	0.37	0.50	0.37	0.50	0.76
0.75	0.76	0.00	-0.23	-0.05	0.23	0.05	0.08
0.30	0.31	0.00	-0.68	-0.50	0.68	0.50	1.39
0.87	0.87	0.00	-0.11	0.06	0.11	0.06	0.03
1.40	0.58	0.68	0.42	-0.23	0.42	0.23	0.43
0.87	0.26	0.37	-0.11	-0.55	0.11	0.55	0.44
1.30	0.14	1.35	0.32	-0.67	0.32	0.67	0.99
1.10	0.22	0.78	0.12	-0.59	0.12	0.59	0.51
1.00	0.29	0.50	0.02	-0.52	0.02	0.52	0.29
1.65	0.76	0.79	0.67	-0.05	0.67	0.05	0.52
0.90	0.66	0.06	-0.08	-0.15	0.08	0.15	0.05
Average = 0.97	Average = 0.61	Sum = 13.96		IoA = 0.45			Sum = 25.20

Appendix 31

Appendix 31. IoA Calculation for TKN for 1997 Data Set for Barker Inlet only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
1.00	1.21	0.04	0.02	0.40	0.02	0.40	0.18
0.85	1.66	0.66	-0.13	0.85	0.13	0.85	0.96
0.45	0.95	0.25	-0.53	0.14	0.53	0.14	0.45
0.80	0.26	0.29	-0.18	-0.55	0.18	0.55	0.54
0.89	0.89	0.00	-0.09	0.08	0.09	0.08	0.03
1.20	0.70	0.25	0.22	-0.11	0.22	0.11	0.11
0.87	0.64	0.05	-0.11	-0.17	0.11	0.17	0.08
1.40	0.53	0.76	0.42	-0.28	0.42	0.28	0.50
0.97	0.93	0.00	-0.01	0.12	0.01	0.12	0.02
1.10	0.91	0.04	0.12	0.10	0.12	0.10	0.05
1.41	1.26	0.02	0.43	0.45	0.43	0.45	0.77
0.80	1.17	0.14	-0.18	0.36	0.18	0.36	0.29
0.90	1.58	0.46	-0.08	0.77	0.08	0.77	0.72
0.80	1.86	1.12	-0.18	1.05	0.18	1.05	1.51
0.70	1.71	1.02	-0.28	0.90	0.28	0.90	1.39
0.70	0.98	0.08	-0.28	0.17	0.28	0.17	0.20
0.98	0.44	0.29	0.00	-0.37	0.00	0.37	0.14
1.20	0.79	0.17	0.22	-0.02	0.22	0.02	0.06
0.83	0.72	0.01	-0.15	-0.09	0.15	0.09	0.06
1.20	0.52	0.46	0.22	-0.29	0.22	0.29	0.26
0.88	1.18	0.09	-0.10	0.37	0.10	0.37	0.22
1.90	0.98	0.85	0.92	0.17	0.92	0.17	1.19
1.85	1.43	0.18	0.87	0.62	0.87	0.62	2.22
1.00	1.21	0.04	0.02	0.40	0.02	0.40	0.18
0.95	1.58	0.40	-0.03	0.77	0.03	0.77	0.64
1.15	1.95	0.64	0.17	1.14	0.17	1.14	1.72
0.80	1.95	1.32	-0.18	1.14	0.18	1.14	1.74
0.75	1.03	0.08	-0.23	0.22	0.23	0.22	0.20
0.71	0.71	0.00	-0.27	-0.10	0.27	0.10	0.14
1.30	0.59	0.51	0.32	-0.22	0.32	0.22	0.30
0.82	0.50	0.10	-0.16	-0.31	0.16	0.31	0.22
0.75	0.36	0.15	-0.23	-0.45	0.23	0.45	0.46
0.64	1.18	0.29	-0.34	0.37	0.34	0.37	0.50
1.30	0.91	0.15	0.32	0.10	0.32	0.10	0.18
1.80	1.11	0.48	0.82	0.30	0.82	0.30	1.25
0.62	0.76	0.02	-0.36	-0.05	0.36	0.05	0.17
0.90	0.70	0.04	-0.08	-0.11	0.08	0.11	0.04
0.90	0.79	0.01	-0.08	-0.03	0.08	0.03	0.01
0.90	1.23	0.11	-0.08	0.42	0.08	0.42	0.25
0.70	0.69	0.00	-0.28	-0.12	0.28	0.12	0.16
Average = 0.99	Average = 1.01	Sum = 11.58		IoA = 0.42			Sum = 20.07

Appendix 32

Appendix 32. IoA Calculation for Phosphate for 1997 Data Set

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.0420	0.0420	0.0000	-0.0810	-0.0246	0.0810	0.0246	0.0112
0.0650	0.0420	0.0005	-0.0810	-0.0016	0.0810	0.0016	0.0068
0.0510	0.0490	0.0000	-0.0740	-0.0156	0.0740	0.0156	0.0080
0.0760	0.0700	0.0000	-0.0530	0.0094	0.0530	0.0094	0.0039
0.0740	0.0540	0.0004	-0.0690	0.0074	0.0690	0.0074	0.0058
0.1200	0.1210	0.0000	-0.0020	0.0534	0.0020	0.0534	0.0031
0.1200	0.1300	0.0001	0.0070	0.0534	0.0070	0.0534	0.0036
0.1150	0.1150	0.0000	-0.0080	0.0484	0.0080	0.0484	0.0032
0.0900	0.0900	0.0000	-0.0330	0.0234	0.0330	0.0234	0.0032
0.0800	0.0800	0.0000	-0.0430	0.0134	0.0430	0.0134	0.0032
0.1080	0.1080	0.0000	-0.0150	0.0414	0.0150	0.0414	0.0032
0.0190	0.0190	0.0000	-0.1040	-0.0476	0.1040	0.0476	0.0230
0.0350	0.0010	0.0012	-0.1220	-0.0316	0.1220	0.0316	0.0236
0.0360	0.0250	0.0001	-0.0980	-0.0306	0.0980	0.0306	0.0165
0.0210	0.0100	0.0001	-0.1130	-0.0456	0.1130	0.0456	0.0252
0.0340	0.0250	0.0001	-0.0980	-0.0326	0.0980	0.0326	0.0171
0.0650	0.0650	0.0000	-0.0580	-0.0016	0.0580	0.0016	0.0036
0.1050	0.1050	0.0000	-0.0180	0.0384	0.0180	0.0384	0.0032
0.0800	0.0800	0.0000	-0.0430	0.0134	0.0430	0.0134	0.0032
0.0450	0.0450	0.0000	-0.0780	-0.0216	0.0780	0.0216	0.0099
0.1250	0.1250	0.0000	0.0020	0.0584	0.0020	0.0584	0.0036
0.0500	0.0100	0.0016	-0.1130	-0.0166	0.1130	0.0166	0.0168
0.0140	0.0140	0.0000	-0.1090	-0.0526	0.1090	0.0526	0.0261
0.0180	0.0180	0.0000	-0.1050	-0.0486	0.1050	0.0486	0.0236
0.0190	0.0190	0.0000	-0.1040	-0.0476	0.1040	0.0476	0.0230
0.0200	0.0200	0.0000	-0.1030	-0.0466	0.1030	0.0466	0.0224
0.0235	0.0235	0.0000	-0.0995	-0.0431	0.0995	0.0431	0.0203
0.0500	0.0500	0.0000	-0.0730	-0.0166	0.0730	0.0166	0.0080
0.0900	0.0900	0.0000	-0.0330	0.0234	0.0330	0.0234	0.0032
0.0700	0.0700	0.0000	-0.0530	0.0034	0.0530	0.0034	0.0032
0.0300	0.0320	0.0000	-0.0910	-0.0366	0.0910	0.0366	0.0163
0.0300	1.3900	1.8496	1.2670	-0.0366	1.2670	0.0366	1.6995
0.0300	0.0320	0.0000	-0.0910	-0.0366	0.0910	0.0366	0.0163
0.0300	0.0230	0.0000	-0.1000	-0.0366	0.1000	0.0366	0.0187
0.0260	0.0410	0.0002	-0.0820	-0.0406	0.0820	0.0406	0.0150
0.0500	0.0500	0.0000	-0.0730	-0.0166	0.0730	0.0166	0.0080
0.0420	0.0356	0.0000	-0.0874	-0.0246	0.0874	0.0246	0.0126
0.0730	0.0990	0.0007	-0.0240	0.0064	0.0240	0.0064	0.0009
0.0620	0.0570	0.0000	-0.0660	-0.0046	0.0660	0.0046	0.0050
0.0770	0.0760	0.0000	-0.0470	0.0104	0.0470	0.0104	0.0033
0.0750	0.0750	0.0000	-0.0480	0.0084	0.0480	0.0084	0.0032
0.1150	0.4460	0.1096	0.3230	0.0484	0.3230	0.0484	0.1379
0.0750	0.5730	0.2480	0.4500	0.0084	0.4500	0.0084	0.2101
0.0550	0.0550	0.0000	-0.0680	-0.0116	0.0680	0.0116	0.0063
0.0650	0.0640	0.0000	-0.0590	-0.0016	0.0590	0.0016	0.0037

