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**DESIGNING SIMULATIONS TO IMPROVE
LEARNER OUTCOMES IN ECOLOGICAL EDUCATION**

**A thesis submitted in fulfilment of the
requirements for the award of the degree**

DOCTOR OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG

by

**ROBERT. M. CORDEROY
B.A.(Geol)., M.Ed(IT)., M.A.C.E., JP.**

FACULTY OF EDUCATION

2001

Declaration

I, Robert Malcolm Corderoy, certify that the material within this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Education, University of Wollongong, is wholly my own original work unless otherwise referenced or acknowledged. This thesis has not been submitted for the award of qualifications at any other institution.

Robert. M. Corderoy
30th August, 2001

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Included Software

Exploring the Nardoo

Hybrid PC/Mac version CD-ROM

(Inside back cover)

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Robert. M. Corderoy
30th August, 2001

Abstract

The study of complex ecological processes presents many difficulties for learners including the time frame in which it may take place and the complexity of the relationships involved. The learning outcomes and level of understanding of the underlying relationships for students studying such processes may be effectively supported and improved through the use of carefully designed simulations which provide the learner with the opportunity to explore and test their ideas, knowledge and understanding without risk. The purpose of this study was to design, develop, implement and test the efficacy of a simulation tool designed to simulate algal bloom in a river catchment environment in terms of its potential to produce improved learning outcomes and understanding of relationships for the learners.

There has always been a 'suspicion' amongst some educators, particularly those who have limited computer literacy, that the platforms of the information technology revolution are simply 'new toys' in the hands of resource developers and researchers, and that the outcome is simply an application of such technologies in the misguided belief that such delivery systems for educational experiences provide some sort of advantage over the more traditional methods.

This study is based on two assertions with regard to the educational effectiveness of simulations in educational environments. First, that to be effective simulations need to have been designed in accordance with contemporary theoretical principles in terms of both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the user may construct knowledge and understanding of complex processes. Second, that students using such simulations will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms the representational media adopted, available resources and teaching methods.

In summary, the study was designed to test the efficacy of the assertion that with careful design, interactive simulations which mimic complex ecological processes can provide the opportunity for improved learning outcomes and the development of a deeper understanding of the underlying relationships.

The experimental materials used in this study comprised the software package *Exploring the Nardoo* and the algal bloom simulation tool embedded within it. The package is an interactive multimedia CD-ROM based learning environment designed with a constructivist approach. It attempts to provide a realistic, risk free information rich learning space in which students may explore, test their understanding of specific issues, and develop solutions to authentic tasks.

The methodological approach adopted for this study was of a classic experimental design (pre/post test) and based in the Scientific Paradigm. Such a pure experimental approach was essential to testing the stated hypotheses, however in order to provide a more complete picture of the nature of user/software interactions, a hybrid quantitative/qualitative approach was used.

The data set on which the analysis of the study was based was collected using researcher designed instruments; a Knowledge Acquisition Schedule (KAS), a Cause and Effect Schedule (CES) and a User Perceived Value Schedule (UPS). Subjective information in the form of field observation records and comments was also collected. Such an approach provided a context in which the research question could be tested and considered while maintaining the necessary research rigour. The operational population, third year pre-service student teachers, was chosen from the target population by the use of the technique of “cluster sampling”.

The data collected from the Knowledge Acquisition Schedule (KAS) indicated that use of the package *Exploring the Nardoo* resulted in significantly improved acquisition of factual knowledge for both the control and experimental groups. This was not unexpected as the overall design of the software was such that all students had access to extensive multi-format information on all aspects of algal blooms and the investigation was designed so as to be ‘independent’ of the algal bloom simulation tool. The fact that the experimental groups KAS mean scores showed a significantly greater increase than those of the control group would suggest that using the simulation tool also supported factual knowledge acquisition.

Analysis of the Cause and Effect Schedule (CES) data suggests that the simulation tool also facilitated a deeper understanding of the processes and the relationships between causal factors for the students who had access to the simulation tool. Examination of the pre and post CES mean scores data indicated that the students using the simulation tool not only improved their CES mean scores, but improved them by a significantly greater margin than those in the control group. This outcome adds support to the assertion that, when students have the opportunity to test and re-assess their mental models of complex systems, the processes and relationships at work, in meaningful learning environments and supported by appropriate tools, there is the potential for improved learning outcomes and the development of deeper understanding. The data collected from the UPS added support to these findings and issues relating to the design and function of the simulation tool.

In summary, the overall findings suggest that, simulations which are designed in terms of contemporary theoretical principles with regard to functionality and pedagogical strategies, and are embedded within rich, multimedia based learning environments have the potential to provide the user with a greatly enriched experience by facilitating the review of existing learner knowledge and the construction of new learner knowledge.

CHAPTER 1

Overview

1.0 Introduction

Simulation and gaming have been used in educational learning environments in an attempt to improve educational outcomes for some time. In their earliest forms these learning strategies were used to provide a means of providing experiences which would otherwise be unavailable for various reasons including cost, time constraints and safety.

The exact nature of what constitutes a simulation differs amongst researchers or designers, but commonly, the goal of the simulation must be to provide interactive experiences which approach or mimic the ‘real world’ experience and which allow learners to engage in deep learning. The experience should “immerse the learner in a complex, evolving situation” in which the learner exerts a high degree of control and perhaps ultimately becomes “one of the functional components” (Gredler, 1996).

There is considerable literature on the value and nature of simulations. They have been defined as the dynamic execution or manipulation of a model of an object system for some purpose (Martin, 1988). A simulation is considered as “... a special kind of model representing a real world system, governed by a set of rules” (Crookall et al., 1987). During the use of such models, the user often comes to see the simulation itself as a real world in its own right. Such models represent systems as either “in-place-of” or a “bring- to-life” format. Whether the terms model and simulation have similar meanings in this context may prove a pivotal point around which a better understanding of the cognitive outcomes for the users may be achieved. The in-place-of interpretation of representation applies to the standard widely accepted notion of a model while, as suggested by Crookall et al., (1987), both the “in-place-of” and “bring-to-life” representations may be applied to and equated with simulations.

The current level of sophistication of interactive multimedia applications provides a vehicle for designers to produce software which more fully utilises the capabilities of the available technologies. Many of the more recent simulation packages, exhibit a tendency to move away from the earlier simulation format, the pre-set model that provided a very simplified approximation of the real world it was trying to mimic. Many earlier simulations were little more than data bases or in-place-of mathematical models, presenting the user with limited and often fixed options in terms of control and outcomes and which allowed limited freedom of exploration and little true interactivity. Taking advantage of computing power and hence the ability to facilitate high levels of user interaction with information in various media formats, it is now possible to provide simulation environments which more closely replicate real world experiences. This is especially so in the study of ecological processes. The natural processes are both complex and often operate over extended time frames making detailed study and the development of an understanding of the underlying processes challenging. These processes are outside the normal experience of the average student most of whom will only ever have the opportunity to examine the mechanisms of nature at a very superficial level.

Bliss and Ogborn (1989) define computer based simulations as programs in which the computer acts as an exploratory tool supporting a real world activity while facilitating user understanding of the processes involved in complex dynamic systems that may otherwise be inaccessible. This notion is compatible with current constructivist views on the nature of learning.

McFarland and Parker (1990) define them as interactive and reactive environments for creating and experimenting with decisions. In an attempt to clarify the situation, some have suggested that simulations fall into two general forms, those in which the student actually builds a model or modifies an existing one during their learning experience (termed exploratory) or behavioural simulations in which the student is given a fixed model to work with.

Gredler (1996) proposed that simulations may be categorised as either symbolic or experiential. In symbolic simulations, the student is provided with dynamic representations of the behaviour of a system or set of processes. Experiential simulations

place the students within the simulated environment by giving them a real task to work with whilst providing them with high levels of user control in decision making. The outcomes of these actions and decisions then are reflected in the behaviour of the model.

Corderoy et al., (1998a) proposed that simulations could be categorised in a broad sense as either illustrative or interactive. Illustrative simulations consist of a set of scenarios with repeatable outcomes which in terms of the outcomes, are essentially unaffected by the students interaction. Interactive simulations however are built around dynamic open ended models designed to closely mimic real world systems. The students interactions with the model are reflected in the behaviour of the system so that the outcomes are driven by the decisions made within the model and are unpredictable.

More recently Harper et al., (2000) have proposed a new design paradigm “constructivist simulations” which combine the characteristics of experiential simulations with the “more traditional symbolic simulations for supporting learners in what the designers call ‘what-if’ investigations” within a constructivist environment. For learners to effectively construct their understanding, they must have the opportunity to test their ideas or mental pictures of the nature of process they are investigating. The traditional symbolic, algorithm based simulation provides the mechanism for achieving this in computer based learning environments. It is the level of sophistication, openness of the modelled environment, degree of user control and level of user induced change in the environment that is available within the symbolic simulation that is perhaps critical to the learning outcomes. To be able to test hypotheses and what if situations, which many researchers agree is important, is an essential component of the natural learning process for all students in the real world. Embedding this ability, using symbolic simulations within an environment rich in a variety of representations of information and presented in a way which reflects a real world experience, must provide the potential for improved learning outcomes. Currently, few simulation environments could be classified within this model and there is little research available on the use of these in educational settings or on the learning outcomes that learners may experience.

As an instructional strategy, simulations have an enormous potential to facilitate effective learning experiences for all students, their essential value being that they:

- provide risk free environments in which students may practice skills and test their intuitions without consequence;
- situate a task in meaningful context which motivates and elicits students to be active participants;
- facilitate contextualisation where a real world context is impractical;
- elicit active participation in these meaningful tasks;
- allow students to investigate complex processes, build and re-asses their own mental models;
- scaffold the development and modification of these mental models and;
- support a number of learning styles by providing students with multiple representations.

1.1 The Study

This thesis is divided into three distinct but interwoven sections. The first section is a review of the literature and current research with regard to the use of simulations to improve educational outcomes. It comprises a review and analysis of design issues in terms of contemporary theoretical principles for simulations which provide effective and realistic replicas of real world systems (in this case, the complex natural process of algal bloom development) and their implications in terms of the construction of knowledge and overall learning outcomes for students using them. It also provides an overview of simulations and their role in educational settings.

The second section provides a detailed account of the design and development of an algal bloom simulation tool in terms of these principles, for implementation in the water management software package *Exploring the Nardoo*. The author had several roles in the development of this package including; being a member of the instructional design team, responsibility for the development of the simulation module, development of additional resources such as the theoretical content and, research and development of resources designed to support students in the preparation and presentation of their findings .

The software provides students with the opportunity to investigate water management issues in a simulated inland river system. A rich information base including documents, video clips, newspaper cuttings and the like supports their investigation of problems based in real life scenarios. The students are also provided with a flexible set of tools to assist them in their investigations including, the algal bloom simulation tool reported on in this study. The simulation is open ended and provides the possibility for users to test their hypotheses about the process and relationships they discover as they construct their understanding.

The third section comprises a report on a study carried out to test, in an educational setting, the algal bloom simulation tool against the research hypotheses. A random sample of third year pre-service student teachers, who will eventually teach Science and Technology at a Primary (3 -6) level, was used as the operational population.

The basic aims of this implementation were:

- To determine, using several instruments and techniques designed to capture both parametric and non-parametric data, whether an interactive simulation designed in accordance with best design parameters will improve learning outcomes;
- To provide some indication as to whether current design practice in computer driven interactive multimedia applications fully exploits the technology and;
- To provide some indication of the areas of such design practices and pedagogical approaches which may require further investigation.

1.2 The Research Question

The study of complex ecological processes presents many difficulties for learners including the time frame in which it may take place and the complexity of the relationships involved. The learning outcomes and level of understanding of the underlying relationships for students studying such processes may be effectively supported and improved through the use of carefully designed simulations which provide the learner with the opportunity to explore and test their ideas, knowledge and understanding without risk. The purpose of this study was to design, develop, implement and test the efficacy of a simulation tool designed to simulate algal bloom in a river catchment environment in terms of its potential

to produce improved learning outcomes and understanding of relationships for the learners. Several instruments were developed to collect data for use in addressing this question.

The instruments used included:

- A Knowledge Acquisition Schedule (KAS) - a measure of learning outcomes
- A Cause and Effect Schedule (CES) - a measure of the development of an understanding of relationships between contributing variables, and;
- A User Perception Schedule (UPS) - Additional data (parametric) to gather user perceptions of the learning experience with regard to the pedagogical approach and user interaction in terms of the users preferred learning style.

1.2.1 General Hypothesis

Students using simulations, designed in accordance with contemporary theoretical principles, will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms of resources and teaching methods. In the design process, consideration was given to both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the learners could construct their knowledge and understanding of the complex ecological process under study,

To better focus the study, this general hypothesis was expressed in terms of two definitive research hypotheses:

1.2.2 Learning Outcomes

H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the learning outcomes measure, a Knowledge Acquisition Schedule (KAS), than the students who do not.

1.2.3 Development of an Understanding of Relationships

H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the development of understanding relationships measure, a Cause and Effect Schedule (CES), than the students who do not.

1.3 Design Considerations

One of the most important questions facing all developers whether they are concerned with the technological or instructional aspects, is how to structure computer environments. This is particularly important for those which incorporate multimedia, enriching the experience by utilising the technology and maximising the learning outcomes. The literature identifies several essential issues critical to a complete understanding of the processes involved in the development of successful interactive multimedia software that will maximise the learning.

The issues include;

- the pedagogical approach adopted;
- motivation (need to be motivated and to want to engage);
- the structure and framework of presentation (multiple representations);
- the degree of interactivity ;
- the level of learner engagement (learners must be engaged to get efficient, effective learning);
- navigational issues;
- mapping user action to educational goal in the interface;
- instructional sequencing and;
- perceived risks.

1.3.1 Good Learning Environment Design

The literature on the contemporary theoretical principles of designing learning environments shows agreement on several essential goals. The environment should:

- provide experience in and appreciation for multiple perspectives/representations;

- present students with interesting and worthwhile tasks - embedded in real world contexts;
- provide a high level of user control so that students develop a sense of ownership of their learning experience;
- provide freedom to explore so that students may develop personally meaningful and transferable knowledge and understanding and;
- provide intrinsic feedback, providing information on the effect of the learners interaction on/with the system.

Many researchers in this area including Rieber (1992), Duffy and Cunningham (1996) Grabinger, Dunlap & Duffield (1997), Jonassen & Tessmer (1996-7) have proposed guidelines and criteria for developing constructivist learning environments which can be directly applied to simulation design.

They claim that designers need to develop environments that:

- support and motivate active learners to engage in interaction;
- support learners in exploring these environments strategically;
- support all learners whether intentional, conversational or casual;
- support reflective learners to articulate what they have learned and reflect on the process and;
- support ampliative learners to test what they have learned.

It has been suggested by Hooper (1988a), that ... “the challenge to the interactive multimedia designer in all regards is to create applications that are clearly attractive and superior to materials now available”. “The development of a technology of education will not emerge merely from the attempt to adapt technologies developed for the purposes ... on the contrary, what appears to be needed for the development of useful technology in education (interactive multimedia applications and the like), is a firm foundation of scientific knowledge in the area of learning” (Travers, 1986). Such a foundation is one would suggest, pivotal to good design practice.

1.4 Simulations in Ecological Education

In learning about and exploring ecological systems, students face a number of significant hurdles which may inhibit or prevent them from realising a full understanding of the processes involved. These include, the complexity and dynamic nature of most ecological systems, the often extended time frame over which the system must be observed or tracked in order to make sense of the underlying processes, the risk involved, both with respect to the student or the equipment which may be used to carry out investigations and the cost factor, both in terms of time and money in providing an educationally useful experience. Interactive multimedia based simulations are powerful tools for supporting such investigations and minimising the impact of these factors on the overall learning outcomes.

One would suggest that, successful learning outcomes for students studying ecological systems using simulated environments are based in how closely the simulated world mimics the real world experience. There must be provision for the students to engage in some authentic task and be able to interact with the software in a fashion not unlike the real world equivalent. Interactivity implies dialogue and one would suggest that there must be a two way dialogue involving constant feedback if an environment is to mimic the real world effectively. Multimedia with its multi-sensorial stimulation possibilities provides the ideal platform to mimic real world experiences.

The literature exploring the design issues for developing interactive multimedia based simulation environments is cited extensively elsewhere in this thesis. In distilling this literature, the attributes which one would suggest are representative of good design practice include:

- The provision of some form of initial entry support, an overview;
- The student must be able to design and test hypotheses even if only in response to guided general problems;
- The degree of complexity possible must be limited by the tools available;
- There must be constant feedback so that the user may confirm the correctness of their decisions or the level of their understanding;
- The results of student interaction must be reflected in the behaviour of the system;

- The user should have measured freedom and be permitted to determine the course of an investigation within the confines of the system so that they are active in the learning process and;
- The use of multiple perspectives (and pathways) which will allow the students to access materials in a manner more suited to their needs (Reeves, 1992) and learning style as well as support them in a more reflective approach to learning Laurillard (1993).

In summary, the study hopes to show that with careful design, interactive simulations which mimic complex ecological processes, can provide the opportunity for improved learning outcomes and the development of a deeper understanding of the underlying relationships.

CHAPTER 2

Literature Review

2.0 Introduction

In presenting the reviewed literature in this chapter, only that which is most pertinent to the nature and purpose of the research reported upon in this thesis is discussed. Some of the early literature has been included as it traces the evolution of the main ideas and amplifies the current study. The literature on effectiveness and efficiency of multimedia based simulation in educational environments falls into two broad areas, design issues and pedagogical issues.

The key ideas are presented in three major sections. The first, deals with simulations, simulation theory and design in a broad sense. In the second, the application of simulations in educational settings is explored in terms of design issues, suggested benefits and expected learning outcomes for students. In the third, the literature discussed relates to the development of both the original model of algal bloom in lakes and its re-development for river environments, together with the sources of data for algorithm development and performance testing.

In each section, there is coverage of the most significant literature available while maintaining a balance between what might be called ‘foundation’ literature and more recent literature.

2.1 Simulations: Real World Substitutes or ‘Pre-set’ Experiences.

Games and simulations have been used in education and training environments for many years “and have been based on a variety of theoretical views of learning” (Harper et al., 1998). It is only in the more recent literature that the characteristics of these two categories together with the intermediary category, simulation games, have been more clearly defined. Previously the games/simulation nexus was confused, with simulations

often being described as special types of games. This confusion was compounded (Gibbs, 1975) by the fact that both were used side by side in educational environments and have many similar characteristics. There is now however general agreement (Martin 1988, McFarland & Parker 1990, Corderoy et al., 1993, Russo 1994, Dowling 1997, Juang et al., 1999, and Harper et al., 2000) that the key distinguishing feature of simulations designed for educational environments is that they make use of a model to represent some event or process which the user can interact with and manipulate during their exploration within a learning landscape that presents information in a multi-representational format. This landscape provides the context for the learner and may in itself be a simulation of a complete real world system in which embedded 'mini-simulations' represent the underlying processes.

There seems to be common agreement that the goal of simulation must be to provide interactive experiences, which approach or mimic the real world experience as closely as possible. Edwards & Holland (1992) suggest that the closer a simulation mimics reality the more effective it will be as a pedagogical tool. Yeo (1998) takes a different view and proposes that it is the proliferation of computers and the harnessing of their power in simulations, which has resulted in much more realistic results and hence better learning outcomes. Gibbs (1975) suggested that the two most relevant variables, which need to be considered in examining the relationship between games and simulations, are the degree of determinism (range of options for the participants) and the amount of structure (level to which the inputs, processes and outcomes are controlled by the designer).

In comparing the literature on simulation presented in this review and that which deals with non-computer based simulation, it becomes apparent that similar findings are being reported (Theobald, 1988 and Matheidesz, 1987). Simulations using in-class role-plays and the like (O'Toole, 1993), have been used for many years in educational environments as have board based games and simulations. The overall design concerns and the outcomes for educational experiences involving simulation are essentially the same whether based in a board or classroom based game or a computer screen (Ellington, 1992 and Randel et al., 1992).

The need for interactivity, active engagement, and navigational support in board based games and simulations have been noted as significant to the educational outcomes of such tools. Most of the essential features of a simulation can be incorporated within board and classroom based simulations and games. O'Toole (1993) pointed out that it is not a difficult task to set up board games that require the user to make decisions which will affect later stages of play and have specific consequences for the user and the ultimate outcome of the game.

2.1.1 Games and Simulation games

In reaching a workable definition for simulations that encompasses the many sub-groups now recognised it is necessary to distinguish games and simulation games from simulations. As a starting point, Figure 2.1 sets out an overview of the basis of the various game/simulation taxonomies reflected in literature cited within this chapter. In terms of simulations, division has been most commonly based on three criteria, learner control, characteristics, and model access.

There is a considerable volume of literature exploring the nature and characteristics of games in all their forms. Jones (1998) defined a game, as a system involving rules while a simulation is a system involving representations. Games have been defined as “an activity which is carried out by cooperating or competing decision makers seeking to achieve their objectives within a framework of rules” (Gibbs, 1974a), while a simulation is “a dynamic representation which substitutes components and relationships to replace their real or hypothetical counterparts” (Gibbs, 1974b).

Shirts (1975) stated that games are activities that are governed by a set of rules or conditions that have the sole purpose of creating some desired end or state. He further pointed out that many people limit their definition of a game to one that involves a ‘winning condition’ as the essential outcome when clearly there are many games that are designed to have other outcomes. Gredler (1996) concurs with this and expands on it by noting that the rules under which the game is conducted may be imaginative and not related to the real world. She states that this is in stark contrast to the basis of simulation in which the rules under which the simulation operates “reflect authentic causal

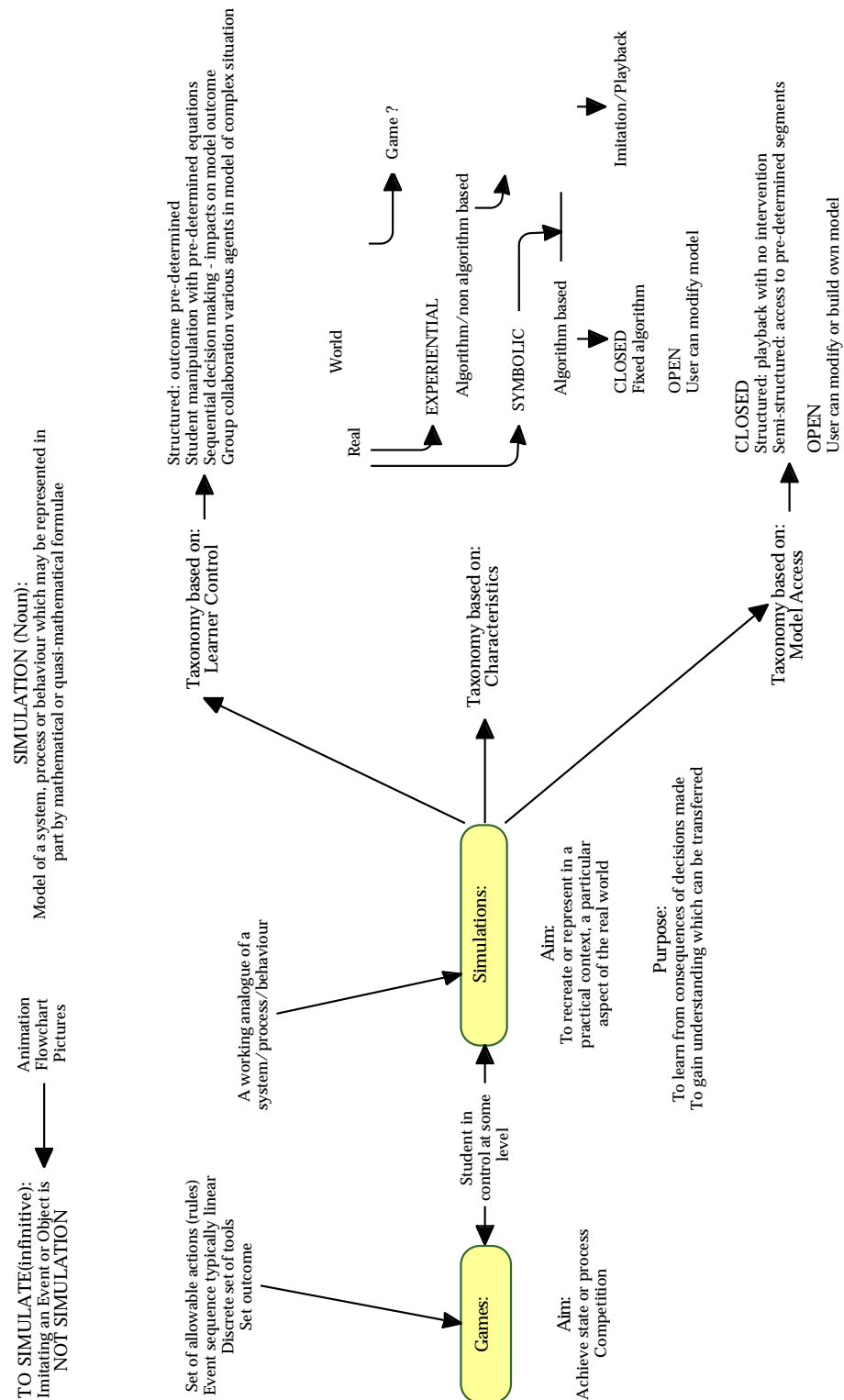


Fig 2.1: Overview of Simulation Taxonomies

processes”. It was suggested by Gibbs (1975) that the two most significant aspects to be considered in differentiating between games and simulations are the degree of determinism and the degree of structure, games having a low levels of determinism. It is apparent then that essentially, games involve activities that are directed towards a specific outcome using only the means/tools provided, under the limitations of a specific set of rules or conditions that may or may not be based in real world activity. They do not have the power to facilitate rich learning environments because the learner is unable interact in a way that truly influences the system and the eventual outcome.

Mention is also made throughout the literature of simulation games. This category represents an intermediary form between the pure game and the simulation. They have been described as games which exhibit many of the characteristics of ‘true games’ including in many cases the ‘contest’ aspect of games while being governed to varying degrees of fidelity by rules based on real world system. They also use representations of real events or objects.

2.1.2 Simulations

The confusion in differentiating between games and simulations suggested Shirts (1975), arises in part from the fact educators attempt to differentiate between the noun “simulation” and the infinitive “to simulate”. He points out that in the past, the term “simulation” has usually been applied to modelling systems using mathematical or quasi-mathematical approaches. He proposes that one should simply define simulations as anything that simulates or models reality. In adopting this approach, he points out that under this taxonomy, mathematical formulae, models of physical and social systems, role playing, film making and literature may all be considered simulations. This would however seem to be too encompassing to be useful.

In much of the early literature, the term simulation is used almost exclusively in reference to the design and use of models to represent some aspect of a process that forms a part of a larger and more complex system. In real world experience, understanding comes about by experiencing these segmented aspects within the context of the whole system, along with many other stimuli that are related to the process and the experience as a whole.

Russo (1994) points out that the real world is one of colour, sound and action in which we experience all manner of data, events, processes and phenomena in a myriad of ways, so it would seem only natural that to simulate the real world one must not simply rely on the output of numbers from a model but to immerse the learner in an experience which utilises these multiple stimuli and forms of feedback so that the fidelity of the experience is a closer match to the real world. Dowling (1997) suggests that the main advantage of using computer-based simulations in educational settings is “the degree to which modes of representation can be more closely specified, controlled and varied than in a real life situation”.

Crookall et al., (1987) proposed that a simulation is “defined as a special kind of model representing a ‘real world’ system, governed by a set of rules”. In terms of the proposed taxonomy, (Figure 2.2) such a definition can encompass symbolic algorithmic based simulations as well as experiential and open forms such as role-play. The literature reviewed for this thesis reflects the fact that the underlying simulation tool designed and implemented within this study is symbolic and underpinned with algorithms.

Others have defined simulations as “the dynamic execution or manipulation of a model of a ‘real world’ situation” (Martin, 1988). The use of computers as tools for simulation is not a new idea, in fact, as pointed out by Martin (1988) and others, they have been used in such a role since the 1940’s. In their earliest forms they were used as aids for training students in processes which were too costly, time consuming or dangerous to deal with in any other way. This definition however is rather restrictive in that it refers only to modelling of specific processes or parts of systems, when in the real world, ones experience is shaped by the interaction of a whole series of such processes working together.

In categorising simulations, Bell & Scott (1985) divide them into, those that are structured, those that are semi-structured and those that are open. They suggest that the latter are the most successful in recreating real life situations and as such provide excellent support for inquiry learning. Although such categorisation is useful, it is a rather simplistic way of making distinctions. Martin (1988) suggests that although there is an almost infinite array of variations in simulation structure, two trends have evolved in the

way in which simulations are perceived. There are ‘in-screen’ simulations in which the computer is used as a modelling device to present an image of a functioning model. Such models are bounded by the computer interface and have their origins in mathematical models. Such simulations would better be described as computer modelling.

The second category is the ‘out-of-screen’ simulation in which the computer acts as “an exploratory tool”, as defined by Bliss & Ogborne (1989), that supports an essentially real world activity while facilitating user understanding of the processes involved in complex dynamic systems which may otherwise be inaccessible to them. This type of simulation has its origins in our everyday activity and learning within the real world, play and gaming and is characterised by user participation.

They suggest that these exploratory tools support real world activities. Simulations are environments in which designers seek to provide a realistic representation of a real world experience. Their essential worth if designed well, lies in their ability to replace the real world experience at a low monetary, time and equipment cost relative to the real experience. They can model and substitute for the ‘real thing’ when danger and other constraints make access by individuals inappropriate and they provide an ease of availability and repeatability which may in some cases surpass the real thing.

During the use of such models, the user often comes to see the simulation itself as a real world in its own right. Such models represent systems as either an “in place of” or a “bring to life” format. The question posed by some as to whether the terms model and simulation have similar meanings in this context may provide a pivotal point around which a better understanding of the cognitive outcomes for the users may be achieved. The *in place of* interpretation or representation applies to the standard notion of a model.

The question is posed in some of the literature as to whether the terms model and simulation means the same thing. Crookall et al., (1987) suggested that the *in place of* interpretation of representation applies to models only while both the *in place of* and *bring to life* representations may be applied to simulations, particularly the author suggests, those which strive to be truly interactive.

The term interactive has been used here as it is still widely used in the literature but it is no longer particularly useful as it now has such a broad context, encompassing the concepts of fidelity, type of underpinning model (mathematical or social), form of representation (logical, analogical, realistic, iconic) and form of interaction. Sims (2000a) has suggested that a more useful approach is to examine the level of learner engagement. In a recent study, Sims (2000a) found that although the participants were quite capable of using interactive devices, regardless of the title, interface design or format, based on what the participants said, most were not necessarily in control and any consequential engagement with the content material tended to be limited. According to Jonassen (1998), constructivist learning environment (CLE) products will work better when a more comprehensive understanding of the interactive phenomenon is developed.

It is the authors contention that many of the earlier simulation packages were little more than ‘in place of’ mathematical models, presenting the user with limited and often fixed options in terms of control and outcomes, that is the interaction that the students had with the system was not reflected in any change in the behaviour of the system nor possible outcomes. Interactive programs of the 70’s states Preston (1994) were typified by computer control of the learning materials with students responding to the information provided. In terms of a proposed 7 stage taxonomy of levels of interactivity suggested by Sims (1994), most fell into the hierarchical (level 2) or update (level 3) degrees of interactivity.

Schweir & Misanchuk (1994) suggested that rather than tying levels of activity to hardware, it is “more productive to characterise interaction according to the sophistication and quality of interactivity available to the learner”. Hedberg and Sims (2001) proposed a “communications model, based on the notion of encounters, by which a range of interactions can be implemented to enhance learner engagement and subsequent learning” to describe the level of interaction possibilities in computer-based learning environments. In terms of this model, much of the early software falls into what Hedberg and Sims (2001) call “controlling encounters”, interaction being restricted to navigation and menu selection. If a simulation is to truly mimic real world experiences, a key factor in its operation must be the provision of higher levels of learner engagement,

strategic and sympathetic encounters where there is a sense of two way personal communication between the user and the system.

In the more recent literature, simulations are being described as encompassing a much broader context. Alessi (2000) categorised instructional simulations as either conceptual or procedural in nature. Conceptual simulations are those that teach about something, for example the rules that govern the system under study. Procedural simulations however teach how to do something, how to apply processes or practice skills. While both have specific advantages given the different situations and educational aims that arise, he asserted that the best simulation environments are probably only achieved when both types are incorporated.

Gredler (1996) proposed that simulations might be categorised as either ‘experiential’ or ‘symbolic’. The recognition of the experiential nature of simulations was made some six years earlier. According to Thatcher (1990), “all games and simulations are a form of experiential learning ...”. This proposition has most recently been restated by Petranek (2000) in a paper examining the role of debriefing in learning with simulations. Thatcher & Robinson (1990) also present the proposition that all simulations have two characteristics: they usually depict a real-world situation, and they are dynamic and ongoing.

Experiential simulations are those which combine stimuli and rich resource bases in multi-representational forms, allowing the user to interact with and move freely through the virtual world much as they do in the real world. Harper et al., (2000) proposed that simulations that contain elements of both experiential and symbolic simulations might be most effective in terms of learning outcomes. As discussed earlier in this chapter, the real world in which we operate contains both these elements and both are needed to provide a real world experience that places the learning in a meaningful context. Nature operates on rules and algorithms and it is our interaction within the whole framework and the use of our senses to experience the end products of these interactions that provide the real world experience.

Symbolic simulations are dynamic representations of a system over which the user has some control of variables and can use them to discover scientific relationships.

It could be argued however that the degree of variation in terms of complexity and user control observed in current examples of educational simulations makes such a categorisation too broad.

Figure 2.2 represents an attempt on the part of the author to clarify the issue of definition and to categorise the simulation tool used in this study. It sets out a proposed taxonomy for symbolic simulations in particular, based in current literature. The author proposes at least three levels of symbolic simulation, the first two levels being ‘closed’ in terms of the generally accepted definition of the term and the third level being open in terms of the parameters described by Gibbs (1975). It needs to be stressed that these categories or levels are not mutually exclusive and much of the software developed for teaching, learning environments, use simulations exhibiting varying degrees of hybridisation.

Simulations belonging to the ‘Symbolic - Level 1’ category in the proposed taxonomy (Figure 2.2), the author proposes to call “Illustrative simulations”. Purely Illustrative simulations may be defined as those that involve a minimum of interaction and provide simple feedback, often in the form of images. The user does not provide significant input data, often only being required to click on the start button to commence the playback of some designer-determined sequence. This type of simulation could be aligned with simulations which Rose et al., (1998) label “inanimate simulations”. If the simulation is under-pinned by algorithms, it is often nothing more than an engine to drive the animation and as such is not predictive of real world outcomes. Further, the user is unable to influence the outcome to any significant degree. The outcomes are fixed with the simulation providing an ‘illustration’ of the process. While such illustrations can be useful in depicting an event, they are less educationally useful as they do not allow the user to make inferences regarding cause and effect relationships nor do they allow for the testing of hypotheses. Such simulations in their simplest forms are little more than animated sequences depicting a process.

Simulations belonging to the ‘Symbolic - Level 2’ category in the proposed taxonomy, (Figure 2.2) the author calls “Dynamic-Interactive simulations”.

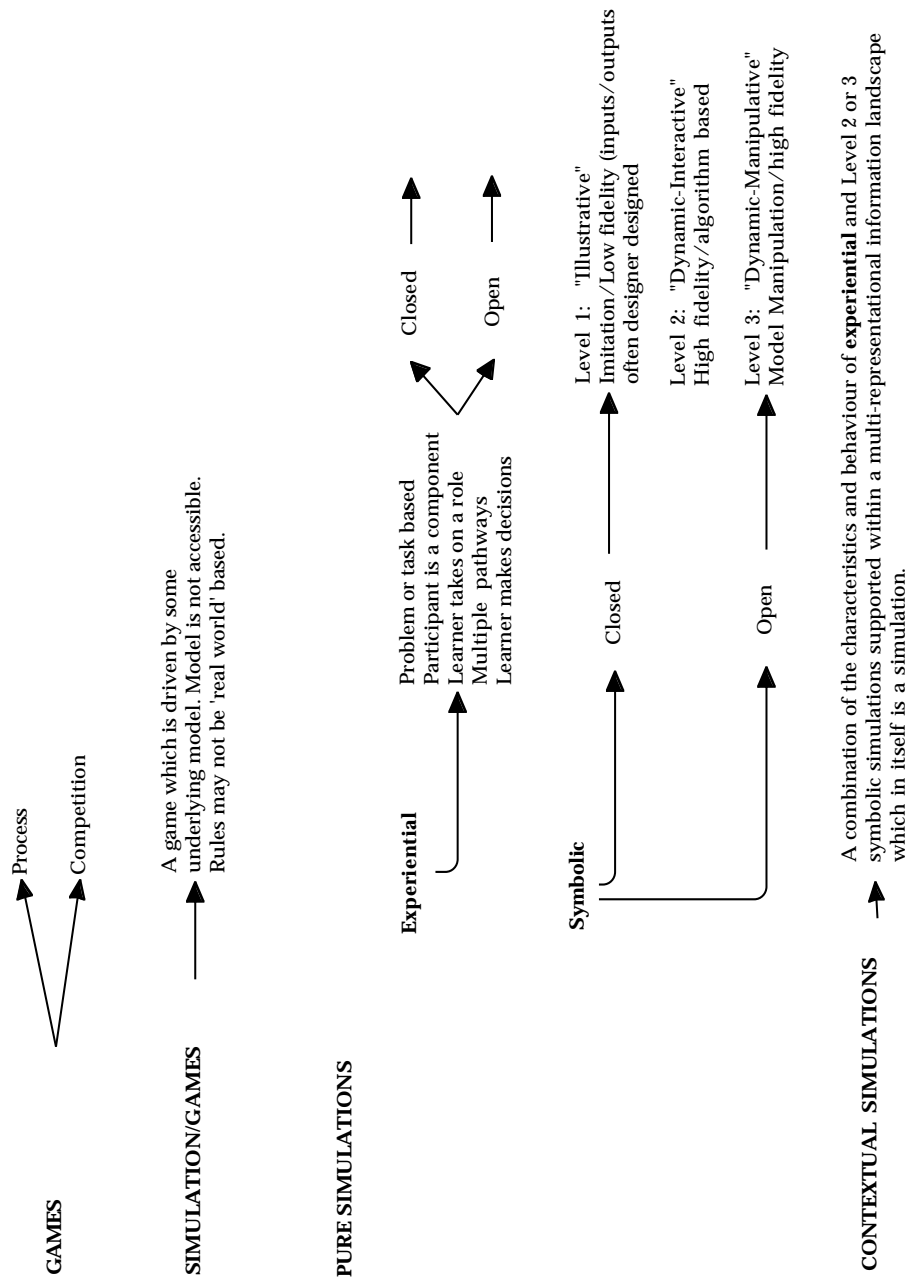


Fig 2.2: Proposed Taxonomy

Purely Dynamic-Interactive simulations are highly interactive. They could be aligned with simulations Rose et al., (1998) label as ‘live simulations’.