Appendix 32 (Continued)

0.0410	0.0410	0.0000	-0.0820	-0.0256	0.0820	0.0256	0.0116
0.0550	0.0540	0.0000	-0.0690	-0.0116	0.0690	0.0116	0.0065
0.0470	0.0470	0.0000	-0.0760	-0.0196	0.0760	0.0196	0.0091
0.0540	0.0550	0.0000	-0.0680	-0.0126	0.0680	0.0126	0.0065
0.0680	0.0560	0.0001	-0.0670	0.0014	0.0670	0.0014	0.0047
0.0700	0.0670	0.0000	-0.0560	0.0034	0.0560	0.0034	0.0035
0.0750	0.0750	0.0000	-0.0480	0.0084	0.0480	0.0084	0.0032
0.0950	0.0930	0.0000	-0.0300	0.0284	0.0300	0.0284	0.0034
0.0800	0.0820	0.0000	-0.0410	0.0134	0.0410	0.0134	0.0030
0.0550	0.0530	0.0000	-0.0700	-0.0116	0.0700	0.0116	0.0067
0.0750	0.0072	0.0046	-0.1158	0.0084	0.1158	0.0084	0.0154
0.0500	0.0450	0.0000	-0.0780	-0.0166	0.0780	0.0166	0.0090
0.0630	0.0410	0.0005	-0.0820	-0.0036	0.0820	0.0036	0.0073
0.0440	0.1840	0.0196	0.0610	-0.0226	0.0610	0.0226	0.0070
0.0510	0.2530	0.0408	0.1300	-0.0156	0.1300	0.0156	0.0212
0.0890	0.2030	0.0130	0.0800	0.0224	0.0800	0.0224	0.0105
0.2700	0.1960	0.0055	0.0730	0.2034	0.0730	0.2034	0.0764
0.1050	0.2110	0.0112	0.0880	0.0384	0.0880	0.0384	0.0160
0.1150	0.2830	0.0282	0.1600	0.0484	0.1600	0.0484	0.0434
0.0900	0.6620	0.3272	0.5390	0.0234	0.5390	0.0234	0.3162
0.0550	0.6720	0.3807	0.5490	-0.0116	0.5490	0.0116	0.3143
0.0650	0.0567	0.0001	-0.0663	-0.0016	0.0663	0.0016	0.0046
0.0500	0.0600	0.0001	-0.0630	-0.0166	0.0630	0.0166	0.0063
0.0500	0.8330	0.6131	0.7100	-0.0166	0.7100	0.0166	0.5280
0.0720	0.3400	0.0718	0.2170	0.0054	0.2170	0.0054	0.0494
0.0870	0.0304	0.0032	-0.0926	0.0204	0.0926	0.0204	0.0128
0.0590	0.0304	0.0008	-0.0926	-0.0076	0.0926	0.0076	0.0100
0.0030	0.0164	0.0002	-0.1066	-0.0636	0.1066	0.0636	0.0290
0.0460	0.0284	0.0003	-0.0946	-0.0206	0.0946	0.0206	0.0133
0.1250	0.0478	0.0060	-0.0752	0.0584	0.0752	0.0584	0.0178
0.1050	0.0590	0.0021	-0.0640	0.0384	0.0640	0.0384	0.0105
0.0900	0.0602	0.0009	-0.0628	0.0234	0.0628	0.0234	0.0074
0.1020	0.0430	0.0035	-0.0800	0.0354	0.0800	0.0354	0.0133
0.0700	0.0663	0.0000	-0.0567	0.0034	0.0567	0.0034	0.0036
0.0650	0.0403	0.0006	-0.0827	-0.0016	0.0827	0.0016	0.0071
Average = 0.0666	Average = 0.1232	Sum = 1.8917	IOA for Phosphate = 0.538				Sum = 4.0955

Appendix 33

Appendix 33. IoA Calculation for 1997 Phosphate Data for Port River only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.1150	0.1150	0.0000	-0.0080	0.0484	0.0080	0.0484	0.0032
0.0900	0.0900	0.0000	-0.0330	0.0234	0.0330	0.0234	0.0032
0.0800	0.0800	0.0000	-0.0430	0.0134	0.0430	0.0134	0.0032
0.1080	0.1080	0.0000	-0.0150	0.0414	0.0150	0.0414	0.0032
0.0190	0.0190	0.0000	-0.1040	-0.0476	0.1040	0.0476	0.0230
0.0350	0.0010	0.0012	-0.1220	-0.0316	0.1220	0.0316	0.0236
0.0360	0.0250	0.0001	-0.0980	-0.0306	0.0980	0.0306	0.0165
0.0210	0.0100	0.0001	-0.1130	-0.0456	0.1130	0.0456	0.0252
0.0340	0.0250	0.0001	-0.0980	-0.0326	0.0980	0.0326	0.0171
0.0650	0.0650	0.0000	-0.0580	-0.0016	0.0580	0.0016	0.0036
0.1050	0.1050	0.0000	-0.0180	0.0384	0.0180	0.0384	0.0032
0.0800	0.0800	0.0000	-0.0430	0.0134	0.0430	0.0134	0.0032
0.0450	0.0450	0.0000	-0.0780	-0.0216	0.0780	0.0216	0.0099
0.1250	0.1250	0.0000	0.0020	0.0584	0.0020	0.0584	0.0036
0.0500	0.0100	0.0016	-0.1130	-0.0166	0.1130	0.0166	0.0168
0.0140	0.0140	0.0000	-0.1090	-0.0526	0.1090	0.0526	0.0261
0.0180	0.0180	0.0000	-0.1050	-0.0486	0.1050	0.0486	0.0236
0.0190	0.0190	0.0000	-0.1040	-0.0476	0.1040	0.0476	0.0230
0.0200	0.0200	0.0000	-0.1030	-0.0466	0.1030	0.0466	0.0224
0.0235	0.0235	0.0000	-0.0995	-0.0431	0.0995	0.0431	0.0203
0.0500	0.0500	0.0000	-0.0730	-0.0166	0.0730	0.0166	0.0080
0.0900	0.0900	0.0000	-0.0330	0.0234	0.0330	0.0234	0.0032
0.0700	0.0700	0.0000	-0.0530	0.0034	0.0530	0.0034	0.0032
0.0300	0.0320	0.0000	-0.0910	-0.0366	0.0910	0.0366	0.0163
0.0300	1.3900	1.8496	1.2670	-0.0366	1.2670	0.0366	1.6995
0.0300	0.0320	0.0000	-0.0910	-0.0366	0.0910	0.0366	0.0163
0.0300	0.0230	0.0000	-0.1000	-0.0366	0.1000	0.0366	0.0187
0.0260	0.0410	0.0002	-0.0820	-0.0406	0.0820	0.0406	0.0150
0.0500	0.0500	0.0000	-0.0730	-0.0166	0.0730	0.0166	0.0080
0.0420	0.0356	0.0000	-0.0874	-0.0246	0.0874	0.0246	0.0126
0.0730	0.0990	0.0007	-0.0240	0.0064	0.0240	0.0064	0.0009
0.0620	0.0570	0.0000	-0.0660	-0.0046	0.0660	0.0046	0.0050
0.0770	0.0760	0.0000	-0.0470	0.0104	0.0470	0.0104	0.0033
Average =	Average =	Sum = 1.8548		IOA = 0.127679			Sum = 2.1263