The user is able to fully manipulate inputs and receive and manipulate output in various forms from the system. More importantly, the users actions are reflected in the behaviour of the system, modifying the outcome and resulting in ‘custom solutions’. In its most powerful form, the algorithms are such that they provide a ‘high fidelity’ model that fully mimics the real world processes and can be fully predictive. User’s also receive feedback on their actions, thus allowing them to study cause and effect relationships and test hypotheses without risk in situations which may otherwise not be available for reasons of cost, safety and time. This type of model supports the development of understanding and the student’s mental models of the process in context, but may be less effective if used outside a real world context.

The issue of cost is extremely important on two levels. Firstly a consequence free environment is an integral component of the development and maintenance of user motivation to start or complete a task that may otherwise be perceived by the user as too difficult. This perception may have its origin in their low entry level knowledge or experience base or, perhaps simply self-esteem. They may also consider it too risky in terms of the possible outcomes and peer approval. Secondly, the real life process may in itself be too dangerous, costly or difficult to carry out so that the fear of the consequences or cost of failure would rule out the possibility of attempting it in real life.

The final level in the proposed taxonomy of symbolic simulations, ‘Level 3’, the author calls “Dynamic-Manipulative”. This type of simulation is discussed here because there is an increasing interest being shown in the educational value of allowing students to both build their own models of systems and be able to manipulate underlying models.

It is suggested by Alessi (2000) that an increasingly popular approach in constructivist educational environments is to allow the students to build and experiment with their own models based on their current mental models. This he asserts is becoming more easily achieved through the proliferation of System Dynamics software packages such as STELLA®, PowerSim®, Model It, iThink® and the like. It would seem logical that this should be the next direction taken in researching the use of simulations in

educational environments. However, care must be taken as there is ample evidence in the literature that supports the proposition that such an approach can only be effective with consideration of design in terms of the degree of model visibility and the incorporation of substantial student support. It must not become a model building exercise for the sake of model building.

Kurtz dos Santos, Thielo & Kleer (1997) in a study on students modelling environmental issues using VISQ, a tool that allows the creation of semi-quantitative models using the mathematics of neural networks to run causal diagrams on a computer screen, reported that students gained better understanding of the models they were constructing when the output was also presented in graphical form. They suggested that the students were able to engage in system level thinking; when they use variables with reasonable causal links in fully coherent models and; when, during model building, they ask for simultaneous graphs of variables, use graphic outputs to improve the model and relate the model to reality.

Simulations belonging to the proposed 'Level 2' provide an environment in which the user receives constant feedback that reflects their interactions with the system and a level of fidelity which places the user in a real context and brings the simulation to 'life'. Such attributes can promote learner engagement and in so doing support the active construction of knowledge by the student during the process of solving a problem. However, embedding such simulations within a multimedia environment that in itself simulates a broader context for the process being simulated and providing an interface that takes full advantage of the capabilities of such environments can provide unparalleled support for the user. Further, it is argued that these simulated environments have the potential to lead to improved educational outcomes, providing they are used in conjunction with appropriate teaching methods.

The relative value of the delivery mechanism vs. teaching method adopted in the learning process has long been under debated and simulations are no exception. Much of the literature, (Trow, 1963; Witt, 1968; Perkins & Leondar, 1977; Preston, 1994; Kozma, 1994 and Reiser, 1994) suggests that the delivery mechanism is in fact as important as the teaching methods adopted and in many cases facilitates the use of certain methods.

While many side with Kozma (1994), accepting that the delivery vehicle is as important as the teaching method, there are many who are convinced by Clark's (1994) argument that media will never influence learning. The author however takes the view along with Reiser (1994) and others, that the two must work together. The design of the system and teaching method adopted are critical to the outcome and cannot be separated. Further, it is argued that in fact, it is the delivery vehicle which in many cases enables and facilitates the use of particular methods.

The author proposes a new category, "Contextual Simulations" (Figure 2.2) and argues that the simulation tool used in this study falls into this new category. Although the simulation tool itself is clearly algorithmic in nature and 'Symbolic Level 2' in terms of the proposed taxonomy, its integration within a multi-representational landscape which in itself simulates a 'whole system' at a higher level has effectively created a new and more powerful simulation format. Alessi (2000) hints at this type of structure in referring to "simulations with Instructional Overlay". It combines the characteristics and behaviour of simulations that are termed experiential and algorithm driven, high fidelity Level 2 and 3 symbolic simulations. The 'component simulation' is established within the context of a second simulation representing a whole system. This format was hinted at by Reiber (1994) where he argued for a hybrid interactive learning environment that could be best described by the combination of the labels microworld, simulation and game. He suggested that these are usually considered as separate and distinct environments, however if the attributes of each were merged, educators would have "the foundation of interactive learning environments where structure and motivation are optimised without subverting personal discovery, exploration and ownership of knowledge" (Reiber, 1994).

It is claimed by the author that this has been achieved in *Exploring the Nardoo*. The whole environment with its problems to solve, rich resources set in the context of a real world problem, multiple representations of information and the ability of the user to role play at a simple level provides the experiential component while the algal bloom simulation along with several others that provide the dynamic-interactive simulation of key aspects of the underlying elements of the whole environment. Multimedia based learning

environments “provide significant affordances to enrich student learning” (Bagui, 1998) by providing multiple perspectives which lead ultimately, to a deeper understanding of relationships.

All these concerns acknowledged, the overriding purpose for simulation and modelling systems regardless of the delivery system remains, to provide a substitute experience for some real world environment and the ultimate aim of the developer must be to meet certain essential design criteria.

These include:

- Producing a simulation which entices the user to be an active learner in an environment which through high fidelity, emulates as closely as possible the real world experience.
- Ensuring that design decisions are based on some appropriate educational paradigm. It is argued that a constructivist approach with the broad principles of individuals building their own individual experiences, learning through the discovery of inconsistencies between their current knowledge representations and experience and, learning within a social context would seem to be an ideal basis for design in multimedia. With individuals forming their own representations of knowledge, it would seem appropriate that no single representation of knowledge should be presented as the correct one. Providing the ability to explore and test ones pre-existing understanding or mental pictures is essential to the process of re-evaluation of these mental models and the learning process that ensues. The power of modern technology to provide the vehicle to fix the experience within an authentic real world context.
- Ensuring that design decisions are made which are based on a sound knowledge of cognitive science theory. There are many examples of the use of the behaviourist approach to designing learning experiences. Designers need to be concerned with supporting the learner’s cognitive activity and mental model formation rather than the best way to elicit the desired response. This must be supported suggests Jonassen (1991), by a change of focus from reinforcing ‘correct’ responses in learning situations to transferring the ‘correct’ mental model to the learner.

The Contextual Simulation, a symbolic, algorithmic-based simulation tool embedded within a rich multi-representational information landscape that is the focus of this study is based on these premises.

2.1.3 Design Issues of algorithmic simulations

Most of the earlier literature on design methodology was more concerned with the mechanical issues such as interface design principles. Stanton & Baber (1992) provide a list of criteria that they consider are amongst the most important aspects to be considered in designing multimedia simulations:

- allow for different experience and knowledge entry levels;
- encourage active learner, exploration;
- allow the user to adapt the material to their own learning style and;
- provide an appropriate navigation system.

Petranek (1994) suggested that in designing simulations the simpler ones work best. This notion is certainly acceptable in terms of non-computer based systems but may not be an issue for computer-based simulation environments. Loveluck (1989) suggests that computer games and simulation technologies have not progressed conceptually since their first introduction. Progress to date has followed two main routes:

- to make equations more complex and;
- to make equations more realistic (increase the fidelity).

These two aims may be contradictory, the complexity not necessarily adding clarity and comprehension to the learning process. Hatzipanagos (1995) warns that the fidelity must not be considered in isolation of the complexity of the simulation. “Interaction between fidelity in the surface representation and complexity in the underlying model can affect the ease of learning from computer simulations” (Hatzipanagos, 1995). If this is the case, then it is essential that simulations be designed with more attention given to fitting them to learning theories.

In terms of overall design, the design and implementation of simulations can be viewed from three perspectives, and for each, one should be concerned with where the design philosophy sits in terms of the parameters that constitute good design, on the continuum between the two extremes.

The first of these perspectives concerns the technology vs. the educationally driven design process. Design based on technology constraints lies at one extreme and is the driving force behind many currently available packages. However, no matter how good the technology, the outcome cannot be educationally effective unless one takes design decisions with reference to the ideas and findings being presented from research in the field of cognitive science with respect to learning theories.

A second perspective concerns the pedagogical approach, with the Instructivist approach at one extreme and the Constructivist approach at the other. The third perspective concerns the degree of guidance needed in complex simulation environments. At one end of this axis is the total freedom non-guided approach, while at the other is the step by step, guided, instructor/designer interventionist approach. Many of the current papers concerned with what constitutes good design, fail to effectively examine these extreme perspectives. Examination of the literature representing various mixes of these perspectives provides unequivocal support for the notion that good design must embrace a carefully considered mix of all approaches, a balanced view. The literature would suggest that an 'ideal approach' might involve the combination of an educationally driven constructivist approach with a level of guidance appropriate to the needs of the individual users.

A recurring theme in the research literature is the need to take into account the physical structure of the software content and the associated navigational concerns, which arise from it. Beasley & Vila (1992) in a case study looking at navigational patterns in multimedia environments found that lower ability users generally needed a more structured linear environment in which to work. Such findings are not isolated. Nelson & Palumbo (1992) and Layman & Hall (1991) support the need to provide structure and guidance, at some level, in the increasingly complex non-linear multimedia environments being presented.

Jacques et al., (1993), Beasley et al., (1992) and Rieber (1994) all report that one of the major problems that arises in the use of simulations based in multimedia environments is the 'getting lost syndrome'. Each of these authors support the need for some degree of structuring and some degree of guidance, particularly in the early stages of the programs, until the users learn a little about how it works. Depending on the complexity of the system and the level of expertise, they may also require on-going support in the form of feedback in decision-making.

There is continuing debate on the aspects of linearity and guidance in relation to the design of all computer-based instruction including simulations. It is particularly important now because of the increased use of multimedia based delivery systems. The debate (Rieber 1994, Jacques et al., 1993, Small & Grabowski 1992), centres on the level of instruction that is provided and the degree of freedom. Whether one follows an approach of providing freedom to explore within an open information framework (non-linear) and, whether one provides support and guidance in whatever form, be it suggested starting pathways or perhaps directed problems, it is certain that complete alignment with one or other approach will bring disaster. This is particularly so if the guidance/non-guidance design issues are to be adequately resolved. The literature to date has strongly suggested that there needs to be a balance.

"Regardless of the amount of care and attention put into designing simulations and games, there always remain some elements of choice to affect the outcome" (Cryer, 1988), and many of these cannot be foreseen. Gredler (1990) lists design errors that occur most often in simulations in which the outcomes are determined by chance, that is completely unstructured and without instructor intervention as, inadvertent reinforcement for inappropriate behaviour or responses, lack of reinforcement for appropriate behaviour and the operation of the concept of 'negative utility', involving the reinforcement of an individual for a particular action which in the long term has punishing consequences for those same behaviours, (that is, the reinforcement of behaviours leading to ultimate defeat for some users).

Rose et al., (1998) state that simulations are powerful learning tools because they encourage exploration by allowing users to manipulate parameters and visualise results.

The connection between the dynamic representation of the underlying model and the visual representation as it runs is very important for the outcome. “Manipulating simulation design parameters is one way to help learners further explore how a system works”. Well-designed multimedia provides multifarious forms for presentation both in delivery and feedback. Some form of visual representation such as concept mapping is usually used as a presentation tool, but can also be used as a powerful problem solving tool. The outputs of the simulation tool described later in this study are examples of this.

Hazari (1992) suggests that although the benefits of multimedia platforms are well documented—

- easy access to sound, images, motion etc.,
- allows for the different entry-level experiences of users,
- facilitates “own pace” working,

the decision as to whether it is in fact the right platform must be made in conjunction with the designers ability to recognise its strengths and weaknesses and hence design so as to maximise the potential of the medium to “support ... *and maximise* ... the learning process and not hinder it” (Grabowski & Curtis, 1991).

From a constructivist viewpoint, the essential aspects to consider in designing effective learning environments were succinctly described by Cunningham, Duffy and Knuth (1993) in their seven pedagogical goals for designers of constructivist learning environments:

1. Provide experience with the knowledge construction process.
2. Provide experience in and appreciation for multiple perspectives.
3. Embed learning in realistic and relevant contexts.
4. Encourage ownership and voice in the learning process.
5. Embed learning in social experience.
6. Encourage the use of multiple modes of presentation.
7. Encourage self-awareness of the knowledge construction process.

Although these goals were later re-worked to provide a list of seven “metaphors we teach by” (Duffy & Cunningham, 1996) with the addition of a new element “learning is mediated by tools and signs”, they still provide a substantive guide to design, provided (as proposed by Harper & Hedberg, 1997) a re-assessment is made by designers of the instructional paradigms they are using.

The traditional recall and application of knowledge model must give way to a new taxonomy described by Jonassen & Tessmer (1996/7) that “elaborates structural and higher order cognitive, metacognitive and motivational learning outcomes that are not included in the currently used taxonomies of learning outcomes”

Harper & Hedberg (1997) provide a listing of key issues that they suggest must be embraced by designers of interactive multimedia learning environments. They include:

- **Information and Visual Design** – rich resource bases need to be carefully structured, involve multiple representation, provide content maps and support the learner through the use of cognitive tools (simulation tools), search engines and the like;
- **Access and navigation** – provide the user with a bounded information space and the tools with which to explore and investigate it being always mindful of the issues and implications for the cognitive load placed on the student working within the space;
- **Interactivity and Control** – encourage the user to become an active learner by forcing them to think before being able to respond to a situation, ensure that the experience is truly interactive in that communication between user and system is two-way and that the users interactions are reflected in the feedback from the system;
- **Motivation** – should be intrinsic rather than extrinsic, setting the learning within an authentic context so that the students initiate their own motivation to ‘find things out’ and,
- **Problem based learning as a framework** – provide ill-structured problems so that students have to identify and search for the information they need to progress in developing a solution to the problem, result in quality learning outcomes in that skills that centre on independent learners will be developed. However, this also means the degree of help provided must match the amount of ill-structuredness.

Jonassen (1998) uses the term ‘problem manipulation space’ in a discussion on using models to simulate real world tasks. He defines them (simulations) as causal models that provide the students with the opportunity to test the effects of their manipulation and receive feedback in various forms that reflects their interaction with the system. Among the design criteria essential for such simulations he suggests that:

- they should be manipulable;
- they should be sensitive, responding in a realistic way to the learner’s manipulation;
- they should be realistic, having a high fidelity of simulation and,
- they should be informative, providing contextualised feedback.

In terms of these criteria, several key areas of consideration emerge.

Navigation

Navigational aspects are considered by all to be crucial to good design. Stanton & Baber (1992) propose an appropriate navigation system should have the following basic characteristics:

- simple and easy to use and;
- intuitive and based on everyday experience.

Research indicates that one of the major obstacles to success for all users remains the fear and reality of getting lost in hypermedia environments. An appropriate navigation system is one that will minimise this. It should be simple and easy to use so that there is not an undue increased demand on cognitive processing capacity and it should be intuitive and based on everyday experience. Rieber (1994) claimed that a key feature of a useful navigation system is that it must ensure and support effective and meaningful interaction. It should be apparent to the user what pathways need to be taken or what actions are needed to achieve their goals. Simple navigational functionality works well and does not add to the cognitive effort.

Maps of various kinds are increasingly being used by designers as a standard basis of navigation systems. Although maps often can provide excellent navigational assistance and reduce the overhead in terms of needing to think about moving around within the environment, Stanton & Baber (1992) warn that without care they may increase

the cognitive load on the user or reduce the users need to be cognitively active thus having a negative effect.

Motivation

Motivating the user to engage in a task is a critical factor in the ultimate success or effectiveness of an educational experience. “Fundamental to the entire field of cognition ... *and learning* ... is the finding that unless people engage a task, they will not learn from it” (Ambron & Hooper 1988). However, it is not only the ‘engagement step’ that is important, but also, the level and depth of engagement that controls the outcome of the educational experience.

Small & Grabowski (1992) provide supportive findings in their research into the increased use of hypermedia based systems which do not provide any guidance and the factors which are critical to the success of the user in such environments. Motivation is one such critical factor and is only supported when the designer builds environments, which support interest, and self esteem. The user must also perceive that what is being presented, is important. Wenzler & Chartier (1999) in the context of simulations and games in organisational contexts assert that simulations help users to develop symbolic thinking which they define as the ability to identify the critical elements of a complex problem and then be able to relate it to the situation as a whole, but perhaps most importantly, they develop the user’s motivation and confidence to act.

Engagement and Interactivity

Interactive multimedia provides an attractive delivery system which incorporates both the complexity and sophistication necessary to support dynamic real world based mathematical models and, the versatility to present these models as convincing real world experiences while at the same time providing the high degree of measured freedom and manipulation needed by the users to convincingly construct their understanding and knowledge from such real world substitute experiences.

The proposition that for learners to gain the most from learning environments they need to be active in the learning environment, not just “acceptors of information” is a key consideration in design. (Li, 1993).

Bork (1984) suggested that in many educational situations, the students have lost the ability to be creative and active learners, willing to engage in the experience. Further he suggested that, in correctly developed and designed software environments, whatever the instrumentation involved, there should be a mechanism by which the software can return the active mode to the student.

The issue of interactivity and its importance was broached earlier in this chapter. Sims, in a series of papers, examines the issue of interactivity and design. In defining interactivity he states that it involves “those functions and/or operations made available to the learner to enable them to work with content material presented in a computer based environment” (Sims, 2000). He suggests that interactivity is often rated as a crucial element of the new technologies but there is still much to understand about how interactivity per se adds value to computer-based learning (Sims, 1998).

Aldrich et al., (1998) categorises interactivity in what may be considered more ‘traditional’ terms.

- Visibility and accessibility – visualise content in different formats and access it in different ways
- Manipulation and annotatability – construct content
- Creativity and combinability – create new content and combine media and;
- Experimentation and testing – run simulations and building/modifying models.

In a paper dealing with the relationship between the independent learner and computer based learning resources, Sims (1999) suggests that interactivity in the context of computer-based learning is best described in terms of the level of learner control, adaptation and communication and participation. Further, he proposes that a greater understanding of the function and role of interactivity may be achieved by considering the learner as an actor within a digital performance space (the learning environment) “integrated, engaged and achieving in a computer based environment” ... taking part in a “narrative” or role play. In terms of achieving learner-centred environments, Li (1993) asserts that it is not until learners; teachers and designers engage in the roles they play, that a true learner-centred environment becomes possible.

Interactivity implies dialogue. Feedback asserts the author, must be considered an essential component of interactivity. There must be a two-way dialogue involving feedback if an environment is to be truly interactive. A significant number of the so called interactive systems in use today, do not provide any form of useful feedback and give the user only nominal input, while others provide limited feedback and greater freedom of input and control. Ring, Ellis, & Reeves (1994) assert that, if it is to provide any educational value, interactivity must involve an exchange of information, responses and appropriate feedback, and suggested Land & Hannafin (1996) this feedback must reflect the impact and changes within the system resulting from the interaction. La Follette (1993) supports the notion that interactivity is critical to the learning process as it mirrors the real life process of learning

To be truly interactive, in terms of Sims definition (Sims 2000), the user must be able to interact with the software in a manner not unlike the interaction which is possible and is experienced in a real world environment. To achieve this the interaction must be reflected not only in the consequent behaviour of the learning environment but also in the possible future interactions available to the user. If one accepts this notion, truly interactive computer software is not as common as one might surmise.

The design goal for true interactivity must be to approach a one on one dialogue between the computer and the user, with continuous feedback on actions and their consequences, a real world replacement. Perhaps the ultimate simulation will be based in a virtual reality, cyberspace environment, a microworld in which the user is able to fully interact with a system which models all the processes, experiences and actions of the real world, a notion alluded to by Russo (1994) and again more recently by Bielecki (2000), stating that “virtual reality is a perfect simulation”. This level of interactivity Sims (1994) categorises, situate interactivity (level 7), a combination of all 6 of the lower levels into “a virtual training environment” and Hedberg & Sims (2001) classify as engagement at the “sympathic encounters” level.

Learner control

Leyland (1996) suggested that for a simulation to be an effective learning tool, control must be allowed to reside with the user. This will act as a motivating agent and

result in the user becoming fully immersed in the system. The user must also feel that they have ownership of the process/outcomes. This can only be achieved by feedback that is responsive to the users interactions with the system and reflects the effects on the system of that interaction.

Designers need to provide appropriate levels of learner control to ensure that interactive environments are realistic and relevant to learning and until this is achieved, interactivity will rarely be anything more than “clicking a mouse and non-adaptive feedback” (Sims, 1997). Arnone & Grabowski (1993) note that learner control is extremely important as a design issue. They suggest that it should be conceptualised as a continuum. At one extreme is the situation in which there is no learner control, the structure is linear and directed and the result is that there is little opportunity for exploration or choices.

At the other extreme is the situation where there is a high level of learner control, providing many chances for exploration and self-direction. Although this would be a desirable goal for simulations, research shows that it is more efficient in terms of learning with the inclusion of some level of guidance and support. Arnone & Grabowski (1993) propose that designers should be aiming for a high level of “learner control with advisement” as the goal, a design aim voiced by others including Williams (1993) and Simsek (1993). Williams (1993) points out that there is a strong connection between both ability of students and preferred learning styles in regard to success in making decisions in a learner controlled environment. However this research is based on constrained environments, limiting learner outcomes.

La Follette (1993) supports the notion that learner control is an important issue and that some type of “coaching” or direction is critical to ensuring success for all users. Hannafin & Land (1997) also support the importance of students assuming a greater responsibility for their learning in open ended learning environments and suggest that this enriches their understanding and gives them greater control over the learning process. They also suggest that some level of guidance to help students make effective choices using techniques such as model building and testing and experimentation with immediate feedback is necessary to capitalise on the student centred approach in design.

Fidelity and Complexity

While it is argued that the level of fidelity must be sufficient so as to provide realism and meaningful experiences if the simulation is to motivate the learner to engage in the learning experience, it has been suggested that high fidelity may in the right circumstances prove counter-productive. Trollip (2000) warns of unfavorable interactions that may manifest themselves between the level of fidelity and the status of the learner on the novice-expert scale. A novice can be easily overwhelmed by too much detail, finding it difficult to assimilate the experience and hence ultimately having a poorer outcome from the experience than would otherwise be expected. Hatzipanagos (1995) supports this notion and suggests that the complexity of the underlying model can be a major factor in thwarting the learning process while using simulations. He proposes a strategy of replacing certain parts of complex simulations with simplified representations of parts of the underlying model (Symbolic - Level 1 simulations as proposed and defined earlier in this thesis), so as to minimise problems without compromising the fidelity.

Degree of Model Visibility

Closely associated with the issue of complexity is the degree to which the underlying model is transparent or opaque to the user. Alessi (2000) states that this will ultimately depend on the instructional philosophy adopted, be it 'discovery' (Constructivist) or 'expository' (Instructivist). However, Alessi suggests that in most current educational simulation software the design philosophy lies somewhere between the two, with due consideration to the nature of specific instructional objectives. In support of the strategy for reducing complexity proposed by Hatzipanagos (1995) and outlined in the previous section, Alessi states that in order to achieve desired outcomes it may be legitimate to have some parts of the model more visible than other and that the degree of visibility may change depending perhaps on the learners progress.

Feedback

The process of knowledge acquisition can be improved by designing simulations that support hypothesis formation and problem solving techniques and thus encourage the user to actively engage and explore the knowledge domain. This can only be supported in an environment that has a feedback component. The issue of quick feedback is a critical

aspect with regard to strategies designed to help the development of cognitive processes in students. Guttormsen Schar et al., (1999) note that there is common agreement that rapid feedback is beneficial only if the computing power makes it possible. Providing the system can support it, continuous, rapid feedback induces an implicit learning mode (deep learning) while discontinuous feedback induces an explicit learning mode.

As pointed out by Ohlsson (1987), computers have the potential to carry out moment-by-moment monitoring of the user. This allows for the continuous adaptation of content and representation to meet the changing cognitive needs of the individuals. It was suggested by Salomon (1981) that this is a most important aspect in the learning process. Such functioning is normally found in the more sophisticated systems, the intelligent tutors and expert systems, although monitoring of progress and the production of some form of record of the student's progress through a system is not beyond the capabilities of a well-built simulation/modelling environment.

McCowan, Driscoll & Roop (1996) make the statement that within student centred learning environments, feedback is essential to their success. To be effective in the learning process Land & Hannafin (1996) suggest that feedback must involve more than simple confirmation of accuracy of a response by the user. It must be the systems response to the learner's action, including manipulation of tools and it should take on varied forms. This will provide the student with a means to re-evaluate their beliefs and mental models through the exploration of alternative explanations.

Jackson, Stratford, Krajcik & Soloway (1994) assert that direct manipulation of variables using meters, dials and the like during a simulations run, affords the opportunity for the user to make the link between their cognitions and the model. The instant visual feedback from the meters and dials also allows them to evaluate their models with expectations providing a highly efficient and motivating way of exploring the process.

Ruiz, Gil and Corbo (1989) developed a program in BASIC designed to simulate the growth of micro-organisms. The simulation is simple and uncomplicated, providing an ongoing measurement of such pertinent parameters as, Glucose levels, temperature and pH among others. Of particular interest in this paper is the information relating to the educational evaluation of the simulation. The rapid feedback of results of the process

being simulated faithfully reflected the reality of the situation and according to the students was a contributing factor to a high achievement of the educational objectives for the experience.

2.1.4 Summary

Simulations have been variously defined as:

- a system that simulates or models reality, (Reiber, 1994);
- mathematical models that depict natural events and processes, (Ellington et al., 1981)
- powerful substitute training environments for real world events, (Shirts 1992, McAteer, 199 and, Tonks & Armitage 1997);
- the dynamic execution or manipulation of a model of a real world process, (Thatcher & Robinson, 1990);
- exploratory tools that support real world activities, (Bliss & Ogborn, 1989);
- environments in which designers seek to provide realistic representations of real world experiences, (Edwards & Holland, 1992) and,
- cognitive tools that support learners in their development and testing of mental models in a safe, risk free environment. (Jonassen & Reeves, 1996)

Analysis of the literature has resulted in a list of defining characteristics for simulations. Essentially they can;

- permit the study of processes, events or phenomena that could not otherwise be accessed by students using a problem based scenario;
- provide a safe, risk free environment in which a student may experiment with solutions to the problem;
- afford the student a chance of applying skills in unfamiliar environments without serious consequences;
- provide students with the facility to practice skills in advance to encountering the real world scenario;
- provide a range of realistic consequences based on the users interactions;

- provide an opportunity for the user to interact with the system at different levels which may include the ability to alter the underlying algorithm;
- provide feedback via change in the behaviour of the model which reflects the users on-going interaction;
- support guidance when needed or requested and;
- facilitate opportunity to revisit and revise.

2.2 Simulations in Educational Settings

The literature presented in this section represents a cross section of that dealing with the expected benefits and outcomes simulations can have when employed in educational settings from a theoretical standpoint. Literature based in a pure research perspective has been blended with the theoretical perspective to illustrate, support or clarify the arguments where appropriate. A separate section dealing with specific simulation studies that add clarity to the issues has also been included later in this chapter (2.2.7).

“The theoretical foundations for simulations, games and other forms of interactive, experience-based learning has been in place at least since the writings of Aristotle and the practices of Socrates, re-framed and popularised in the period in the works of ... and many others” (Ruben 1999).

The value of simulation packages in educational settings has been recognised for some time by researchers. Lebowitz (1986) referred to the instruction method as “explanation-based learning”. Nickerson (1988) and Silver (1987), indicated its value as “relating everyday learning to real world based problems”, a notion also supported by Pea (1987). Information technologies used in education have for many years been restricted to the storage and manipulation of data and facts based in the “computer control mode” (Preston 1994). Studies have shown that there is a slow but growing movement towards the idea that the computer can support more than mere data storage and manipulation providing a vehicle for those interested in learning how to learn.

In designing educational software, be it simulation, game or other, and regardless of the intended audience or the level of sophistication one wishes to build in, a paramount concern must always be whether the software is educationally sound, that is, is it

structured so as to take into consideration the accepted principles of education and learning. “The use of media in education implicitly assumes that each medium ... (be it a simple computer terminal, a CD-ROM system, a video disc) or any other of the multimedia instrumentation commonly in use today ... entails some particular, even unique, attributes that matter or can be made to matter in ... (the learning) ... situation.” (Salomon, 1979).

Salomon also suggests that the objective for use of any form of (interactive multimedia based software) in the educative process should be centred on identifying these ‘unique’ attributes and exploiting them to the full in conjunction with the theories of learning. Whether such unique properties exist or contribute to the educative process in special ways is a point of conjecture throughout the literature, however, the consensus of opinion seems to be that the essential aspect of the use of interactive multimedia based systems in education should be concerned with the fitting of such systems to the theories of cognition and learning, rather than designing and developing systems for the technologies sake.

DeCorte (1990) asserts that the new information technologies can only contribute substantially to the improvement of schooling if they are appropriately embedded in powerful learning environments. It is the multifarious nature with respect to delivery and feedback, which provides multimedia with an attractiveness to the developer of complex educational environments. Gagne & Glaser (1987) suggest that we should not be interested in ‘What’ when designing and implementing instructional systems, be they computer or other, but ‘How’!

“The most general dimension in the educational use of computer simulation is whether one learns by building simulations or by using existing simulations” (Alessi, 2000). While allowing students to build their own models is the ‘norm’ in the field of System Dynamics, most educational simulations asserts Alessi (2000), are currently based on the alternative approach, providing a simulation in which the students can explore, experiment and practice. It is argued by Alessi (2000), Lehrer et al., (1994) and others that the building of models is an essential part of learning about systems (models) per se. Whether the value of doing this is outweighed by the increased complexity this imprints

on the learning environment, the cognitive effort it adds for the user and the possible negative impact this may have on the learning outcomes, needs further research.

Lehrer et al., (1994) asserts that for students to work successfully in model building learning environments, they need to develop a new type of reasoning ability, “model-based reasoning”. Development of this skill is slow and only emerges with proper contextual and social support. Hannafin & Land (1997) in discussing the foundations and assumptions of technology-enhanced student-centred learning environments state that model building and simulation should go hand in hand as the model building supports the learners in formulating intuitions or mental models and the simulation affords them the opportunity to refine these through experience. Pilkington & Parker-Jones (1996) suggest that the way to gain the most benefit from using simulation tools may actually be to be involved in building the model, a notion supported by Alessi (2000) and outlined earlier in this chapter. It must be stressed however, that care must be taken, as the evidence in the literature would suggest, that such an approach can only be effective with substantial student support.

It could be argued however that if the simulations match real world experiences sufficiently well, both these processes (learning from using and building models) could be managed at the simulation level, without the need to actually build models. A simulation, which is sufficiently flexible, has the right level of transparency and is based in a supported context, will allow users to test their hunches or mental models ‘on the fly’ and gain an understanding of both the processes at work and the underlying relationships.

Jacques et al., (1993) state that “understanding design practices will provide feedback on the learning potential and method of achievement.” They assert that the quality of the outcomes and learning by individuals operating within simulations based in multimedia delivery systems is essentially determined by two factors:

- the knowledge entry level of the user in as much as it must be sufficient to support the acquisition of new knowledge, and;
- the degree to which the learner interacts with, or is forced to interact with the knowledge presented in a meaningful way.

With most educational software in use today incorporating simulations in some form, usually as pre-built models, it is essential that they be structured so as to minimise any negative impact the lack of opportunity to build and modify the model might bring. It is argued that provided these simulations are of the type described elsewhere in this chapter, namely Contextual Simulations, the students have the opportunity to gain from their use. Given the direction of current research, it would seem logical that perhaps the next phase in design will be to follow a hybrid approach.

2.2.1 Educational Criteria

Educationally based criteria considered important for the design of effective software including simulations have been enumerated by many authors, however those outlined below represent the more important considerations.

- a) Each learner is unique and hence allowance must be made for differences in ability and speed of working. Obviously one must consider the plethora of physical and cognitive differences encountered in individuals (Ohlsson, 1987).
- b) Appropriate and clear presentation of information. Perception is the foundation of learning. Every individual operates at different levels of symbolic perception or processing and since symbolics are very important in many of the delivery systems used to design and present software today, this becomes an important issue.
- c) The concerns of effective design and the minimisation of cognitive load and effective navigation systems. The concerns over cognitive load have been voiced by a number of researchers including more recently Bagui (1998), Jonassen (1998), Lajoie (1993) and Standen & Herrington (1997).

Ring, et al. (1994) asserted that learners must cope with and integrate three types of demand ...

“the content”

“the structure of the system”

“the response strategies available” or how they are manipulated”.

Tucker (1990), likens navigation through a piece of software, with that of navigation at sea and suggests that after many years of being “channelled into fixed patterns of interaction with the computer through both limitations of both the available programs and the imagination of those writing them, we are once again ... inviting the user ... to set sail... in open “uncharted seas” in whatever direction takes their fancy.”

d) Stimulation of interest. The learner must become involved (motivated). “The interactive nature of the delivery system being used ... (should be such that it will) ... encourage active involvement of users, and hence enhance learning” (Hooper, 1988).

e) The content must be suitable, both in terms of the curriculum and the user.

f) Appropriate teaching strategies must be taken into account when preparing the software. This need has been recognised since the early days of educational software development. Leith (1972) asserted that it is a paramount consideration in software design. Dalgarno (1996) and others assert that there has been a shift from a behaviourist approach with emphasis on learning through repetition to a cognitivist approach (embodied in constructivism) where the emphasis is centred on developing and using higher order cognitive processes to develop and test mental models rather than being concerned with the best way to elicit a desired response to a problem.

g) Creativity should be the goal of learning. “The issues of creativity and high technology will ... become increasingly interwoven ... more and more, questions of purpose and relationship, come into the context of creativity” (Hoffman, 1990).

h) Creation of meaningful contexts by the designers. Choi & Hannafin (1995). “Knowledge is most meaningful when rooted in relevant, scaffolded contexts” Hannafin & Land (1997).

i) Provide scaffolding for the development of higher order cognitive skills through the use of reinforcement and feedback, which may then be further, enriched by offering alternative representations. (Quinn, 2000; Harper et al., 2000)

Sprague (1999) takes a novel approach to stating the educational value of simulations by listing 10 hunches, based on the experiences of students and instructors. They include:

1. Simulations are motivators, they can generate enthusiasm or commitment.
2. Simulation experience leads students to more sophisticated and relevant inquiry. Perhaps the value comes from the comparison by the students with their model and the real world that is the value they derive in testing and modifying their own mental models. The greatest learning may come about when the students build their own models. This aspect will form the basis for further research in the area of using simulations in educational settings.
3. Simulation experience helps them integrate ideas and information they already have.
4. Allows learners to test and modify existing ideas or mental models.
5. Participants learn skills, decision-making, and communication.
6. Simulations affect attitudes. Users gain empathy for real-life decision-makers, gain a feeling of being able to affect a situation. They gain a sense of ownership.
7. Simulations provide participants with explicit, experiential, gut-level referents about ideas and concepts.
8. Simulations may act as a retrieval device to bring existing knowledge to consciousness.
9. Simulations provide support in learning about the intrinsic relationship within a system.
10. The main importance of simulations may lie in their effect on the social setting in which learning takes place and this will impact on the quality of learning outcomes. Simulations may have a role in personal growth through the high degree of involvement.

It is interesting to compare these with the *educational needs for simulations* based in educational research suggested by Jonassen & Tessmer (1996/97) They stated that among other things, simulations need to be engaging, encourage interaction, facilitate exploration and provide an environment in which learners can test what they have learned.

In comparing the theorists approach with the list of hunches based on training in business environments there is a marked correlation given that in such environments the emphasis on simulation function is to demonstrate events rather than to explore and investigate processes and relationships. Reeves (1992) proposes a similar listing in what he terms “effective dimensions of interactive learning systems” and also includes such considerations as instructional sequencing, the value of errors and the role of the instructor.