Appendix 34. IoA for Phosphate 1997 Data for Barker Inlet only

Observed (O)	Predicted (P)	(P-O) * (P-O)	O'	P'	Absolute O'	Absolute P'	(Absolute O'+ Absolute P')^2
0.0750	0.0750	0.0000	-0.0480	0.0084	0.0480	0.0084	0.0032
0.1150	0.4460	0.1096	0.3230	0.0484	0.3230	0.0484	0.1379
0.0750	0.5730	0.2480	0.4500	0.0084	0.4500	0.0084	0.2101
0.0550	0.0550	0.0000	-0.0680	-0.0116	0.0680	0.0116	0.0063
0.0650	0.0640	0.0000	-0.0590	-0.0016	0.0590	0.0016	0.0037
0.0410	0.0410	0.0000	-0.0820	-0.0256	0.0820	0.0256	0.0116
0.0550	0.0540	0.0000	-0.0690	-0.0116	0.0690	0.0116	0.0065
0.0470	0.0470	0.0000	-0.0760	-0.0196	0.0760	0.0196	0.0091
0.0540	0.0550	0.0000	-0.0680	-0.0126	0.0680	0.0126	0.0065
0.0680	0.0560	0.0001	-0.0670	0.0014	0.0670	0.0014	0.0047
0.0700	0.0670	0.0000	-0.0560	0.0034	0.0560	0.0034	0.0035
0.0750	0.0750	0.0000	-0.0480	0.0084	0.0480	0.0084	0.0032
0.0950	0.0930	0.0000	-0.0300	0.0284	0.0300	0.0284	0.0034
0.0800	0.0820	0.0000	-0.0410	0.0134	0.0410	0.0134	0.0030
0.0550	0.0530	0.0000	-0.0700	-0.0116	0.0700	0.0116	0.0067
0.0750	0.0072	0.0046	-0.1158	0.0084	0.1158	0.0084	0.0154
0.0500	0.0450	0.0000	-0.0780	-0.0166	0.0780	0.0166	0.0090
0.0630	0.0410	0.0005	-0.0820	-0.0036	0.0820	0.0036	0.0073
0.0440	0.1840	0.0196	0.0610	-0.0226	0.0610	0.0226	0.0070
0.0510	0.2530	0.0408	0.1300	-0.0156	0.1300	0.0156	0.0212
0.0890	0.2030	0.0130	0.0800	0.0224	0.0800	0.0224	0.0105
0.2700	0.1960	0.0055	0.0730	0.2034	0.0730	0.2034	0.0764
0.1050	0.2110	0.0112	0.0880	0.0384	0.0880	0.0384	0.0160
0.1150	0.2830	0.0282	0.1600	0.0484	0.1600	0.0484	0.0434
0.0900	0.6620	0.3272	0.5390	0.0234	0.5390	0.0234	0.3162
0.0550	0.6720	0.3807	0.5490	-0.0116	0.5490	0.0116	0.3143
0.0650	0.0567	0.0001	-0.0663	-0.0016	0.0663	0.0016	0.0046
0.0500	0.0600	0.0001	-0.0630	-0.0166	0.0630	0.0166	0.0063
0.0500	0.8330	0.6131	0.7100	-0.0166	0.7100	0.0166	0.5280
0.0720	0.3400	0.0718	0.2170	0.0054	0.2170	0.0054	0.0494
0.0870	0.0304	0.0032	-0.0926	0.0204	0.0926	0.0204	0.0128
0.0590	0.0304	0.0008	-0.0926	-0.0076	0.0926	0.0076	0.0100
0.0030	0.0164	0.0002	-0.1066	-0.0636	0.1066	0.0636	0.0290
0.0460	0.0284	0.0003	-0.0946	-0.0206	0.0946	0.0206	0.0133
0.1250	0.0478	0.0060	-0.0752	0.0584	0.0752	0.0584	0.0178
0.1050	0.0590	0.0021	-0.0640	0.0384	0.0640	0.0384	0.0105
0.0900	0.0602	0.0009	-0.0628	0.0234	0.0628	0.0234	0.0074
0.1020	0.0430	0.0035	-0.0800	0.0354	0.0800	0.0354	0.0133
0.0700	0.0663	0.0000	-0.0567	0.0034	0.0567	0.0034	0.0036
0.0650	0.0403	0.0006	-0.0827	-0.0016	0.0827	0.0016	0.0071
Average =0.0755	Average = 0.1580	Sum = 1.8900		IOA = 0.0394			Sum = 1.9693

Appendix 35

Appendix 35. Average Error Calculation for 1997 Phosphate Data

Observed	Modelled	(Observed-Modelled)
0.042	0.042	0
0.065	0.042	0.023
0.051	0.049	0.002
0.076	0.07	0.006
0.074	0.054	0.02
0.12	0.121	-0.001
0.12	0.13	-0.01
0.115	0.115	0
0.09	0.09	0
0.08	0.08	0
0.108	0.108	0
0.019	0.019	0
0.035	0.001	0.034
0.036	0.025	0.011
0.021	0.01	0.011
0.034	0.025	0.009
0.065	0.065	0
0.105	0.105	0
0.08	0.08	0
0.045	0.045	0
0.125	0.125	0
0.05	0.01	0.04
0.014	0.014	0
0.018	0.018	0
0.019	0.019	0
0.02	0.02	0
0.0235	0.0235	0
0.05	0.05	0
0.09	0.09	0
0.07	0.07	0
0.03	0.032	-0.002
0.03	1.39	-1.36
0.03	0.032	-0.002
0.03	0.023	0.007
0.026	0.041	-0.015
0.05	0.05	0
0.042	0.0356	0.0064
0.073	0.099	-0.026
0.062	0.057	0.005
0.077	0.076	0.001
0.075	0.075	0
0.115	0.446	-0.331
0.075	0.573	-0.498
0.055	0.055	0
0.065	0.064	0.001

Appendix 35 (Continued)