Several themes emerge from the literature providing a framework for discussing the issues for simulations in educational settings. They include:

- Engagement, motivation and challenge.
- Supporting learners in developing their understanding of the process – encompassing the issues of visualisation, mental models, multiple representation.
- Providing an environment/mechanism for testing the efficacy of these models – encompassing the issues of authenticity/fidelity of task/setting, interactivity and feedback.
- Providing a community of practice in which they are supported in constructing their knowledge – encompassing the issues of novice/expert modelling, measured freedom to explore.
- Matching technology to educational theory.

2.2.2 Engagement, motivation and challenge.

A recurring theme in the literature seems to be that the major strength of computer-based instructional technologies, including simulations, rests in its ability to provide motivation, enrichment and elaboration. Chanlin & Reeves (1994) make the observation that well designed computer based interactive learning systems which incorporate different media engage learners in more dynamic ways and provide high levels of motivation for most learners. Using media rich environments has the potential to motivate students to “interact more directly and voluntarily” with the information presented.

Educationalist and designers alike recognise the need to engage the student in a meaningful task. Rieber (1994) and Stanton & Baber (1992) emphasise the need for learning to be an active process. “Hypermedia has the ability to provide a new freedom in the learning process” (Stanton & Baber, 1992). Spada et al., (1989) suggest that a common goal for all designers and developers is the need to provide environments that support hypothesis formation and encourage the users to examine their strategies, to think and take an active part in their knowledge construction. Researchers in this field are not certain of, nor agreed upon, how active the learner needs to be to achieve the best outcomes, the instructivist approach versus the constructivist approach.

In discussing how games are useful in the classroom Schwartzman (1997) proposed that they are motivational by virtue of the fact that students see what they are doing as play, rather than work and so are more likely to immerse and complete the task. Simulations to be useful need to do the same and not simply be an animation (Symbolic Level 1) of some process but rather real world based user modified experiences (Contextual) set in authentic situations with authentic tasks and outcomes.

2.2.3 Learners building models of the world.

Simulations, which incorporate a higher order of interactivity, beyond mere clickability, have the potential to be much more than exploratory tools as defined by Bliss & Ogborn (1989). They may facilitate, scaffold and support students in the formation, testing and modification of their intuitive understandings, mental models of processes and concepts they are studying. Simulations provide a means for students to construct meaning “by actively and selectively working through a variety of information sources, a process which mimics real-world learning and enhances higher order learning outcomes that is, understanding and making ...(sense of) ... relationships” (Standen & Herrington, 1997).

Quinn (2000) supports the proposition that simulations are scaffolds for learners, allowing them to make mistakes, and test the efficacy of their mental models before they carry out an experiment on expensive equipment. Wenzler & Chartier (1999) in the context of simulations and games in organisational contexts assert that simulations help

users to develop symbolic thinking among other things, but perhaps most importantly, they develop the user's motivation and confidence to act.

Mandinach & Cline (1994) suggest that modelling both in our heads and on paper or computer is an essential part of the learning process for all. The process is part of the natural learning process. The utilisation of the computer, particularly in regard to simulation is that it has provided us with a tool to learn about and understand much more complex systems. Computer based simulations allow us to explore and quantify ideas, investigate their consequences and validity and make decisions.

Modelling tools such as simulations provide a mechanism by which students are afforded the opportunity to act and become immersed in a risk free real situated process, manipulating it and creating mental models and visualising processes and relationships that may then be tested and modified and tested again. This type of environment "enables the learner to ground their cognitive understanding in their action in a situation" (Laurillard 1996).

The most obvious contribution simulations make to supporting learning assert Pilkington & Parker-Jones (1996), is that in providing students with the ability to manipulate objects or variables and observe the effect, "visualisation (internal cognitive manipulation), becomes easier and, through visualisation, abstract reasoning in the domain becomes possible".

Rieber (1994) suggested that the aspect of visualisation is important in that its use provides both a powerful tool for delivery and a powerful adjunct to the problem solving process. It has been argued that computers can make a unique contribution to learning by providing a platform that allows learners to create visual representations of complex concepts and relationships. The power of the computer has facilitated the development of new tools, visualisation tools, that allow us to reason visually and represent ideas visually. One might surmise that the success and strength of multimedia based educational environments lies in a strong emphasis on visualisation and the incorporation of such tools. Much of our everyday, real world based communication has its basis if not its origins in visual representation.

Complex learning requires students to build a mental representation of what they are studying (Jonassen and Carr, 2000). All students develop mental models of varying degrees of complexity based on their experiences. Well-designed simulations have the capability of allowing students to build, test and rebuild their models without risk. They may test their existing models over and over again or they may have access to experiences which they may never normally have access to, thus having the opportunity to think about the processes and build up a mental picture of what is happening.

Hannafin & Land (1997) assert that simulating, model building supports learners in formulating intuitions or mental models. If they are then able to test these intuitions they are able to refine and deepen their understanding through the experience. Gredler (1996) noted simulations have the potential to support students in both the development and refining of the mental models they build to understand complex processes and their development of strategies for problem solving. They can provide the testing ground for the efficacy of their models in explaining events and predicting events, and a vehicle for exploration of 'what if' scenarios. The result will be a deeper understanding of the process. Lehrer, Horvath & Schauble (1994) assert that model-based reasoning of the sort that is developed during the use of simulations or the building or modification of the models is a capability that emerges slowly and then only with appropriate contextual and social support.

Novice learners require examples on which to base their development of mental models as they lack the experiences of the real world. This is often achieved by providing a set of related experiences, which the students may learn from. The alternative may be to provide them with a substitute world that provides them with the experience that may otherwise take a lifetime to acquire without risk.

Current research focuses on the value of allowing the students to build the models or modify models with which they have been given to work with. Mindtools such as simulations are "knowledge construction tools that learners learn with, not from" (Jonassen & Carr, 2000). "A critical characteristic of meaningful learning is mindful activity" (Jonassen, 1998). As mentioned earlier, there are a number of commercial systems available to do this including: STELLA®, PowerSim™, and Model It.

To be active the learners must be able to manipulate something, construct a product or affect the environment in some way. According to Jonassen & Carr (2000), using modelling tools to build simulations allow learners to:

- Design and run elaborate models quickly.
- Develop important thinking and imaging skills.
- Represent their knowledge as complex semantic and quantitative models of reality.
- Test and revise their mental models.

The simulation tool in *Exploring the Nardoo* is designed to provide this opportunity and support learners during the process of solving problems associated with algal blooms.

It could be argued that Mindtools are simply a ‘species’ of the broader scaffolding tools, *cognitive tools*, which support learners in developing and using higher order cognitive skills. The concept of *cognitive tools* in the sense of a tool that can assist learners in accomplishing cognitive tasks has been described in the literature since writers such as Pea (1985) proposed the term *cognitive technologies*. Similarly, Jonassen and Reeves (1996) describe *cognitive tools* as technologies that may enhance the cognitive powers of human beings during thinking, problem solving and learning. There are a number of commercially available software based tools with varying degrees of user manipulability and he has used the term *Mindtools* as an umbrella term to categorise them.

Jonassen and Reeves (1996) suggest that cognitive tools are best used as reflection tools that amplify, extend, and even reorganise human mental powers, helping learners construct their own realities and complete challenging tasks. Lajoie (1993) asserted that cognitive tools can assist learners when they;

- support cognitive and metacognitive processes,
- share the cognitive load by providing support for lower level cognitive skills so that (cognitive) resources are left over for higher order thinking skills,
- provide the learner with the opportunity to engage in cognitive activities that would be otherwise out of reach and,
- provide learners with the facility to generate and test hypotheses in the context of problem solving.

2.2.4 Providing an environment/mechanism for testing the efficacy of these models

The most satisfying learning outcome is achieved in simulations/gaming when what is being looked for is not made clear in advance. Bredemeier & Greenblat (1981). An essential function of good simulations is to provide a system in which what is learned is controlled by variables which are to a degree, outside the users control, that is there is some level of instructor/designer intervention. Some of the variables that seem to affect the outcomes of simulations include the way the system is run and other procedural variables and the internal structure of the simulation that may be the major source of variation in experiences.

The need for the content to be real world based is particularly important if the “participants are to learn the *right things*” (Bredemeier & Greenblat, 1981). Gredler (1990) makes the assertion that deep structures exist within simulations and games, which involve the interactions between the user and the system itself as well as between the users. This latter point has been supported by much of the current research studies that there is great learning value in group interaction such as the collaborative development of a solutions to a problem and group reflection on feedback and experiences. (Larkin 1983, Fletcher 1985, Bell & Scott 1985, Lane & Lane 1986, Resnick 1987, Vockell 1990 and Watson 1991).

Kozma (1991), suggested that the computer has the capacity to create “dynamic symbolic representations of non-concrete, formal constructs ... *and is able to* ... proceduralise the relationships between these objects ... and ... manipulate these representations ...”. Teachers, researchers and indeed, the learners themselves, (from discussions between the author and a variety of high school students), have confirmed the notion held by many researchers including Choi & Gennaro (1987), that good simulations are at least as good as “hands on” experiences. Berryman (1998) suggests that effective learning occurs when the experience is “a situated, authentic activity which synchronises learning and doing.” Further, the “Context is critical for understanding and thus for learning.”

Well-designed simulations are able to place the user in a position where they are required to interact and respond to situations by “executing serious responsibilities”

mirroring the real world requirement (Gredler, 1996). This has been termed as the ability of the simulation to provide reality of function or “fidelity of representation” (Hedberg et al., 1994). It could be argued that such simulations represent a form of ‘role play’ in that, the learner in executing these responsibilities, which are modelled on a real world, is taking on the role of the real world operator.

Simulations or “problem manipulation spaces” (Jonassen, 1998) when well designed are a special type of exploratory tool capable of supporting students in solving problems and developing their own understanding of how things work, they are in fact cognitive tools. They provide the student with the facility to explore the problem in a real world context, manipulate and make decisions, experiment and immediately see the results and test their mental models against ‘a reality’. They have the potential to afford the novice an expert’s knowledge base.

2.2.5 Providing a community of practice in which they are supported in constructing their knowledge

In the real world students operate in learning environments where they are supported by experts who model aspects of learning, both context specific and non-specific. These experts may be teachers, content specific persons, their peers or the general community. Students are not experts and do not innately possess the strategies employed by experts in solving problems and making decisions. They require some form of scaffolding/support while they learn how experts operate and they need a consequence neutral environment in which to develop and practice the skills of an expert.

In considering the development of expertise or competence a number of aspects need to be addressed. There is a need to develop expertise in students working in computer driven educational environments in particular, which stems partly from the fact that in most cases, such environments have been developed by experts and as such, are inherently structured around the *modus operandi* of the expert.

The development of expertise requires the acquisition of better-organised knowledge. In instructional environments such as simulations, there is therefore a need to provide structuring that ensure students, particularly those who are field dependent, the

non experts or novices, are led more quickly and efficiently to the kind of organisational levels that experts exhibit. Coupled with this is the further complication that arises from the fact that experts store information in bigger chunks of a more general nature which requires a greater level of reasoning in its application, thus operating in the expert mode imposes a greater cognitive load on the student. There are many references to the inhibitive effect this can have on the learning process.

Jackson, et al., (1994) suggest that well designed simulations could form a bridge between the novice learner's understanding and the experts understanding and practices while at the same time coupling the learner's mental model with "testing actions and model feedback".

Spada et al., (1993) maintain that computer-based simulations can provide environments in which this can be achieved. Wishart (1990) outlines the importance of producing simulations in which the user is in control. It appears that being in control of the action is one of the most important aspect to be considered when examining the learning that takes place when using simulations. This assertion by Wishart (1990), seems on the surface to be at odds with Bredemeier & Greenblat (1981), however the author feels that they are concerned with internal operational variables in their paper.

Wishart (1990) states "... Players pay little attention if they have no choice to make ... and ... even less if they have no picture to look at". Loveluck (1989) proposes that designers should structure simulations so that the user may switch at any time during the simulation, to a graphic display of the current 'state of play'. The essential contribution of this to the effectiveness of a simulation would seem to lie in the aid it provides in the making of further decisions based on this feedback.

Roth (1990), Schoenfeld (1987), and Yazdani (1987) among others, suggest that all meaningful learning requires the acquisition of declarative knowledge, (new knowledge which forms a basis for problem solving), procedural knowledge, (rules and procedures to follow in solving problems), and self knowledge, (higher-order cognitive and metacognitive skills, often called control knowledge or executive skills.) This latter type of knowledge includes cognitive structures and strategies that translate information and stimuli into meaningful patterns (schema).

Experts, according to Disessa (1987), Glaser (1976), and others, are characterised by having a large store of declarative knowledge, and an extensive procedural knowledge in the form of well-organised schema (Kutnick, 1990 and Salomon, 1979), so that for them, recall is quick and problem solving is efficient. This notion of schema formation and its ability to facilitate rapid recall and lower the cognitive load in problem solving is recurrent throughout much of the literature. “The higher the initial knowledge base (declarative), the better the schema formed”... thus the greater the success at problem solving because the processing capacity required is lowered (lower cognitive load), hence allowing more attention to be paid to the thinking process (metacognition).

Goldstein & Blackman (1978), contend that students who have these higher-order skills are experts. Further, suggests Dillon (1986) and Silver & Marshall (1990), the basic process of knowledge acquisition is underlain by structural elaboration (the formation of extensive schema or production development) (Yazdani, 1987), and structural transformations, the domain of experts. It is the author’s belief that one of the aims of science teaching using simulations is to produce experts, (in the sense of being expert at the scientific way of processing data), from novices, by their acquisition of learning strategies (programs that guide the learning process ... “learning to learn” (Kugel, 1986).

The term expert in the context of this paper does not necessarily have the meaning that one would usually ascribe to it. Willson (1990) suggests that one should think in terms of an expert/novice continuum, and that one can be considered to be competent, with developed ‘self knowledge’ skills without being at the absolute expert end of the line. It is in this field of novice/expert learners, where the thrust of research in the teaching of science using information technologies is taking place. Recognition of the differences between these students is essential to the successful design and development of computer based information technologies such as simulations that will promote enriched learning.

There are profound differences between the way experts and novices take in and use information. “Experts understand at a deeper, more abstract level than novices” (Koneman & Jonassen, 1994). Without due consideration of this point, the use of computers in the classroom to ‘teach cognition’ will never be possible. In a comparison between the way in which the expert and the novice process knowledge, it is suggested by

Fischler & Firschein (1989), Hayes & Broadbent (1988), Payne (1988) and Rist (1989), that experts use backward or bottom-up, (means-end based) processes which place a heavy cognitive load demand on the user, particularly in the early stages, suggest Stanton & Baber (1992).

Some of the earlier studies, for example, those of Dillon (1986) and Sternberg (1986) suggest that the use of the computer as a tool to promote “discovery learning”, works best with the brighter students. A possible explanation for this apparent anomaly may be that such students lie further towards the expert end of the expert/novice continuum and as such have more entry correct conceptions (also referred to by Linn (1986) and by others as *intuitive conceptions*). These may not need as much modification as those of students at the novice end of the continuum, who may need to use an inordinately large amount of their central processing capacities in modifying their incorrect intuitive conceptions. It is suggested by Wainwright (1989) that this excessive “load demand”, is an aspect of poorly designed software which may void its value, particularly for those who are “less cognate” although this is by no means certain. It is also possible that because experts design the simulation, there may be some mismatch, which disadvantages the novice. It could be argued that unless steps are taken to support novice learners in such environments while they develop some of the working skills of experts, the learning outcomes for these non-experts or less able students could be compromised.

When it comes to learning from simulations, Hatzipanagos (1995) and Trollip (2000) take the stance that there is an interaction between the level and fidelity of the simulation and the level (expert/novice) of the learner. In terms of the fidelity of the simulation environment, high fidelity for novices overwhelms them with detail that they cannot assimilate. He suggests that the novice needs to attain an initial feel for the process via a low fidelity version of the simulation. A solution to this suggestion is to provide varying, user controlled levels of fidelity so that as experience and comfort levels rise the user is able to adjust the system to suit. The ability to show output in different forms in the simulation tool described in this study as well as the facility to select the number of input

parameters initiated and output parameters displayed represents an attempt to address this concern.

Learners must cope with and integrate a number of demands associated with context, system structure and available response strategies when operating in complex environments. Giving consideration to these demands is extremely important in the design of any multimedia systems, including simulations since to be effective, suggests Oliver (1994) multimedia based materials must deliver instruction in a form that allows the user to understand and develop knowledge and skills with what one might term *minimum interference from the delivery system itself*. Experts are experts because they chunk and have well-developed schema, all resulting in a reduction in the processing space required, leaving more memory available for cognitive functions. It is essential that the users processing ability is not over taxed to the point where it hinders the learning process (Grabowski & Curtis, 1991).

Roth (1990) and Sweller (1988) suggested that schema acquisition was possibly the most important component of problem solving expertise and so design of computer-based simulations must aim at facilitating this. Rigney et al., (1979), asserted “the central tenet of schema theory is ... knowledge guides thought”. Cognition is based on internal symbolic representations (schema). Further, Salmon (1981), claimed that schema directed exploration modifies the learners original schema and that this directs further exploration. Good simulation/modelling software can facilitate this schema training, forcing the students to build on, or refine their schema using abstract information.

Anderson (1980) sums the characteristics of the expert by stating ... “a well stocked and well organised body of knowledge, organised into readily available units (chunks or schema), is what distinguishes an expert”.

On the other hand, the novice uses forward reasoning (Anderson, 1980). This has also been referred to as top down processing. The novice uses declarative knowledge in a real time framework. They carry out information processing at a superficial level rather than at a deeper level which requires a knowledge and understanding of processes and procedures. Disessa (1987), in a study on physics students, reports that many of the subjects are novice physicists, that is, they exhibit simple superficial knowledge

representation and usage. The novice student's knowledge base, lacks coherence and procedural interpretation, that is it contains very few or poorly developed schema.

“Computer-based learning environments should support the active and constructive learning processes in students ... moreover, they must try to develop and enhance more active learning strategies in passive learners” (DeCorte, 1990). Hayes & Broadbent (1988), suggested that the aim should be to use strategies and support mechanisms that develop in the students, the ability to work in the expert's learning mode, which is selective, effortful and reportable; the type of learning normally associated with problem solving.

In reviewing a research agenda for interactive multimedia, virtual reality and situated learning, Hedberg and Alexander (1994), have argued that interactive multimedia can provide a useful context for the development of what Lave and Wenger (1991) call *legitimate peripheral participation*. This participation refers to the engagement of a novice in a socially based practice in which they can perform the same range of skills as an expert. Interactive multimedia provides an ideal structured environment, which allows the novice to work with problems and learning situations, which are some *distance* (peripheral) from the core of the expert's world. As the novice begins to practice more as a full practitioner the skills and shared experiences overlap more with those who are acknowledged as expert.

While it is possible for all the elements of an information landscape to appear as unique discrete elements, the sheer volume of resources that the technology allows may appear overwhelming. Often interactive multimedia packages seek only to provide access to a vast array of resources which, if anything, de-construct knowledge into a series of potentially unrelated and discrete elements. Such information packages do not provide a focus for the systematic development of a novice's skills. Laurillard (1993) claims that “it is possible for new technology to support the more integrative view of knowledge, and the articulation and representation of experience, but this philosophy needs to be built into the design process explicitly, from the beginning.”

Hedberg & Alexander (1994) identify a number of dimensions, which have appeared in the literature to define the growing ability of learning context to provide a sufficient range of legitimate practice. These dimensions might form the basis for the development

of appropriate supports for learning from interactive multimedia environments and include:

- Immersion – considered by many to be a major advantage of interactive multimedia technology.
- Fidelity of representation – educational needs and the resulting use of faithfulness of representation has not received full discussion in the literature.
- Active participation – the claim for active participation of the learner who cannot take a passive role in the interaction.
- Creating an environment for practice – the crucial features of a traditional method of situated cognition.

It should be noted that “each dimension does not define the complete range of useful options in learning landscapes” (Hedberg & Alexander, 1994).

2.2.6 Matching Technology to Educational Theory

With the development of such sophisticated delivery systems as, interactive video, digital video, CD-ROM, CAI, MBL, intelligent tutoring systems, expert systems and the like that provide the *right tools*, it is imperative that research and the consequent design now concentrate on designing systems that take into account the cognitive processes involved, (Nelson & Palumbo, 1992; Quinn et al., 1993, and Rieber, 1994), rather than simply applying the technology to education because of its availability and the perception that there is some kudos to be had by using it in one’s classroom.

Many would suggest that this is the case at present.

While it is claimed that simulations teach facts and concepts more effectively than conventional techniques, some research evidence (Bredemeier & Greenblat, 1981), suggested that simulations are only more efficient with respect to the retention of information. Flick (1990), found in a computer based simulation of force and motion studies that, the computer simulation did not provide any significant improvement on “traditional methods”. It was noted that “many subjects in this study *learned* the simulation very well, but did not express a coherent understanding of the physics”.

Collis (1988) listed some general features, which one may associate with effective simulations in educational environments. They include the provision of; visualisation, both in terms of predetermined illustration of an event and user determined; replication of some process or event that would otherwise not be available; tests of cause and effect, facilitating hypothesis testing; model building opportunities and experiences at role playing, an aspect examined extensively by Crookall et al., (1987), and the facility to build models and ask, 'what if?'. It is suggested by Eysenck & Keane (1990), that the worth of simulations is two fold. They allow conceptualisation of cognitive processes and representation in concrete form. Good simulations also allow the input of unexpected data, which generates unexpected outcomes.

Some interesting observations are presented by Laveault & Corbeil (1990) concerning the learning process occurring in simulations and some of the important aspects of user control and it's bearing on the learning process. They outline two models for learning acquisitions in simulations. The first, proposed by Kryukov & Kryukova (1986) suggests that the process comprises a series of phases of interaction or dialogue (both direct and intellectual) between the player and the game. On the other hand, Thatcher's model (Thatcher, 1990), suggests that the process involves a series of cycles leading to the acquisition of complexities (rules of the game or simulation). According to Thatcher's model, all games and simulations are a form of experimental learning. The total experience of a simulation is a series of micro-experiences and repetitions at ever increasingly higher levels of complexity.

The structuring of simulations must be carefully considered and it is important to assess whether the user knows the *rules of the system* well enough to allow learning to take place. The question to be addressed is, when does the user stop learning about the system itself and start learning from it? Research to date, both cognately and technically based, would seem to suggest that the sooner this occurs, the better. Ideally the simulation should be structured so as to progress from highly parametered scenarios to less parametered ones, Thatcher's model of increasingly higher levels of complexity. The need to place the minimum load, (Kozma, 1991; Disessa, 1987 and Mayer, 1983), on rule learning so as to free as much cognitive capacity to facilitate efficient learning could not be more apparent.

Quinn et al., (1993) claimed that simulations and games are the ideal tools for the promotion and development of thinking skills and that computer-based simulations and games in particular can provide an ideal environment in which to promote these skills without risk, consequence, or cost. The issue of cost is extremely important on two levels. Firstly, a consequence free environment is an integral component to the development and maintenance of motivation of the user to start or complete a task, which may otherwise be perceived, by the users as too difficult to contemplate. This perception may arise by nature of their low entry level knowledge or experience base or, perhaps simply self esteem. They may also perceive it as too risky in terms of the possible outcomes and peer approval. Secondly, the real life process may in itself be too dangerous, costly or difficult to carry out so that the fear of the consequences or cost of failure would rule out the possibility of attempting it in real life.

When using hypermedia based systems the key is to ensure that “learning is supported rather than hindered” (Grabowski & Curtis, 1991). Both poorly and well-designed hypermedia based systems can be confusing. They are structurally based in an emulation of the expert mode of learning and, as the general user will not necessarily be an expert, the role of cognitive processes in learning must be addressed in order to prevent the complexity of the system overcoming or over taxing the user’s processing ability and thus hindering the learning process.

The role of cognition and metacognition in the learning process is being more closely examined by many researchers and its importance is becoming more obvious. In particular, the notion that the development of metacognitive skills is an essential ingredient in the attainment of improved performance is expounded by a number of researchers including, Derry (1990); Gerlach & Ely (1971); Rieber (1994); Quinn (1991) and Reif (1987b). According to Anstey (1988), children need to be able to regulate how they go about tasks, so that they can complete them more successfully. They suggest that the poor students are those who do not have well developed metacognitive skills and that, by virtue of the nature of the technology and its use to support the inquiry approach in science teaching, they may be helped to overcome this shortfall.

The recognition that inquiry or discovery-based learning of the type which can be evoked by simulations is a means of providing effective education in terms of the stated goals, Lane & Lane (1986); Gagne & Glaser (1987); Stinner (1989); Berge (1990) and Tweney & Walker (1990), has ensured continued research and development in the use of simulations in teaching. Linn (1986) suggested that the worth of discovery learning lies in the fact that it encourages students to 'figure out' principles and consequences by interacting with materials and situations.

Computers can provide a model of human cognition, (Bunderson & Dillon, 1987; Esyneck & Keane, 1990; Goldman & Pellegrino, 1987 and Silver, 1987), which has become the driving force behind research in the area of learning with computers in educational environments. The computer ... "offers a new tool for generating and testing theories of human thinking" (Mayer, 1983). Mayer, however, sounds a note of caution concerning this modelling by pointing out that care must be exercised when making the comparison. A similarity in behavioural output does not mean that humans and computers are using the same cognitive processes!

Schools have always recognised the importance of the domain-specific aspects of learning but must now recognise the importance of the cognitive processes, particularly those of higher-order, Lawrenz (1990), Resnick (1987), and Singley & Anderson (1989), in the process of providing a meaningful educational outcome for all students. These higher level cognitive skills include, reasoning, problem solving and executive control strategies that are assumed to be useful across a wide variety of content domains. Derry (1990) suggested that the most effective way to develop these cognitive skills is to "present the learner with challenging materials, situations and problems" which make the learner consider possible solutions. These solutions, with practice and perhaps some resulting change, provide the learner with useful schema, which will ultimately transfer to other problem solving situations.

This may be achieved by the use of strategies and delivery systems, particularly those which are computer-based, that develop cognitive heuristics. Anderson, Farrell & Sauers (1984), Gange & Glaser (1987) together with Nickerson (1988) and others including Stanton & Baber (1992); Spada et al., (1989); Paris & Winograd (1990) and

Resnick (1989) note a growing consensus between educators as to this need. Tweney & Walker (1990) suggested that the aim of science teaching should be to restructure the existing knowledge, thus producing meaningful conceptual change, which is the basis of improved educational outcomes.

Many authors contend that the key to science teaching is the development of the higher order cognitive skills such as inquiry and problem solving and thus, the development and use of thinking skills. Problem-solving occurs when the student translates a problem into an internal representation and then searches for a pathway from the (initial state) concept, to the (goal state) application. Inquiring into the solution of a problem encourages the learner to re-assess their first conceptions, “intuitive conceptions”, (Linn, 1986), and modify their thinking about pathways. Cognition then is the basis of the problem solving/inquiry method of learning.

One of the measures of effective learning is the users ability to use knowledge and skills they have developed in one context in a new or novel situation. St-Germain & Laveault (1997) noted that a major benefit of simulations in educational environments was their support for the development of users ability to transfer knowledge and skills to other situations. However, this effect is often not achieved because at the learner level, the experience is not placed within a context that makes sense. They suggest that success in this transfer of knowledge and skills is directly related to how well the simulation generalises to the real world thus preparing the learners to deal with the real world will provide. At the user level, the system itself may be too complex, requiring a high level of expertise just to use it. They propose that designers need to look at the types of students who will benefit most and how to design a system that fits all. The use of multiple representations of the data is a step in this direction. According to Bruning et al. (1999) the context in which the knowledge is originally encoded is critical to the learner’s ability to recall and use it in a new context. Tessmer & Richey (1997) suggested that providing multiple examples during the learning process would enhance the ability of learners to achieve this transition of knowledge and skills into new domains. Although multiple representations may assist the individual thinker, Dowling (1997) notes, this may have a negative outcome in terms of communication and common understanding if it is not used with caution. Students should

be making the decisions as they would do in the real world. To this end, the simulation should not be seen as a direct teacher but rather a tool that provides a means of discovering information or practicing a skill or testing an idea.

A recurring theme throughout the research literature is the role the computer plays as a tool for lowering the overall work load and as some researchers suggest including, Disessa (1987); Kozma (1991); Mayer (1983); O'Shea & Self (1982); Silver & Marshall (1990); Silver (1987); Harper et al., (1993) and Harper et al., (1997), the "cognitive load" involved in processing information.

Simulations have the capacity to eliminate some of the drudgery, the menial tasks, leaving... "more of one's cognitive capacity for the more important learning task" (O'Shea & Self, 1982). The student may then concentrate on the acquisition of Higher-Order thinking skills including, planning, evaluation and problem solving, referred to as "executive skills" by a number of researchers including, Reif (1987a) and Schoenfeld (1987). As stated by Larkin (1983), "science is hard to learn" ... needing a large slice of one's processing capacity to develop the extensive "basic knowledge" stores required to reach the status of "expert", that is, being a competent user of such Higher-Order skills. As indicated by Sweller (1988), problem solving, the basis of learning in science, often requires processing capacities which far exceed those available to the "novice" student, resulting in less than effective learning, so ... why not use a device such as a well designed interactive simulation to lessen the drain on this processing capacity.

Stanton & Baber (1992) along with others, including Schroeder and Kenny (1994), point out that the cognitive load on users in the early stages of working in an unfamiliar environment will be great regardless of their entry knowledge level or experience. With time, this load is lowered, as they become familiar with the rules. Perhaps the solution lies in providing some level of guidance for all in the early stages. It is certain though, that the 'trick' in maintaining interest and willingness to engage the learning experience until this familiarity is obtained is to provide some level of help or guidance.

Jacques et al., (1993) and Rieber (1994), claimed that this process can take some time for those who are not as cognately developed as others. Unlike the more cognately developed user group, this group of users will always require support for success.

The solution may lie in providing some level of guidance for all in the early stages and this need to be supported by careful and balanced content structuring.

Exploratory learning is intrinsically self-directed and involves constructive mental activity. It usually involves working and constructing understanding of knowledge embedded within complex domains and the acquisition and application of higher order skills such as critical thinking and reflection. Kashihara et al., (2000) asserted that both of these activities require the expenditure of a cognitive effort. They suggest that without some type of intelligent or adaptive support, these cognitive efforts may bring about cognitive overload particularly in the case of novice learners unless special care is taken to manage the exploration space in such a way that cognitive effort is not wasted.

A solution to this may be to adaptively control the exploration space based on the users level of experience, the educational goals and level of domain knowledge understanding by for example restricting the number of pathways available to the user. In simulations Kashihara et al., (2000) suggested that this could most easily be done by restricting the number of parameters that can be manipulated at any one time.

2.2.7 Specific Simulation Studies

This section outlines the findings from a selection of the most pertinent literature dealing with actual studies that are illustrative of some of the points made in this chapter.

Rieber & Noah (1997) report on a study with adult learners to investigate the influence of game-like and graphical organisers during a computer-based simulation in physical science. What they found was that although the users enjoyed and were able to use the simulation they had difficulty transferring the experiential knowledge gained in using the simulation into an explicit understanding of the scientific principles which they measured using a traditional performance test.

Burke (2000) asserted that experiential learning is an essential element of any learning situation because it mirrors how we learn in the real world. He suggested that one of the reasons for this might be that the highly experiential nature of the visual representations of the simulation coupled with the game like context may not promote a feeling or need to be reflective, that is there may be a surface approach to learning

triggered by a trivialisation of the process as an impression that one is engaging in a game rather than a learning experience with consequential outcomes is presented. This study resembles the study described in this thesis. In dealing with users who are used to working in such frameworks because they have been brought up using them, this effect was not observed. The simulation tool seems to have improved their deeper understanding of the underlying principles as reported in the chapter on findings.

Lawrence & McDonald (1997) report on a study on the use of simulation to develop an appreciation of Risk Assessment in the insurance industry. A simulation was developed to address the problems of accessibility to real life situations, the large volume of information needed to be covered and the vocational commitments of the participants. The simulation was to provide accessibility at all times, guidance for first time users, the provision to ask questions and feedback based on the student's actions. Student responses to the experiences provide an insight into the effectiveness of simulation in this type of learning situation. They indicated that the ability to 'see the results' helped the students in understanding the process, supporting the strong view of the importance of visualisation. Students were able to 'get a feel' for the process because it was in a meaningful context and it was supported by the use of real examples. Finally, they found it fun and were motivated to work on it.

Yildiz & Atkins (1996) conducted a study examining the cognitive impact of multimedia simulations on high school students, using three different types of multimedia simulation (physical, procedural and process). The physical simulation was designed to provide the students with a real world substitute learning environment in which they were able to see animations, use games, select their own pathway through the materials and most importantly have immediate feedback as to outcome of their actions. The results of the study showed that the cognitive gain was much greater for the physical simulation than when the students used either a procedural simulation, which had a high level of real life relevance for them but gave them very little freedom of choice as to how to go about solving the problem or the process simulation which did not have a high real life relevance.

When students were given the opportunity to select their own pathways through a multi-representational learning framework grounded in a relevant context, were supported

via pre-activity help in the form of advance information about what they could do and expect and received immediate feedback on their actions, better learning outcomes were observed.

Learning by doing has long been considered as one of the most effective ways of learning and engaging students, but as Draper (1997) points out, we must not fall into the trap of thinking of this engagement or interaction in the physical sense. He suggested that the doing or interaction supports the mental engagement by contextualising it, matching the way learning takes place in the real world. In using a simulation students can practice making decisions just as people in the real world do so in a safe risk free environment. What this means to the educator is that tasks can be set in accordance with situated learning principles without having to consider risk.

2.2.8 Exploring the Nardoo - A Simulation Developed

This study was based on the CD-ROM *Exploring the Nardoo*, a simulation of an inland river catchment region in which students could investigate the issues of whole catchment water management and explore solutions to authentic problems.

Research has been conducted at the Interactive Multimedia Learning Laboratory since 1990 on the implications for the design and delivery of instruction in constructivist environments. The research has explored the provision of motivating and interactive learning environments that could generate high quality learning outcomes by allowing students to participate in communities of practice through immersion in authentic activities, supported by cognitive tools. The research on the design and use of these packages in classrooms has been variously reported (Corderoy et al., 1998a; Corderoy et al., 1998b; Corderoy et al., 1996; Hedberg et al., 1996; Harper et al., 1995; Hedberg et al., 1994 and Harper et al., 1993). The laboratory is a research facility within the Faculty of Education at the University of Wollongong and has been responsible for the development of a number of internationally recognised simulation packages based on constructivist theories.

The first of these was *Investigating Lake Iluka* (1993), a simulation of the ecology of a lake. The package is based on the concept of an information landscape that incorporates the biological, chemical and physical components of a range of ecosystems

that make up a coastal lake environment. The design was such that the cognitive skills required are authentic and the graphic and metaphorical representations were believable. The package provides experience in and appreciation for multiple perspectives through access to information presented in various media formats. The package provides practice in inquiry and problem solving techniques through a range of embedded case studies. *Investigating Lake Iluka* is a structured environment that allows the novice to operate in an experts world, developing a shared understanding of the expert approach to problem solving. A number of tools that support knowledge construction are provided. Designers believe that the expected outcome for users would be the development of “a broad array of scientific investigation skills” (Harper & Hedberg, 1997).

Evaluation of *Investigating Lake Iluka* through the use of the package in classrooms and an on-going program of postgraduate research provided insights into a fuller realisation of the “metaphors we teach by” (Duffy & Cunningham, 1996) in a constructivist learning environment. The evaluation with students in the classroom expressed a need to:

- have greater access to information resources to construct their knowledge, (select own pathway in a high fidelity environment);
- have the challenge (problem) presented up-front and in a context that is relevant to them (authentic task with authentic outcomes);
- have access to information in multiple forms and modes, (multiple representation of information together with effective reporting tools which utilise multiple reporting modes and;
- have access to “suck it and see” tools, simulations that allow them to test out their ideas. (Harper & Hedberg, 1997).

The last point, alluding to cognitive tools represented an area of research being reported by a number of researchers in the area, most notably, Jonassen & Reeves (1996) and Lajoie & Greer (1995) and under investigation by the Interactive Multimedia Learning Laboratory.

The outcomes from this research lead to the development of a further project *Exploring the Nardoo*, which was the resource for this study. The acceptance of a brief from the New South Wales Government Department of Water Resources, later known as

Sydney Water, for the development of *Exploring the Nardoo* provided the opportunity for the clearer understanding of the needs of learners supported by a range of constructivist environments, gained through the development and research on *Investigating Lake Illuka* to be utilised.

Exploring the Nardoo provides a vehicle for students to investigate water management issues for inland river systems through the simulation of a dynamic inland river catchment from its pristine condition before human interaction, through to the present day. The software supports the study of the interaction between living organisms and their physical and chemical environment with emphasis on the impact of humans.

On entry the students are presented with a challenge to address a problem and solve it by becoming an active participant in the learning process. A rich information base using a full range of media is provided to support their investigations both as embedded data within the environment and as resources (documents, video clips, newspaper cuttings) within a Water Resource Centre located in the simulated environment. The students have access to researchers within the Water Resource Centre who take on the role of research assistants to help them during their investigations. Suggestions are made as to how they may begin their investigation and how they might best present their findings. Apart from these suggestions the students are given control over the access of embedded information and the final product of their investigation.

The students are provided with a flexible set of tools to assist their investigations and reporting, including a suite of simulation tools. The simulation tool reported on in this thesis allows the students to investigate the issue of blue-green algal blooms in inland rivers. They are able to manipulate variables and examine the consequences in a risk free environment. It allows the users to learn at a deeper level through the testing of their own ‘what if’ scenarios, a process that can “facilitate more detailed exploration and learning by;

- allowing the user to take readings at a sight and study the changes as the simulation runs,
- allowing the monitoring of all parameters while the simulation is running, with the aim of exploring the relationships between them” (Corderoy et al., 1993)

The simulations “scaffold the experiential component of the package, offering learners a means to test their hypotheses” (Harper et al., 2000). Feedback from the simulators is provided in several formats and this has added significant power to the learning experience by helping students in their visualisation of the complex processes involved. Hypermedia based systems such as that implemented in the software package *Investigating Lake Iluka*, and *Exploring the Nardoo* provide a multi-representational resource rich learning environment in which the student may explore, solve problems and test hypotheses and in so doing have the opportunity to learn at a deep level than they might otherwise do.