0.041	0.041	0
0.055	0.054	0.001
0.047	0.047	0
0.054	0.055	-0.001
0.068	0.056	0.012
0.07	0.067	0.003
0.075	0.075	0
0.095	0.093	0.002
0.08	0.082	-0.002
0.055	0.053	0.002
0.075	0.0072	0.0678
0.05	0.045	0.005
0.063	0.041	0.022
0.044	0.184	-0.14
0.051	0.253	-0.202
0.089	0.203	-0.114
0.27	0.196	0.074
0.105	0.211	-0.106
0.115	0.283	-0.168
0.09	0.662	-0.572
0.055	0.672	-0.617
0.065	0.0567	0.0083
0.05	0.06	-0.01
0.05	0.833	-0.783
0.072	0.34	-0.268
0.087	0.0304	0.0566
0.059	0.0304	0.0286
0.003	0.0164	-0.0134
0.046	0.0284	0.0176
0.125	0.0478	0.0772
0.105	0.059	0.046
0.09	0.0602	0.0298
0.102	0.043	0.059
0.07	0.0663	0.0037
0.065	0.0403	0.0247
Average = 0.06664375	Average = 0.1232025	Sum = -4.5247
	Average Error = -0.056727	

Appendix 36

Appendix 36. The values of Moran indices for the minimum, mean and maximum values of water quality parameters (Source: Analysis in GIS)

PASTW = Port Adelaide Swage Treatment Works
BSTW = Bolivar Sewage Treatment Works
STWT = Stormwater
PRSP = Penrice Soda Product

No.	Activities Included	Moran Indices	Note
1	PASTW, BSTW, STWT, PRSP	0.93680	Maximum concentration of Chlorophyll a in 1996
2	PASTW, BSTW, STWT, PRSP,	0.92695	Mean concentration of Chlorophyll a in 1996
3	PASTW, BSTW, STWT, PRSP,	0.91411	Minimum Concentration Of Chlorophyll a in 1996
4	PASTW, BSTW, STWT, PRSP	0.90879	Maximum concentration of Chlorophyll a in 1997
5	PASTW, BSTW, STWT, PRSP,	0.92330	Mean concentration of Chlorophyll a in 1997
6	PASTW, BSTW, STWT, PRSP,	0.93293	Minimum Concentration Of Chlorophyll a in 1997
7	PASTW, BSTW, STWT, PRSP	0.97853	Maximum concentration of Ammonia in 1996
8	PASTW, BSTW, STWT, PRSP,	0.97853	Mean concentration of Ammonia in 1996
9	PASTW, BSTW, STWT, PRSP,	0.850149	Minimum Concentration Of Ammonia in 1996
10	PASTW, BSTW, STWT, PRSP	0.97853	Maximum concentration of Ammonia in 1997
11	PASTW, BSTW, STWT, PRSP,	0.97853	Mean concentration of Ammonia in 1997
12	PASTW, BSTW, STWT, PRSP,	0.91433	Minimum Concentration Of Ammonia in 1997
13	PASTW, BSTW, STWT, PRSP	0.97853	Maximum concentration of TKN in 1996
14	PASTW, BSTW, STWT, PRSP,	0.97853	Mean concentration of TKN in 1996
15	PASTW, BSTW, STWT, PRSP,	0.97853	Minimum Concentration Of TKN in 1996
16	PASTW, BSTW, STWT, PRSP	0.97579	Maximum concentration of TKN in 1997
17	PASTW, BSTW, STWT, PRSP,	0.9785	Mean concentration of TKN in 1997
18	PASTW, BSTW, STWT, PRSP,	0.9730	Minimum Concentration Of TKN in 1997
19	PASTW, BSTW, STWT, PRSP	0.9785	Maximum concentration of Phosphate in 1996
20	PASTW, BSTW, STWT, PRSP,	0.9730	Mean concentration of Phosphate in 1996
21	PASTW, BSTW, STWT, PRSP,	0.9785	Minimum Concentration Of Phosphate in 1996
22	PASTW, BSTW, STWT, PRSP	0.9785	Maximum concentration of Phosphate in 1997
23	PASTW, BSTW, STWT, PRSP,	0.9785	Mean concentration of Phosphate in 1997
24	PASTW, BSTW, STWT, PRSP,	0.9025	Minimum Concentration Of Phosphate in 1997

Appendix 36 (Continued)

25	PASTW, BSTW, STWT, PRSP, Dredging	0.844589	Maximum concentration of Chlorophyll a when dredging
26	PASTW, BSTW, STWT, PRSP, Dredging	0.87154	Mean concentration of Chlorophyll a when dredging
27	PASTW, BSTW, STWT, PRSP, Dredging	0.84733	Minimum Concentration Of Chlorophyll a when dredging
28	PASTW, BSTW, STWT, PRSP	0.97648	Maximum concentration of Ammonia when dredging
29	PASTW, BSTW, STWT, PRSP, Dredging	0.91617	Mean concentration of Ammonia when dredging
30	PASTW, BSTW, STWT, PRSP,, Dredging	0.9721	Minimum Concentration Of Ammonia when dredging
31	PASTW, BSTW, STWT, PRSP, Dredging	0.95979	Maximum concentration of TKN when dredging
32	PASTW, BSTW, STWT, PRSP, Dredging	0.87081	Mean concentration of TKN when dredging
33	PASTW, BSTW, STWT, PRSP, Dredging	0.96089	Minimum Concentration Of TKN when dredging
34	PASTW, BSTW, STWT, PRSP, Dredging	0.97855	Maximum concentration of Phosphate when dredging
35	PASTW, BSTW, STWT, PRSP, Dredging	0.966917	Mean concentration of Phosphate when dredging
36	PASTW, BSTW, STWT, PRSP, , Dredging	0.978544	Minimum Concentration Of Phosphate when dredging
37	PASTW, BSTW, STWT, PRSP, After Dredging	0.91415	Maximum concentration of Chlorophyll a after dredging
38	PASTW, BSTW, STWT, PRSP, After Dredging	0.67052	Mean Concentration of Chlorophyll a after dredging
39	PASTW, BSTW, STWT, PRSP, After Dredging	0.940519	Minimum concentration of Chlorophyll a after dredging
40	PASTW, BSTW, STWT, PRSP, After Dredging	0.97855	Maximum concentration of TKN after dredging
41	PASTW, BSTW, STWT, PRSP, After Dredging	0.978537	Mean concentration of TKN after dredging
42	PASTW, BSTW, STWT, PRSP, After Dredging	0.9719	Minimum concentration of TKN after dredging
43	PASTW, BSTW, STWT, PRSP,, After Dredging	0.934798	Maximum concentration of Ammonia after dredging
44	PASTW, BSTW, STWT, PRSP, After Dredging	0.97854	Mean concentration of Ammonia after dredging
45	PASTW, BSTW, STWT, PRSP, After Dredging	0.93479	Minimum concentration of Ammonia after dredging
46	PASTW, BSTW, STWT, PRSP, After Dredging	0.978534	Maximum concentration of phosphate after dredging
47	PASTW, BSTW, STWT, PRSP, After Dredging	0.978532	Mean concentration of Phosphate after dredging
48	PASTW, BSTW, STWT, PRSP, After Dredging	0.98234	Minimum concentration of Phosphate after dredging
49	After dredging, loads from PASTW, BSTW, STWT, PRSP are stopped	0.93051	Maximum concentration of Chlorophyll a after dredging and when the loads to the estuary are stopped

Appendix 36 (Continued)