2.2.9 Summary

The notion that the incorporation of information technologies such as simulation systems in the educative process could provide an additional agent for the improved efficiency of the process has developed since the Second World War. “Instructional technology contributes knowledge to training (and education) that aims to improve the individuals learning, mastery and competence” (Kaufman & Thiagarajan, 1987). In the past, the ideas and designs were very much ‘tool-technology’ based, (Goodman, 1972), providing support and relief from the more uninteresting tasks, for the educator and student alike. Researchers in the late 1980’s including Collis (1988), and Good (1987), suggested that in many instances that state of affairs still held.

Currently however it is generally accepted that, if properly implemented, interactive multimedia can provide for simulations, an attractive delivery system which incorporates both the complexity and sophistication necessary to support dynamic real world based mathematical models and, the versatility to present these models as convincing real world experiences while at the same time providing the high degree of measured freedom and manipulation needed by some users to convincingly construct their understanding and knowledge from such real world substitute experiences.

One would suggest that the notion of measured freedom or the need to control the users activities to some degree, particularly in the early stages of exposure to a multimedia environment, represents a crucial aspect with respect to the educational outcomes for the

user. Hsu et al., (1994) pointed out that the motivational potential of multimedia based environments rests in part with the freedom the user has to explore pathways of their own choosing. However, too much freedom of choice they suggest, can be counter productive and they like many others, suggest there needs to be some direction for the user, what one has termed measured freedom.

Quinn (1997) lists, as part of a discussion centred on games, engagement and learning, several features that he considers necessary for engagement in educational games and suggests that they may also be considered as constituting essential ingredients for educationally successful simulations. They include:

Context orientated.

Thematically coherent

Tight coupling between action and feedback

High level challenge.

Large and meaningful choice of action.

Bagui (1998) lists several general design principles which when applied to multimedia learning environments can result in improved learning outcomes. Each of these it is suggested can also be applied to the design of multimedia based simulations. They include:

- based on the Dual Coding Theory, multiple representations will improve outcomes;
- multiple representations could help reduce cognitive load in a “students working memory”;
- the ability to select multiple pathways and vary the pace allows students to view things from various perspectives and this supports them in developing a much more “robust understanding of the relationships among concepts”;
- chunking;
- interactivity and;
- flexibility.

Regardless of how one defines a simulation, or the type or format category into which it falls, the essential rationale behind using simulations in educational environments remains:

- to support learners in the development of mental models in order to understand processes and relationships;
- to provide a mechanism for them to test the efficacy of these models in explaining or predicting events; and
- to discover and test relationships between among variables, within a manageable, risk free and cost /time efficient system.

The challenge to the designer is to produce an innovative, useful, interesting and educationally sound package. The worth of the resulting simulation based interactive multimedia systems may ultimately rest with their outcomes, namely that they make the learning easier and not with the notion that they provide a better means of teaching some particular aspect of a curriculum.

2.3 Model Development and Performance Testing

The design of the simulation of algal bloom implemented in *Exploring the Nardoo* has been based on many of the features attributed to simulations throughout the literature concerning the technical vs. cognitive considerations in design. Allied to this has been the recognition for the need to take a balanced view between providing a complex predictive model and one that provides a realistic representation of the processes operating without compromising the validity of its output in terms of the user being able to discover and explore relationships and test hypothesis.

A number of authors in the area of modelling and simulation, Wymore (1983); Leigh (1983); Jorgensen (1994) and Renshaw (1995) pointed to effective ways of developing models. One methodology, a ‘top down’ approach, suggested as being effective for model development is to assemble, in the initial stages, all the known equations representing the physical mechanisms that are believed to be applicable. The result however is a very complex model in which it may be difficult to identify and eliminate non-essential

entities, resulting in an overly complex representation of the process, which in turn may have a negative impact on the user. In the best-case scenario for this ‘top down’ development model, the non-critical segments will not interfere with and compromise the validity of the model. However it is more likely that there will be unwanted interaction and it then becomes a more difficult task to recognise and eliminate non-essential segments.

The alternative methodology, used in the development of the models used for this study involves a ‘bottom up’, from simple to complex approach. It involved the identification of the significant parameters, but rather than lumping them all together, each is treated as a discrete module which is built, tested and then linked into the whole structure. Such an approach is advocated by Leigh (1983). The modelling process followed a number of steps. In each step, testing against established bench marks, described in chapter 3, for behaviour and performance was carried out and in the final system, the integrated modules were tested as a whole system against the target system to verify its efficacy.

The first step involved a search of available research literature on the modelling of algal blooms in lakes, which had similar characteristics to the one being used as the modelled lake. The purpose of this was twofold. It would establish whether a pre-existing model could be utilised and it would also facilitate identification of the key relationships that needed to be incorporated within the model to ensure a high degree of fidelity.

Working sub-models for each of the identified key relationships were then built and tested to ensure the adoption of the most effective and stable structure which provided output data that matched the existing modelled environments as closely as possible. This methodology was greatly enhanced by the fact that the initial model building was carried out in STELLA®, and the artifacts of this modular approach are clearly visible in Figures 3.1, 3.2 and 3.3 in chapter 3. At this stage, determination of the best values for unknown variables, variables for which no real data existed, was carried out through an iterative process. The values chosen were based on estimations provided in the literature. (See Appendix 3.16 - Equation Programming Notes)

The existing sub-units were then combined and their behaviour was again tested to ensure that the interaction between relationships was as expected and that the overall output still provided an accurate simulation of the known systems. At this stage, some modification was required to various sections, to correct for model *over-run* and anomalies in behaviour.

2.3.1 Data Sources

The initial development of a model of algal bloom growth was developed for the package *Investigating Lake Iluka* and was designed to simulate the growth of algal blooms in lakes. Although the mathematical model which was used to provide a reference point for the model described in this thesis was based on lakes elsewhere, a local lake was used to provide data and general information in terms of conditions leading to algal blooms. Although not implemented in the *Investigating Lake Iluka* package, it was developed to finality and formed the basis for the development of a model to simulate the growth of algal blooms in rivers for implementation in the package *Exploring the Nardoo*.

Lake Illawarra is an important recreational water body for the City of Wollongong and surrounding areas. It lies some 8 km south of the city, has a surface area of about 35 square kilometres, a perimeter of approximately 40 kilometres and a catchment area of 270 square kilometers. It was originally a shallow saltwater lagoon, but was cut off from the sea some 6,500 years ago and now has a semi-permanent opening to the sea.

Water depth in the lake is typically between 1.5 and 2 metres, with an average depth of 1.7 metres. More than 35% of the lake has a depth of less than 1 metre at normal water level. Being essentially non-tidal, the water levels in the lake are tied to rainfall. Over the past 20 years parts of the lake have become shallower and nutrient levels have increased chiefly as a result of human impact on the lake and its surrounds. It has consequently become an ideal breeding ground for algae and has experienced a number of significant and destructive algal blooms in recent history. For this reason it has attracted extensive study.

Literature available on Lake Illawarra was used to provide the basis for the factual information to be built into the initial simulation of algal bloom. The Lake

Illawarra Management Committee reports #1,2 and 3 (undated) provide information concerning the general structure of this lake and the problems it has in common with similar lakes elsewhere. A number of physical parameters are presented and discussed in terms of; causes, effects, and control methods.

Also included are, water quality (turbidity, particulates etc.), temperature, salinity, dissolved gases and light levels all of which are interrelated in that they either directly or indirectly impinge on the conditions which are necessary for algal growth. In most circumstances, provided there is sufficient light and the temperature is within known tolerances, the essential controlling factor for algal growth in the lake is the supply of nutrients. Three conditions can exist with respect to nutrient levels:

- oligotrophic (nutrient poor)
- eutrophic (nutrient rich)
- hypertrophic (nutrient excessive) (Bowker & Randerson, 1989).

The chief nutrient forms presented in the literature (Marra et al., 1990; Pedersen & Borum, 1996 and Laws & Chalup, 1990) as being significant are, phosphates and nitrates, which have wide and varied sources (most of which are related to human involvement around the lake). They can be found in the lake as solutions or particulates and can also be locked into the sediment for later release under the right conditions.

The Lake Illawarra Environmental Audit produced by the State Pollution Control Council (1986) provides an extensive analysis of both physical and chemical parameters of concern in this simulation.

It is suggested within the report that the essential features determining the water quality in Lake Illawarra are:

- siltation (shallowing), changing water temperature profiles and potentially adding to the nutrient load;
- nutrient enrichment, arising from influx from the catchment, release from sediment and decaying matter in and around the lake;
- excessive growth of aquatic plants, leading to heavier nutrient load and;
- poor exchange of ocean waters, preventing regular flushing of nutrient load.

In a paper on nutrient pools in Lake Illawarra, Yassini (1985) supported the contention of a number of other researchers that the lake was essentially operating in a eutrophic / hypertrophic phase at various times and under certain conditions, this has lead to excessive algal blooms involving such species as;

- Ulva, Chaetomorpha, Enteromorpha (Green algae)
- Ectocarpus (Brown algae), and,
- Gracilaria (Red algae, responsible for the increased incidence of the toxic so called ‘red tide’).

Included in Yassini’s paper are a number of excellent graphics indicating the relationships between the various factors, which, with some modification, were used within the content resource section of the package as flowcharts.

In a paper on Coastal Waterways Management, Clarke (undated) outlined the serious implications for nutrient and pollution supply to Lake Illawarra based on the data, which indicated that there had been a 6-fold increase in sediment input to the lake over the past 100 years. In support, Mills (undated) in a paper on Environmental Protection for a local conservation society suggested that such sediment input increases were the result of large-scale environmental alterations to the catchment area of the lake. These alterations also produced a steady increase in other pollutants, many of which are toxic to both plant and animal life in the lake.

Re-development of the lake based model for use in a river environment, required the incorporation of several new parameters and mechanisms to modify existing parts of the model. The essential differences between the two environments that needed to be addressed included the difference in flow patterns, the impact of cold water pollution. the depth of the water and light penetration, the expected levels of nutrients and turbidity. These are discussed in more detail later in this section of the chapter.

During the re-development of the model to suit the conditions and process operation for inland river environments, (essentially the effect of flow patterns on, temperature, turbidity and nutrient levels), the data sources were chiefly provided by the client, Department of Land & Water Conservation through two avenues. Subject matter experts were constantly testing the model as modifications to it were made to ensure its validity

and fidelity. Scientific officers employed by the client also provided data sets to ensure that the outcomes were realistic as well as advice on their application as development proceeded. Much of this data was in unpublished form, being internal client documentation.

2.3.2 The Base Model

Although many of these papers outlined in this section are dated in terms of their actual publication dates, they still provide a valid and useful reference point for the development of a model for algal bloom.

The literature dealing with modelling the eutrophication process is reasonably extensive. Similarly, literature dealing specifically with the processes involved in the development of algal blooms is also reasonably extensive. However, a significant number of papers reported on the processes involved in modelling certain aspects of population dynamics in water bodies, both animal and plant based and in some cases these papers present models which have been developed and tested.

Sepe (1988) in modelling organic evolution, detailed the problems that can occur with the time parameter in simulations particularly when dealing with natural processes, which are normally very slow. The user must gain an appreciation of the real time periods involved, and they must be able to carry out their investigations within a time frame that fits in with the lab time available. The simulation thus needs also to be flexible so that a wide variety of user inputs can be made. Such a high level of user control approaches a condition where the simulation does provide a realistic substitution for a real world experience. Sepe suggests that this “allows them to do real science”.

A paper on modelling blue-green algae in lake Enajarvi in southern Finland by Kettunen, Malve and Varis (1988) was useful in that it provided supportive information for the controlling factors assumed to be of importance in the development of algal blooms in lakes as well as similar numerical and graphical outputs to the model being developed based on Lake Illawarra. Like the materials produced on Lake Illawarra, the report showed that extensive and exhaustive studies had been carried out to arrive at the conclusions made.

Haines-Young (1983) presented a model for nutrient cycling within a terrestrial ecosystem in terms of both the nutrient stores within the soil, litter, vegetation and minerals and their transport between these stores. It was written in BASIC and provided the user with a reasonable degree of control over variables. While it was not of direct use in developing the model for the lake, it provided an insight into the systems approach to ecological study and in particular, both the role and movement of nitrogen and phosphorous in these systems. Kent (1983) takes a graphics approach and represents real world situations using graphic display. He suggested that such output allows the synthesis of implications without the need for extensive and tiresome data collection. This notion may reduce the cognitive load placed on users of multimedia platforms.

Bendoricchio (1988) in modelling eutrophication in the Venice Lagoon provided supportive data for expected values of algal cells (500 cells/ml) but did not make a distinction in terms of the degree. The other literature suggested that in fact such levels are more in line with what might be classed as a minimal value for algal bloom to be recognised. The paper also provided support for the assumption used in the model that nutrient levels in conjunction with light and temperature levels are the key physical factors affecting algal bloom development. The paper reported some very useful graphical output which was used as a cross check against the model developed for this implementation and confirmed what had been reported in other literature on modelling algal blooms.

The impact of technology based instruction on teaching and learning outcomes is examined by Mandinach (1989). It is proposed that the System Dynamics or systems approach, embodied in software such as STELLA® can form the basis for the development of simulations that provide real life situations in which users can refine and exercise their problem solving skills and other higher order cognitive skills. The system dynamics approach attempts to foster the development of understanding of complex phenomena and cause-effect relationships using simulation and computer based-models to represent the complex relationships among the variables. Through its use of graphics, structural diagrams, equations, graphing tools and tables, STELLA® enables non-mathematicians unused to modelling to create their own systems. "Such modelling broadens the range of

cognitive representations and instructional strategies that students ... can bring to bear in problem solving” (Mandinach, 1989).

The simulation model AQUASIM® proposed by Bowker & Randerson (1989) facilitates experimentation with eutrophication in such bodies of water. In this mathematical simulation both zooplankton and phytoplankton are taken into account. Most emphasis was placed on the light levels, temperature and phosphorous levels. The water body had a continuous throughput. It is written in BASIC and provided for the manipulation of phosphorous levels to model eutrophication. Entry of phosphorous to the system was via release from the sediment. Consequently, although the model provided insight into the mechanisms of phosphorous release and uptake, it did not provide a useful engine for the *Investigating Lake Iluka* package essentially because the greatest nutrient load in *Lake Iluka* was meant to have its origins in water input from the surrounding catchment, the modelled lake was significantly deeper and *Lake Iluka* has discontinuous flow rates and mixing patterns. The authors suggested that the driving force behind this models’ development was the lack of software that can help students become aware of systems analysis and its use in studying ecological processes.

Bowker & Randerson (1989) also make reference to a number of models in an anthology on the eutrophication process edited by Middlebrooks et al., (1975). The models presented in this volume provide a rich and diverse source of data, ideas and opinions as to the important factors and processes to be taken into account when attempting to model such a complex natural process. The model by Larsen et al., (1975) provided an invaluable reference point for the construction using STELLA® of the initial engine for the simulation of algal growth in *Lake Iluka* which later formed the basis for the engine used in the *Exploring the Nardoo* implementation.

2.3.3 Re-development

Re-development involved the re-purposing of the *Investigating Lake Iluka* simulation engine for application in an inland, freshwater setting. As outlined in chapter 3 on model development, the essential structure and parameters remained valid for this environment but some additions and modifications were necessary.

Communication with the subject matter experts and research scientists employed by the client to investigate the problems of algal bloom development in the rivers of New South Wales during the re-development of the basic engine provided invaluable assistance and direction in assuring that the new simulation engine provided an accurate and realistic representation of the process. The model presented by Laws and Chalup (1990) was also invaluable in re-developing the engine for its role in *Exploring the Nardoo*.

During the re-development stage, experts in algal bloom employed by the client examined and tested each iteration of the model. Their initial reaction to the base-line model (Iluka Version 5.9.1) Figure 3.3, was that the output it produced in terms of algal cell count, rates of nitrogen and phosphorus depletion and the mathematical relationships between light and temperature and the development/decline of algal bloom was commensurate with observed river bloom development, but in order to better match the real world process some modifications and additions needed to be implemented.

Most notable amongst these was the inclusion of an algorithm to simulate the development of toxicity within the river water and to have a suitable time lag in its appearance and disappearance. Although turbidity was a factor contributing to the original lake based model, there was a need to modify its effect and to link it to factors such as the inflow of water through the river resulting from both flood and dam release. Related to this, there needed to be a flushing mechanism whereby the user could mimic the effects of sudden influxes of water. This also had to be factored into the temperature control routines, as a flush of cold water from the base of a dam would have an effect on both the plant and animal life in the water over and above the obvious one of flushing. A full technical description of both the original and re-developed model and the development process are given in the next chapter.

2.3.4 Summary

The development of an algal bloom occurs when a water body enters the eutrophication phase. The mechanism by which the bloom develops and decays away is essentially the same for all water bodies, whether rivers lakes or open waters. The level at which such blooms become toxic to life in the water column is variable depending on such

factors as flow through rates and the time of year, but in all cases, is apparent after the bloom has peaked and is beginning its own natural decay process.

The essential factors influencing the development of algal blooms in both lakes and rivers are:

- the levels of nutrients in the water (most importantly, soluble phosphorous and nitrogen compounds;
- the temperature of the water (in the range $19^{\circ} - 25^{\circ}\text{C}$), and;
- the ambient light levels in the upper layers of the water (in excess of 400 lux).

Co-factors to the above factors that either impinge on their effects or operate independently of them are:

- the flow through rate of the water;
- the level of turbidity in the water and ;
- the levels of toxicity and oxygen which operate both of the algae itself and the other life existing within the water body.

CHAPTER 3

Development of the Blue-Green Algae Simulation Tool

3.0 Overview

The Blue-Green Algae simulation tool implemented within *Exploring the Nardoo* and reported on in this thesis was developed in two distinct phases. For clarity both will be reported separately.

Phase one involved researching the process of blue green algal bloom development and the design and development of a mathematical model that would provide the engine for the tool. There were two sub-phases to this development arising from the fact that the simulation tool was originally designed to be implemented in an earlier commercial software package *Investigating Lake Iluka*. The first iteration of the model involved the development of an accurate but non-predictive underlying model based on the process of algal bloom growth within lakes. Due to time and cost restraints, the implementation did not proceed and the decision was made to continue development for implementation within the then mooted new ecology based package, *Exploring the Nardoo*. The second iteration involved the re-purposing of the basic mathematical model under the guidance of New South Wales Department of Land and Water Conservation subject matter experts so that it could be used to accurately simulate the development of such blooms within inland river systems. Both of these sub-phases will be reported upon in more detail in later sections of this chapter.