50	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.9417656	Mean concentration of Chlorophyll a after dredging and when the loads to the estuary are stopped
51	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.948228	Minimum concentration of Chlorophyll a after dredging and when the loads to the estuary are stopped
52	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.978548	Maximum concentration of TKN after dredging and when the loads to the estuary are stopped
53	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.978556	Mean concentration of TKN after dredging and when the loads to the estuary are stopped
54	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.973473	Minimum concentration of TKN after dredging and when the loads to the estuary are stopped
55	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.965050	Maximum concentration of Ammonia after dredging and when the loads to the estuary are stopped
56	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.978541	Mean concentration of Ammonia after dredging and when the loads to the estuary are stopped
57	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.965056	Minimum concentration of Ammonia after dredging and when the loads to the estuary are stopped
58	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.9785449	Maximum concentration of Phosphate after dredging and when the loads to the estuary are stopped
59	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.9785416	Mean concentration of Phosphate after dredging and when the loads to the estuary are stopped
60	After dredging, loads from PASTW, BSTW, STWT, PRSP are absence	0.9669956	Minimum concentration of phosphate after dredging and when the loads to the estuary are stopped

Appendix 37a. Analysis of Variance of Ammonia Concentration due to Activities

ANOVA

VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.32E+08	9	47949400.562	3.547	.000
Within Groups	6.31E+10	4667	13519610.318		
Total	6.35E+10	4676			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-626.6950*	240.4953	.009	-1098.1793	-155.2106
	3.00	-645.0935*	240.4953	.007	-1116.5778	-173.6092
	4.00	-645.0599*	240.4953	.007	-1116.5443	-173.5756
	5.00	-645.0908*	240.4953	.007	-1116.5751	-173.6065
	6.00	-645.0874*	240.4953	.007	-1116.5717	-173.6030
	7.00	-.9611	240.4953	.997	-472.4455	470.5232
	8.00	-645.3768*	240.4953	.007	-1116.8611	-173.8924
	9.00	-87.9434	240.7529	.715	-559.9328	384.0460
	10.00	-6.7631	240.4953	.978	-478.2475	464.7212
2.00	1.00	626.6950*	240.4953	.009	155.2106	1098.1793
	3.00	-18.3985	240.3666	.939	-489.6306	452.8336
	4.00	-18.3650	240.3666	.939	-489.5971	452.8672
	5.00	-18.3958	240.3666	.939	-489.6279	452.8363
	6.00	-18.3924	240.3666	.939	-489.6245	452.8397
	7.00	625.7338*	240.3666	.009	154.5017	1096.9660
	8.00	-18.6818	240.3666	.938	-489.9139	452.5504
	9.00	538.7516*	240.6244	.025	67.0141	1010.4891
	10.00	619.9318*	240.3666	.010	148.6997	1091.1640
3.00	1.00	645.0935*	240.4953	.007	173.6092	1116.5778
	2.00	18.3985	240.3666	.939	-452.8336	489.6306
	4.00	3.354E-02	240.3666	1.000	-471.1986	471.2657
	5.00	2.705E-03	240.3666	1.000	-471.2294	471.2348
	6.00	6.122E-03	240.3666	1.000	-471.2260	471.2383
	7.00	644.1324*	240.3666	.007	172.9002	1115.3645
	8.00	-.2833	240.3666	.999	-471.5154	470.9489
	9.00	557.1501*	240.6244	.021	85.4127	1028.8876
	10.00	638.3303*	240.3666	.008	167.0982	1109.5625
4.00	1.00	645.0599*	240.4953	.007	173.5756	1116.5443
	2.00	18.3650	240.3666	.939	-452.8672	489.5971
	3.00	-3.3540E-02	240.3666	1.000	-471.2657	471.1986
	5.00	-3.0835E-02	240.3666	1.000	-471.2630	471.2013
	6.00	-2.7419E-02	240.3666	1.000	-471.2596	471.2047
	7.00	644.0988*	240.3666	.007	172.8667	1115.3310
	8.00	-.3168	240.3666	.999	-471.5489	470.9153
	9.00	557.1166*	240.6244	.021	85.3791	1028.8541
	10.00	638.2968*	240.3666	.008	167.0647	1109.5289

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5.00	1.00	645.0908*	240.4953	.007	173.6065	1116.5751
	2.00	18.3958	240.3666	.939	-452.8363	489.6279
	3.00	-2.7051E-03	240.3666	1.000	-471.2348	471.2294
	4.00	3.084E-02	240.3666	1.000	-471.2013	471.2630
	6.00	3.417E-03	240.3666	1.000	-471.2287	471.2355
	7.00	644.1297*	240.3666	.007	172.8975	1115.3618
	8.00	-.2860	240.3666	.999	-471.5181	470.9462
	9.00	557.1474*	240.6244	.021	85.4099	1028.8849
	10.00	638.3276*	240.3666	.008	167.0955	1109.5598
6.00	1.00	645.0874*	240.4953	.007	173.6030	1116.5717
	2.00	18.3924	240.3666	.939	-452.8397	489.6245
	3.00	-6.1218E-03	240.3666	1.000	-471.2383	471.2260
	4.00	2.742E-02	240.3666	1.000	-471.2047	471.2596
	5.00	-3.4167E-03	240.3666	1.000	-471.2355	471.2287
	7.00	644.1262*	240.3666	.007	172.8941	1115.3584
	8.00	-.2894	240.3666	.999	-471.5215	470.9427
	9.00	557.1440*	240.6244	.021	85.4065	1028.8815
	10.00	638.3242*	240.3666	.008	167.0921	1109.5564
7.00	1.00	.9611	240.4953	.997	-470.5232	472.4455
	2.00	-625.7338*	240.3666	.009	-1096.9660	-154.5017
	3.00	-644.1324*	240.3666	.007	-1115.3645	-172.9002
	4.00	-644.0988*	240.3666	.007	-1115.3310	-172.8667
	5.00	-644.1297*	240.3666	.007	-1115.3618	-172.8975
	6.00	-644.1262*	240.3666	.007	-1115.3584	-172.8941
	8.00	-644.4156*	240.3666	.007	-1115.6478	-173.1835
	9.00	-86.9822	240.6244	.718	-558.7197	384.7552
	10.00	-5.8020	240.3666	.981	-477.0341	465.4301
8.00	1.00	645.3768*	240.4953	.007	173.8924	1116.8611
	2.00	18.6818	240.3666	.938	-452.5504	489.9139
	3.00	.2833	240.3666	.999	-470.9489	471.5154
	4.00	.3168	240.3666	.999	-470.9153	471.5489
	5.00	.2860	240.3666	.999	-470.9462	471.5181
	6.00	.2894	240.3666	.999	-470.9427	471.5215
	7.00	644.4156*	240.3666	.007	173.1835	1115.6478
	9.00	557.4334*	240.6244	.021	85.6959	1029.1709
	10.00	638.6136*	240.3666	.008	167.3815	1109.8457
9.00	1.00	87.9434	240.7529	.715	-384.0460	559.9328
	2 00	-538.7516*	240.6244	.025	-1010.4891	-67.0141
	3.00	-557.1501*	240.6244	.021	-1028.8876	-85.4127
	4.00	-557.1166*	240.6244	.021	-1028.8541	-85.3791
	5.00	-557.1474*	240.6244	.021	-1028.8849	-85.4099
	6.00	-557.1440*	240.6244	.021	-1028.8815	-85.4065
	7.00	86.9822	240.6244	.718	-384.7552	558.7197
	8.00	-557.4334*	240.6244	.021	-1029.1709	-85.6959
	10.00	81.1802	240.6244	.736	-390.5573	552.9177
10.00	1.00	6.7631	240.4953	.978	-464.7212	478.2475
	2.00	-619.9318*	240.3666	.010	-1091.1640	-148.6997
	3.00	-638.3303*	240.3666	.008	-1109.5625	-167.0982
	4.00	-638.2968*	240.3666	.008	-1109.5289	-167.0647
	5.00	-638.3276*	240.3666	.008	-1109.5598	-167.0955
	6.00	-638.3242*	240.3666	.008	-1109.5564	-167.0921
	7.00	5.8020	240.3666	.981	-465.4301	477.0341
	8.00	-638.6136*	240.3666	.008	-1109.8457	-167.3815
	9.00	-81.1802	240.6244	.736	-552.9177	390.5573

*. The mean difference is significant at the .05 level.

Appendix 7b. Analysis of Variance of Chlorophyll a Concentration due to Activities

ANOVA

VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	43677.747	9	4853.083	4.880	.000
Within Groups	4634850.3	4661	994.390		
Total	4678528.1	4670			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-3.2922	2.0659	.111	-7.3422	.7579
	3.00	2.418E-02	2.0636	.991	-4.0216	4.0699
	4.00	-3.7514E-03	2.0670	.999	-4.0560	4.0485
	5.00	-8.9356E-02	2.0636	.965	-4.1351	3.9564
	6.00	-9.4057E-02	2.0636	.964	-4.1398	3.9517
	7.00	-.6932	2.0636	.737	-4.7389	3.3525
	8.00	-2.8382	2.0659	.170	-6.8883	1.2118
	9.00	2.1048	2.0636	.308	-1.9409	6.1505
	10.00	-9.4991*	2.0636	.000	-13.5448	-5.4533
2.00	1.00	3.2922	2.0659	.111	-.7579	7.3422
	3.00	3.3163	2.0636	.108	-.7294	7.3621
	4.00	3.2884	2.0670	.112	-.7638	7.3406
	5.00	3.2028	2.0636	.121	-.8429	7.2485
	6.00	3.1981	2.0636	.121	-.8476	7.2438
	7.00	2.5990	2.0636	.208	-1.4468	6.6447
	8.00	.4539	2.0659	.826	-3.5961	4.5040
	9.00	5.3970*	2.0636	.009	1.3513	9.4427
	10.00	-6.2069*	2.0636	.003	-10.2526	-2.1612
3.00	1.00	-2.4178E-02	2.0636	.991	-4.0699	4.0216
	2.00	-3.3163	2.0636	.108	-7.3621	.7294
	4.00	-2.7929E-02	2.0648	.989	-4.0758	4.0200
	5.00	-.1135	2.0614	.956	-4.1549	3.9279
	6.00	-.1182	2.0614	.954	-4.1596	3.9232
	7.00	-.7174	2.0614	.728	-4.7588	3.3240
	8.00	-2.8624	2.0636	.165	-6.9081	1.1833
	9.00	2.0806	2.0614	.313	-1.9608	6.1220
	10.00	-9.5232*	2.0614	.000	-13.5646	-5.4819
4.00	1.00	3.751E-03	2.0670	.999	-4.0485	4.0560
	2.00	-3.2884	2.0670	.112	-7.3406	.7638
	3.00	2.793E-02	2.0648	.989	-4.0200	4.0758
	5.00	-8.5605E-02	2.0648	.967	-4.1335	3.9623
	6.00	-9.0306E-02	2.0648	.965	-4.1382	3.9576
	7.00	-.6895	2.0648	.738	-4.7374	3.3585
	8.00	-2.8345	2.0670	.170	-6.8867	1.2177
	9.00	2.1086	2.0648	.307	-1.9393	6.1565
	10.00	-9.4953*	2.0648	.000	-13.5432	-5.4474

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5.00	1.00	8.936E-02	2.0636	.965	-3.9564	4.1351
	2.00	-3.2028	2.0636	.121	-7.2485	.8429
	3.00	.1135	2.0614	.956	-3.9279	4.1549
	4.00	8.560E-02	2.0648	.967	-3.9623	4.1335
	6.00	-4.7009E-03	2.0614	.998	-4.0461	4.0367
	7.00	-.6038	2.0614	.770	-4.6452	3.4375
	8.00	-2.7489	2.0636	.183	-6.7946	1.2968
	9.00	2.1942	2.0614	.287	-1.8472	6.2356
	10.00	-9.4097*	2.0614	.000	-13.4511	-5.3683
6.00	1.00	9.406E-02	2.0636	.964	-3.9517	4.1398
	2.00	-3.1981	2.0636	.121	-7.2438	.8476
	3.00	.1182	2.0614	.954	-3.9232	4.1596
	4.00	9.031E-02	2.0648	.965	-3.9576	4.1382
	5.00	4.701E-03	2.0614	.998	-4.0367	4.0461
	7.00	-.5991	2.0614	.771	-4.6405	3.4422
	8.00	-2.7442	2.0636	.184	-6.7899	1.3015
	9.00	2.1989	2.0614	.286	-1.8425	6.2403
	10.00	-9.4050*	2.0614	.000	-13.4464	-5.3636
7.00	1.00	.6932	2.0636	.737	-3.3525	4.7389
	2.00	-2.5990	2.0636	.208	-6.6447	1.4468
	3.00	.7174	2.0614	.728	-3.3240	4.7588
	4.00	.6895	2.0648	.738	-3.3585	4.7374
	5.00	.6038	2.0614	.770	-3.4375	4.6452
	6.00	.5991	2.0614	.771	-3.4422	4.6405
	8.00	-2.1450	2.0636	.299	-6.1908	1.9007
	9.00	2.7980	2.0614	.175	-1.2434	6.8394
	10.00	-8.8059*	2.0614	.000	-12.8473	-4.7645
8.00	1.00	2.8382	2.0659	.170	-1.2118	6.8883
	2.00	-.4539	2.0659	.826	-4.5040	3.5961
	3.00	2.8624	2.0636	.165	-1.1833	6.9081
	4.00	2.8345	2.0670	.170	-1.2177	6.8867
	5.00	2.7489	2.0636	.183	-1.2968	6.7946
	6.00	2.7442	2.0636	.184	-1.3015	6.7899
	7.00	2.1450	2.0636	.299	-1.9007	6.1908
	9.00	4.9431*	2.0636	.017	.8973	8.9888
	10.00	-6.6608*	2.0636	.001	-10.7066	-2.6151
9.00	1.00	-2.1048	2.0636	.308	-6.1505	1.9409
	2.00	-5.3970*	2.0636	.009	-9.4427	-1.3513
	3.00	-2.0806	2.0614	.313	-6.1220	1.9608
	4.00	-2.1086	2.0648	.307	-6.1565	1.9393
	5.00	-2.1942	2.0614	.287	-6.2356	1.8472
	6.00	-2.1989	2.0614	.286	-6.2403	1.8425
	7.00	-2.7980	2.0614	.175	-6.8394	1.2434
	8.00	-4.9431*	2.0636	.017	-8.9888	-.8973
	10.00	-11.6039*	2.0614	.000	-15.6453	-7.5625
10.00	1.00	9.4991*	2.0636	.000	5.4533	13.5448
	2.00	6.2069*	2.0636	.003	2.1612	10.2526
	3.00	9.5232*	2.0614	.000	5.4819	13.5646
	4.00	9.4953*	2.0648	.000	5.4474	13.5432
	5.00	9.4097*	2.0614	.000	5.3683	13.4511
	6.00	9.4050*	2.0614	.000	5.3636	13.4464
	7.00	8.8059*	2.0614	.000	4.7645	12.8473
	8.00	6.6608*	2.0636	.001	2.6151	10.7066
	9.00	11.6039*	2.0614	.000	7.5625	15.6453

*. The mean difference is significant at the .05 level.

Figure 37c. Analysis of Variance of Phosphate Total Concentration due to Activities

ANOVA

VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2023.422	9	224.825	56.638	.000
Within Groups	18533.624	4669	3.970		
Total	20557.046	4678			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.1531	.1303	.240	-.4086	.1023
	3.00	-.1524	.1303	.242	-.4079	.1031
	4.00	-.1524	.1303	.242	-.4078	.1031
	5.00	-.1524	.1303	.242	-.4078	.1031
	6.00	-.1524	.1303	.242	-.4078	.1031
	7.00	-2.2151*	.1303	.000	-2.4706	-1.9597
	8.00	9.182E-02	.1303	.481	-.1637	.3473
	9.00	9.182E-02	.1303	.481	-.1637	.3473
	10.00	9.933E-02	.1303	.446	-.1562	.3548
2.00	1.00	.1531	.1303	.240	-.1023	.4086
	3.00	7.581E-04	.1302	.995	-.2546	.2561
	4.00	7.880E-04	.1302	.995	-.2546	.2561
	5.00	7.667E-04	.1302	.995	-.2546	.2561
	6.00	7.667E-04	.1302	.995	-.2546	.2561
	7.00	-2.0620*	.1302	.000	-2.3173	-1.8067
	8.00	.2450	.1302	.060	-1.0378E-02	.5003
	9.00	.2450	.1302	.060	-1.0378E-02	.5003
	10.00	.2525	.1302	.053	-2.8766E-03	.5078
3.00	1.00	.1524	.1303	.242	-.1031	.4079
	2.00	-7.5812E-04	.1302	.995	-.2561	.2546
	4.00	2.991E-05	.1302	1.000	-.2553	.2554
	5.00	8.547E-06	.1302	1.000	-.2553	.2553
	6.00	8.547E-06	.1302	1.000	-.2553	.2553
	7.00	-2.0628*	.1302	.000	-2.3181	-1.8074
	8.00	.2442	.1302	.061	-1.1137E-02	.4995
	9.00	.2442	.1302	.061	-1.1137E-02	.4995
	10.00	.2517	.1302	.053	-3.6347E-03	.5070
4.00	1.00	.1524	.1303	.242	-.1031	.4078
	2.00	-7.8803E-04	.1302	.995	-.2561	.2546
	3.00	-2.9915E-05	.1302	1.000	-.2554	.2553
	5.00	-2.1368E-05	.1302	1.000	-.2554	.2553
	6.00	-2.1368E-05	.1302	1.000	-.2554	.2553
	7.00	-2.0628*	.1302	.000	-2.3181	-1.8074
	8.00	.2442	.1302	.061	-1.1166E-02	.4995
	9.00	.2442	.1302	.061	-1.1166E-02	.4995
	10.00	.2517	.1302	.053	-3.6646E-03	.5070

Multiple Comparisons

Dependent Variable: VALUE
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5.00	1.00	.1524	.1303	.242	-.1031	.4078
	2.00	-7.6667E-04	.1302	.995	-.2561	.2546
	3.00	-8.5470E-06	.1302	1.000	-.2553	.2553
	4.00	2.137E-05	.1302	1.000	-.2553	.2554
	6.00	.0000	.1302	1.000	-.2553	.2553
	7.00	-2.0628*	.1302	.000	-2.3181	-1.8074
	8.00	.2442	.1302	.061	-1.1145E-02	.4995
	9.00	.2442	.1302	.061	-1.1145E-02	.4995
	10.00	.2517	.1302	.053	-3.6433E-03	.5070
6.00	1.00	.1524	.1303	.242	-.1031	.4078
	2.00	-7.6667E-04	.1302	.995	-.2561	.2546
	3.00	-8.5470E-06	.1302	1.000	-.2553	.2553
	4.00	2.137E-05	.1302	1.000	-.2553	.2554
	5.00	.0000	.1302	1.000	-.2553	.2553
	7.00	-2.0628*	.1302	.000	-2.3181	-1.8074
	8.00	.2442	.1302	.061	-1.1145E-02	.4995
	9.00	.2442	.1302	.061	-1.1145E-02	.4995
	10.00	.2517	.1302	.053	-3.6433E-03	.5070
7.00	1.00	2.2151*	.1303	.000	1.9597	2.4706
	2.00	2.0620*	.1302	.000	1.8067	2.3173
	3.00	2.0628*	.1302	.000	1.8074	2.3181
	4.00	2.0628*	.1302	.000	1.8074	2.3181
	5.00	2.0628*	.1302	.000	1.8074	2.3181
	6.00	2.0628*	.1302	.000	1.8074	2.3181
	8.00	2.3070*	.1302	.000	2.0516	2.5623
	9.00	2.3070*	.1302	.000	2.0516	2.5623
	10.00	2.3145*	.1302	.000	2.0591	2.5698
8.00	1.00	-9.1825E-02	.1303	.481	-.3473	.1637
	2.00	-.2450	.1302	.060	-.5003	1.038E-02
	3.00	-.2442	.1302	.061	-.4995	1.114E-02
	4.00	-.2442	.1302	.061	-.4995	1.117E-02
	5.00	-.2442	.1302	.061	-.4995	1.115E-02
	6.00	-.2442	.1302	.061	-.4995	1.115E-02
	7.00	-2.3070*	.1302	.000	-2.5623	-2.0516
	9.00	.0000	.1302	1.000	-.2553	.2553
	10.00	7.502E-03	.1302	.954	-.2478	.2628
9.00	1.00	-9.1825E-02	.1303	.481	-.3473	.1637
	2.00	-.2450	.1302	.060	-.5003	1.038E-02
	3.00	-.2442	.1302	.061	-.4995	1.114E-02
	4.00	-.2442	.1302	.061	-.4995	1.117E-02
	5.00	-.2442	.1302	.061	-.4995	1.115E-02
	6.00	-.2442	.1302	.061	-.4995	1.115E-02
	7.00	-2.3070*	.1302	.000	-2.5623	-2.0516
	8.00	.0000	.1302	1.000	-.2553	.2553
	10.00	7.502E-03	.1302	.954	-.2478	.2628
10.00	1.00	-9.9326E-02	.1303	.446	-.3548	.1562
	2.00	-.2525	.1302	.053	-.5078	2.877E-03
	3.00	-.2517	.1302	.053	-.5070	3.635E-03
	4.00	-.2517	.1302	.053	-.5070	3.665E-03
	5.00	-.2517	.1302	.053	-.5070	3.643E-03
	6.00	-.2517	.1302	.053	-.5070	3.643E-03
	7.00	-2.3145*	.1302	.000	-2.5698	-2.0591
	8.00	-7.5018E-03	.1302	.954	-.2628	.2478
	9.00	-7.5018E-03	.1302	.954	-.2628	.2478

*. The mean difference is significant at the .05 level.

Appendix 7d. Analysis of Variance of TKN Concentrations due to Activities

ANOVA

VALUES

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	134.213	9	14.913	56.540	.000
Within Groups	1231.465	4669	.264		
Total	1365.678	4678			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: VALUES
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.1646*	3.357E-02	.000	-.2304	-9.8793E-02
	3.00	-1.5662E-03	3.357E-02	.963	-6.7385E-02	6.425E-02
	4.00	3.689E-03	3.359E-02	.913	-6.2165E-02	6.954E-02
	5.00	6.188E-03	3.357E-02	.854	-5.9631E-02	7.201E-02
	6.00	-2.1709E-03	3.357E-02	.948	-6.7990E-02	6.365E-02
	7.00	3.921E-03	3.357E-02	.907	-6.1898E-02	6.974E-02
	8.00	.2887*	3.357E-02	.000	.2229	.3545
	9.00	.3599*	3.357E-02	.000	.2941	.4257
	10.00	.3414*	3.357E-02	.000	.2756	.4072
2.00	1.00	.1646*	3.357E-02	.000	9.879E-02	.2304
	3.00	.1630*	3.357E-02	.000	9.723E-02	.2289
	4.00	.1683*	3.359E-02	.000	.1024	.2342
	5.00	.1708*	3.357E-02	.000	.1050	.2366
	6.00	.1624*	3.357E-02	.000	9.662E-02	.2283
	7.00	.1685*	3.357E-02	.000	.1027	.2344
	8.00	.4533*	3.357E-02	.000	.3875	.5191
	9.00	.5245*	3.357E-02	.000	.4587	.5903
	10.00	.5060*	3.357E-02	.000	.4402	.5718
3.00	1.00	1.566E-03	3.357E-02	.963	-6.4253E-02	6.739E-02
	2.00	-.1630*	3.357E-02	.000	-.2289	-9.7227E-02
	4.00	5.256E-03	3.359E-02	.876	-6.0599E-02	7.111E-02
	5.00	7.754E-03	3.357E-02	.817	-5.8065E-02	7.357E-02
	6.00	-6.0470E-04	3.357E-02	.986	-6.6424E-02	6.521E-02
	7.00	5.487E-03	3.357E-02	.870	-6.0332E-02	7.131E-02
	8.00	.2903*	3.357E-02	.000	.2245	.3561
	9.00	.3615*	3.357E-02	.000	.2956	.4273
	10.00	.3429*	3.357E-02	.000	.2771	.4088
4.00	1.00	-3.6893E-03	3.359E-02	.913	-6.9544E-02	6.217E-02
	2.00	-.1683*	3.359E-02	.000	-.2342	-.1024
	3.00	-5.2555E-03	3.359E-02	.876	-7.1110E-02	6.060E-02
	5.00	2.499E-03	3.359E-02	.941	-6.3356E-02	6.835E-02
	6.00	-5.8602E-03	3.359E-02	.862	-7.1715E-02	5.999E-02
	7.00	2.314E-04	3.359E-02	.995	-6.5623E-02	6.609E-02
	8.00	.2850*	3.359E-02	.000	.2192	.3509
	9.00	.3562*	3.359E-02	.000	.2903	.4221
	10.00	.3377*	3.359E-02	.000	.2718	.4035

Multiple Comparisons

Dependent Variable: VALUES
LSD

(I) TREATMEN	(J) TREATMEN	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5.00	1.00	-6.1880E-03	3.357E-02	.854	-7.2007E-02	5.963E-02
	2.00	-.1708*	3.357E-02	.000	-.2366	-.1050
	3.00	-7.7543E-03	3.357E-02	.817	-7.3573E-02	5.806E-02
	4.00	-2.4987E-03	3.359E-02	.941	-6.8353E-02	6.336E-02
	6.00	-8.3590E-03	3.357E-02	.803	-7.4178E-02	5.746E-02
	7.00	-2.2673E-03	3.357E-02	.946	-6.8086E-02	6.355E-02
	8.00	.2825*	3.357E-02	.000	.2167	.3483
	9.00	.3537*	3.357E-02	.000	.2879	.4195
	10.00	.3352*	3.357E-02	.000	.2694	.4010
6.00	1.00	2.171E-03	3.357E-02	.948	-6.3648E-02	6.799E-02
	2.00	-.1624*	3.357E-02	.000	-.2283	-9.6622E-02
	3.00	6.047E-04	3.357E-02	.986	-6.5214E-02	6.642E-02
	4.00	5.860E-03	3.359E-02	.862	-5.9994E-02	7.171E-02
	5.00	8.359E-03	3.357E-02	.803	-5.7460E-02	7.418E-02
	7.00	6.092E-03	3.357E-02	.856	-5.9727E-02	7.191E-02
	8.00	.2909*	3.357E-02	.000	.2251	.3567
	9.00	.3621*	3.357E-02	.000	.2962	.4279
	10.00	.3435*	3.357E-02	.000	.2777	.4094
7.00	1.00	-3.9207E-03	3.357E-02	.907	-6.9740E-02	6.190E-02
	2.00	-.1685*	3.357E-02	.000	-.2344	-.1027
	3.00	-5.4870E-03	3.357E-02	.870	-7.1306E-02	6.033E-02
	4.00	-2.3143E-04	3.359E-02	.995	-6.6086E-02	6.562E-02
	5.00	2.267E-03	3.357E-02	.946	-6.3552E-02	6.809E-02
	6.00	-6.0917E-03	3.357E-02	.856	-7.1911E-02	5.973E-02
	8.00	.2848*	3.357E-02	.000	.2190	.3506
	9.00	.3560*	3.357E-02	.000	.2902	.4218
	10.00	.3375*	3.357E-02	.000	.2716	.4033
8.00	1.00	-.2887*	3.357E-02	.000	-.3545	-.2229
	2.00	-.4533*	3.357E-02	.000	-.5191	-.3875
	3.00	-.2903*	3.357E-02	.000	-.3561	-.2245
	4.00	-.2850*	3.359E-02	.000	-.3509	-.2192
	5.00	-.2825*	3.357E-02	.000	-.3483	-.2167
	6.00	-.2909*	3.357E-02	.000	-.3567	-.2251
	7.00	-.2848*	3.357E-02	.000	-.3506	-.2190
	9.00	7.117E-02*	3.357E-02	.034	5.353E-03	.1370
	10.00	5.266E-02	3.357E-02	.117	-1.3164E-02	.1185
9.00	1.00	-.3599*	3.357E-02	.000	-.4257	-.2941
	2.00	-.5245*	3.357E-02	.000	-.5903	-.4587
	3.00	-.3615*	3.357E-02	.000	-.4273	-.2956
	4.00	-.3562*	3.359E-02	.000	-.4221	-.2903
	5.00	-.3537*	3.357E-02	.000	-.4195	-.2879
	6.00	-.3621*	3.357E-02	.000	-.4279	-.2962
	7.00	-.3560*	3.357E-02	.000	-.4218	-.2902
	8.00	-7.1172E-02*	3.357E-02	.034	-.1370	-5.3530E-03
	10.00	-1.8517E-02	3.357E-02	.581	-8.4336E-02	4.730E-02
10.00	1.00	-.3414*	3.357E-02	.000	-.4072	-.2756
	2.00	-.5060*	3.357E-02	.000	-.5718	-.4402
	3.00	-.3429*	3.357E-02	.000	-.4088	-.2771
	4.00	-.3377*	3.359E-02	.000	-.4035	-.2718
	5.00	-.3352*	3.357E-02	.000	-.4010	-.2694
	6.00	-.3435*	3.357E-02	.000	-.4094	-.2777
	7.00	-.3375*	3.357E-02	.000	-.4033	-.2716
	8.00	-5.2655E-02	3.357E-02	.117	-.1185	1.316E-02
	9.00	1.852E-02	3.357E-02	.581	-4.7302E-02	8.434E-02

*. The mean difference is significant at the .05 level.