Phase two involved the redevelopment of the skeletal interface existing from the earlier model development phase in line with the specifications stipulated by the client (Sydney Water), contemporary design theory and pedagogical guidelines. It should be noted that many of the innovative design features in the current implementation were first proposed in the design specification for the earlier *Investigating Lake Iluka* software package.

One of the most important changes in the design was the decision to change delivery platforms, and this greatly expanded the possibilities for realising many of the proposed features in *Exploring the Nardoo*. This interface development phase took place in parallel with the redevelopment of the underlying model. A more detailed description is provided in later sections of this chapter. Both of these packages have been well received both in terms of their innovative design and educational value. In particular, *Exploring the Nardoo* has won several awards and has been widely reported on and undergone peer appraisal at both national and international level through research publications and presentation at conferences.

3.1 The Context

In order to fully appreciate the development process of the simulation tool and its significance in the complete package *Exploring the Nardoo*, it is necessary to set the context in which it evolved from both the perspective of its earliest design and its final implementation.

3.1.1 *Investigating Lake Iluka*

The original design brief for this simulation tool was to provide an interactive simulation of algal bloom in a lake. This simulation was to be incorporated in the interactive multimedia package designed for NSW senior Biology/Geography students, *Investigating Lake Iluka* a multi-award winning package which simulated the ecology of a lake. This software was being developed by the University of Wollongong in conjunction with Apple Computer Inc. as part of the Christopher Columbus Project and the Australian Academy of Science. Several factors including time constraints prevented the implementation of the simulation tool within version one of the *Investigating Lake Iluka* package.

3.1.2 *Exploring the Nardoo*

The Blue-Green Algae simulation tool is one of three simulation tools developed for implementation within a whole river catchment simulation, *Exploring the Nardoo*.

The package is a constructivist based learning environment which attempts to provide a realistic, risk free learning experience within an open ended, information rich environment. The students are free to explore the issues associated with water resource management and human habitation on a whole catchment basis. In terms of pedagogical approach it best fits the Experiential model (Harper et al., 2000)

“Whole catchment management of water resources is a complex process as it requires the development of an understanding of systems and processes which operate at both micro and macro levels and over extended time frames and consequently, the relationships between ‘cause and effect’ within the various systems is often not immediately apparent nor observable in the ‘real-world’ environment in which they take place.” (Corderoy et al., 1998a)

The package uses a geographic metaphor which contains a Water Research Centre and a navigable river environment. It presents the issues associated with inland Australian rivers and how they are effected by farming, industrial activity, settlement and water use demand. The metaphor for the knowledge structure is a navigable river that contains biological, chemical and physical data distributed within 4 time zones from pristine to the present across 4 river regions, upper catchment to a mature river flood plain represented in each zone. Plate 3.1 depicts the entire river catchment (comprising all 4 regions) in its present day state, Zone 4.

Each region in the visual representation of the river environment contains an embedded investigation, to follow and resolve. These problems challenge the user to become an active participant in the learning process. This problem-solving approach is introduced to the user at the beginning of the program as they enter the simulated Water Research Centre. The Centre is populated with guides who introduce you to the learning environment and the information access metaphors and who also provide metacognitive support for the problem solving process through hints and problem solving strategies specific to each investigation.

The issues, scenarios and problems presented within this interactive landscape represent complex ecological processes which in nature can act over tens of years and could not normally be experienced by an individual.

- Zone 1 - The pristine state
- Zone 2 - Early habitation (1940's - 1950's)
- Zone 3 - Later habitation (1940's - 1950's)
- Zone 4 - Present day (1990's)



Plate 3.1: Catchment Regions

The package has been designed to facilitate access by learners to a complex information landscape by:

- providing an adaptive navigation system and coherent information metaphor that requires little or no explanation. Thus the learner can rely upon the expected range of operations and functions which are available in the expert's world.
- supplying accessible and usable tools that allow access to the extensive suit of learning support resources presented in a variety of representational forms (such as video and graphic representations of concepts) and to make measurements and investigate the properties of phenomena.
- providing a flexible set of cognitive support tools such as the algae simulation tool, which provide the student with the ability to interrogate, manipulate and extract information in a manner supportive of learning through a constructivist approach.
- providing a hierarchical set of problems to solve. Each problem is based on the information embedded in the landscape, thereby, creating meaning from an otherwise disparate set of resources.

The problem-solving challenge for students to become active participants in the learning process is presented on entry to the metaphorical environment, the data collection facilities allow collection of a full range of media forms and simulators allow the user to ask questions and investigate possible answers to those questions.

By providing a metaphor relating to the real world, students are encouraged to apply scientific concepts and techniques in new and relevant situations in this ecology-based application, throughout the problem-solving process. In so doing, the learner is likely to become more interested in developing questions, ideas and hypotheses about the learning experiences encountered. As an alternative teaching/learning strategy in the development of inquiry and problem solving techniques, this package incorporates high quality visual materials in the form of graphics, sound, text and motion video together with scientific measuring tools to aid in the construction of understanding.

3.2 Phase One: Underlying Model Development

3.2.1 Original Design Brief Parameters

The basic design parameters to be met in the original brief are provided in some detail in Appendix 3.17. In summary they included:

- The simulation is to be built as a HyperCard® stack. The model engine is to be developed and run in a HyperCard® environment..
- The simulation will represent one option available within a simulation component of this package.
- The simulation will be a stand alone, plug-in module.
- The simulation will be based on a mathematical model which operates on the principle that, provided there is sufficient light, and the temperature is within the tolerance levels, the major controlling factor in the development of eutrophication in a lake is the availability of nutrients, namely phosphates and nitrates, both water born and within the sediment.

At the time of preparation of the original design brief, two models were under consideration as possible engine shells for this simulation. Aquasim®, Bowker & Randerson (1989) developed a model which simulates an aquatic system with continuous throughput of water, a lake with fairly regular inflow/outflow, in which there operates a simple food chain comprising phytoplankton, zooplankton and fish. The model parameters may be varied by the user to simulate the response of the two forms of plankton to changes in light, temperature and nutrient concentrations in waters of different trophic status. Bowker & Randerson suggested that their model was the only one to date which had been designed to facilitate interactive learning via practical work at a computer. All previous models had been developed for the purpose of research. The authors also made reference to a model produced by Larsen, Mercier and Malueg (1975).

3.2.1.1 Input / Output

The input of data for the operation of the simulation would be via either the 'tool box' within the system or via animated equivalents.

The parameters over which input control (via the tool box) should be possible, would include:

- temperature
- light levels
- nutrient input from both the water and sediment
- time
- turbidity levels as they impinge on light penetration
- water input to the lake (via rain inflow and ocean exchange).

Using the graphic input method, it may only be feasible to vary one parameter, nutrients, albeit via a number of sources including, homes, industries, agricultural pursuits etc.

3.2.1.2 Output of data

Output should be provided in a clear and attractive way in keeping with the general design of the *Investigating Lake Iluka* package and take advantage of the display capabilities of the interface. Three methods of data presentation were considered:

- an animated lake in which colour patches equivalent to various levels of algal growth appear/disappear as the simulation runs.
- graphic presentation of the data at any selected part of this lake. This will be facilitated using the tool box to sample a selected area during the simulation to examine the effects of parameter manipulation.
- a windoid displaying continuous changes in the key parameters as the simulation proceeds.

The animation output should be available on both the computer screen and snapshots of the computer screen should be able to be cut and pasted into the notebook. It should be noted also that it may also be desirable to have both the display of parameters and the animated output visible on the screen simultaneously.

3.2.1.3 Learning Evaluation

It is desirable that at any stage during the progress of the simulation operation the user should be able to determine what decisions have been made and what effect they have had on the outcomes to date. To this end there should be an option to display for any given moment such parameters as:

- the data input so far
- the original settings for the area under study
- the change in nutrient levels effected as each of the input parameters is changed
- the consequent changes in algae density in the area under study
- it should also be possible to compare these values with some other area in the simulated lake via the tool box.
- it should be possible for the user to obtain a printout containing this information so that the value of group discussions and collaboration concerning the outcomes of parameter alterations can be fully utilised.
- it may also be feasible in a consequent version to provide a means by which the user can directly manipulate the model itself, thus extending the ability to develop higher order cognitive skills such as critical thinking and problem solving.

3.2.1.4 Some Operational Considerations: The General Interface Design

It was envisaged that eventually a number of simulations would be operational, all of which would be structured to follow the same basic format as the *Iluka* package. Those shown in Appendix 3.8, Figure 1 represent examples.

The simulation of algal blooms in lakes was modelled on Lake Illawarra, a relatively small lake which has a semipermanent opening to the sea. Environmental studies have been conducted on the lake by both Government and private bodies, (Lake Illawarra Management Committee, 1985, 1986, Wollongong City Council-University of Wollongong (undated) and Yassini, 1985), yielding a rich data source of the physical and chemical makeup of the lake and the impact encroaching human habitation has had on it. The opening screen was planned to be a colour graphic in the graphic field depicting a general aerial view of the lake.

Labelled buttons were to be employed to facilitate access to the branches within the system.

3.2.1.5 The Interface - Structural Components

In the original design statement, the entry point for the simulator was to have been a Title Screen, Appendix 3.8, Figure 2 with a static colour picture of green algal mats, (from local TV news footage), within the graphics field and the title of the simulation in the text field, with some general information as to navigation. There were to be 4 labelled pathway buttons:

- **An overview:** Selection of this button would provide two choices, a navigational map or, open a windoid on the computer screen in which would appear a video clip. This option may also have a sub-option Help which would provide more detail on operational aspects of the simulation.
- **See News Footage:** The news footage option, Appendix 3.8, Figure 3, would provide three choices via labelled buttons, General Views, extent of the bloom and 'red tide' case, the 'red tide' option will be linked to the Expert View option.
- **An Expert View:** The expert view option, Appendix 3.8, Figure 4 will provide three video clip , Causes of Algal Bloom, the Effects of the Bloom and Possible Solutions. A further option on the experts view screen would lead to a series of flowchart representations of some of the important interrelationships that exist within the ecological structure. Those presented in Appendix 3.2, Figures 9, 10 and 11, are some suggestions. It may be desirable to have others.
- **Run Simulation:** The essential structural layout of the original simulation is shown in Appendix 3.8, Figure 5. The screen was to contain three option buttons, Appendix 3.8, Figure 6 Simulation Overview, (highlighted when the screen opens), a Run preset Simulation option and an Input or Adjust Lake parameters option.

The structure outlined above reflected the intention to provide the simulator as a stand alone component in the package *Investigating Lake Iluka*. The simulator was to have all the supporting resources (video, text etc.) contained and accessible within its own

structure. In the redevelopment for inclusion within *Exploring the Nardoo*, the simulation tool became an integral part of the whole catchment simulation, with the supporting resources (video, expert opinion, text) being common and embedded within the complete simulated environment. Data collection/storage/manipulation was achieved through the use of a complimentary tool, the Personal Digital Assistant (PDA).

3.2.1.6 Input/Output Functions

In the original design, entry to the simulator was to have been via an input option button. Selection of this button would result in the display on screen of an adjust the lake parameters option. It was intended that two methods be presented to the user when this option was selected, an *iconic* and a *dial up* numerical input option. The iconic option was to provide the user with a series of symbols which would represent a nutrient contributing factor or variable, for example, an urban development, a factor or the like, and each symbol would have a finite value ready to be linked into the mathematical model.

If students wished to have a more definitive control over the whole range of parameters they would be given the option of altering the parameters via the tool box. Appendix 3.8, Figure 7. This was to support and facilitate a more detailed exploration of the simulation and consequently, enrichment of the learning taking place by:

- allowing the user to take readings using the tool box at the site being studied and observe the changes as the simulation runs.
- allowing these readings to be compared with readings of the same parameters taken at other locations.
- allowing the monitoring of all the parameters while the simulation is running with the aim of examining inter-relationships.

Once parameters were set, the student would be given the option to:

- make changes to their settings
- run the simulation
- select output options, or
- quit or return to main menu.

Given the richness and realistic nature of the data available in the *Exploring the Nardoo* environment, the fixed variable approach became superfluous. Students would gain far more from the tool with the ability to infinitely alter any or all of the variables and collect data directly from the environment.

The Output options, Appendix 3.8, Figure 8 were to include:

- an animated representation algal growth linked to the model's output and,
- graphical representation of the output.

One of the determining factors in the design and implementation of the simulation tool for *Exploring the Nardoo* was the authoring system with which it implemented and described elsewhere in this chapter. Its versatility allowed the simulator tool to incorporate all of the control features at the same operational level so that students did not have to navigate to various screens or sub parts to make changes to the input or output conditions. All controls were always available and live, resulting in a system which responded immediately to interaction with the user.

3.2.2 Evolution of the Engine: The 'Bench Mark'

Lake Shagawa in Minnesota, described and modelled by Larsen, Mercier and Malueg (1975) was selected as the *reference case* for a number of reasons. Firstly, its physical similarity except for the patterns of surrounding land use and hence sources of nutrients, pollutants etc. to Lake Illawarra. Secondly, the mathematical model used for the mechanism of algal bloom incorporated most of the factors which the current model used as essential to a real life simulation of algal bloom. Thirdly, the model for Lake Shagawa was based on extensive data both in terms of actual data points and longitudinality. Finally, the model had been extensively tested and fine tuned against observed lake conditions to maximise its precision without compromising its generality or more importantly its realism.

3.2.3 The Modelling Environment

The platform used in the development, initial testing and refinement was the modelling software package from High Performance Systems, STELLA®. Development

for the package *Investigating Lake Illuka*, was completed using version 3 of STELLA II®. This version provides the facility to hide much of the detail workings of the model as sub routines, thus minimising the complexity which occurred in the complete model diagrams produced using the earlier version. (Figure 3.3)

STELLA® is particularly suited to the task of helping to build and clarify the developers understanding of the complex interrelationships in dynamic systems and processes. It is a ... “multi level hierarchical environment for constructing and interacting with models”. (Petersen & Richmond, 1994). It has the capacity to allow the novice user to develop and explore sophisticated dynamic models without the use of complex mathematics.

The user can represent and test ideas about relationships, causes and effects. This could be enhanced by providing deeper levels of manipulation. Based on the taxonomy proposed in chapter 2, the current simulation package could take on the form of a ‘Level 3 symbolic simulation’ if a model authoring environment such as a STELLA® were incorporated. The students could then alter the model as well as the variable values, thus facilitating a deeper understanding of the dynamics of the system. STELLA® can provide the vehicle by which users can “see what and how they are thinking”. (Petersen & Richmond, 1994).

3.2.4 Data Sources

Testing of the model was a demanding process as extensive ‘hard data’ for both the bench mark lake, Lake Shagawa, and the local lake, Lake Illawarra were not readily available. Fortunately however, the mathematical model based on Lake Shagawa had been extensively tested and the output data from the model for many different sets of conditions were reported on in the research paper. These output curves together with the suggested limits for the key controlling factors suggested by Larsen, Mercier and Malueg (1975) provided, along with the limited data for Lake Illawarra produced by Yassini (1985) and others, sufficient ‘landmarks’ in the data to develop a model which provides a realistic, non-predictive model of the process of algal bloom without sacrificing accuracy or generality.

3.2.5 Building and Refining the Model

The purpose of a simulation of any system is to mimic that system, however complex it may be, in such a way as to provide the user with a meaningful real life based experience. Perusal of the literature on the cause and effects of algal blooms indicated from the outset, the complexity of the system to be modelled. The goal was to model the process of algal bloom in such a way that it provided a realistic, but not predictive model, without sacrificing its accuracy or generality. Larsen, Mercier and Malueg (1975) among others maintain that such an approach is crucial to the production of models of complex systems which will enrich understanding.

The initial step in modelling involved a search of relevant literature. Although much of it proved to be quite dated, it nevertheless provided an excellent starting point. After drawing together the essential relationships, some test loops were structured. Figures 3.1 and 3.2 depict some of these. These early designs had a two fold functions. Firstly, they provided insight into the functioning of the modelling platform (STELLA II®) and secondly, they helped clarify in the author's mind some of the relationships.

There followed a gradual extension and improvement in the elegance of the structures. Apart from changes in internal mathematical relationships which occurred throughout the development of the model, the following structural changes, modifications and extensions were made as testing against known models proceeded.

- The availability of N (Nitrogen) and P (Phosphorous) through the breakdown and decay of the algal mass was factored into the P and N supply equations.
- Pathways to factor in the effects of the parameters, depth, temperature and turbidity, in the growth equation were added.
- An initial Chlor 'a' value, (concentration of chlorophyll 'a' in the water column), which provided a closer match of the models output with the target output.

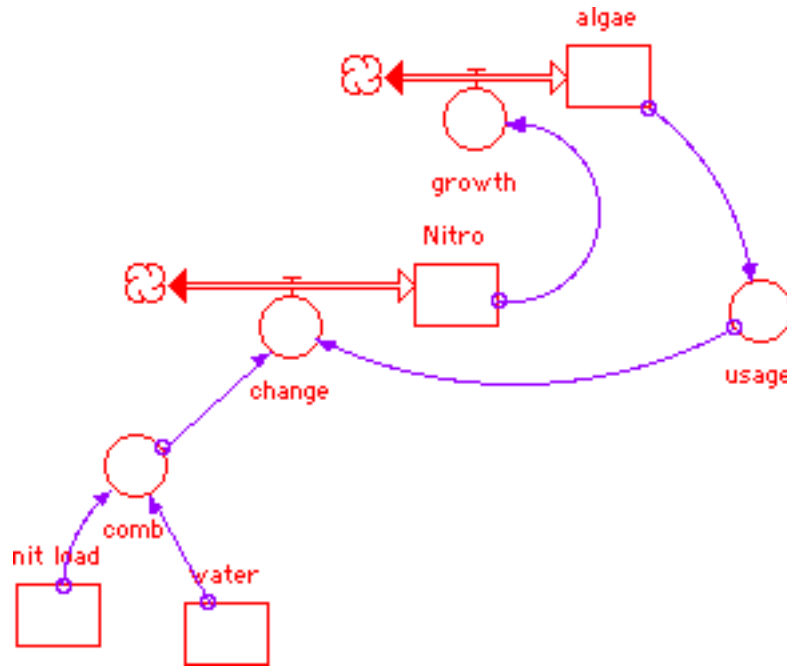


Figure 3.1: Early test loop for algae growth

At this point stability of the output when extreme nutrient values were used caused some problems and further changes were made to the essential relationships to overcome this.

Further structural changes in order to more closely model the real world system included:

- Incorporation of a *flush factor*. Most lakes are periodically flushed and as such flushing has drastic effects on the concentration of all materials in the water column, it was essential to provide a mechanism to flush the lake.
- A further refinement was to separate the *flush control* and the inclusion of a *stirrup control*. This allowed for the increase in turbidity that would naturally occur with flushing of the lake, to be taken into account.
- A mechanism for modelling oxygen depletion. It is one of the most important and devastating effects of algal blooms, and was also incorporated because it can cause extensive fish kills.

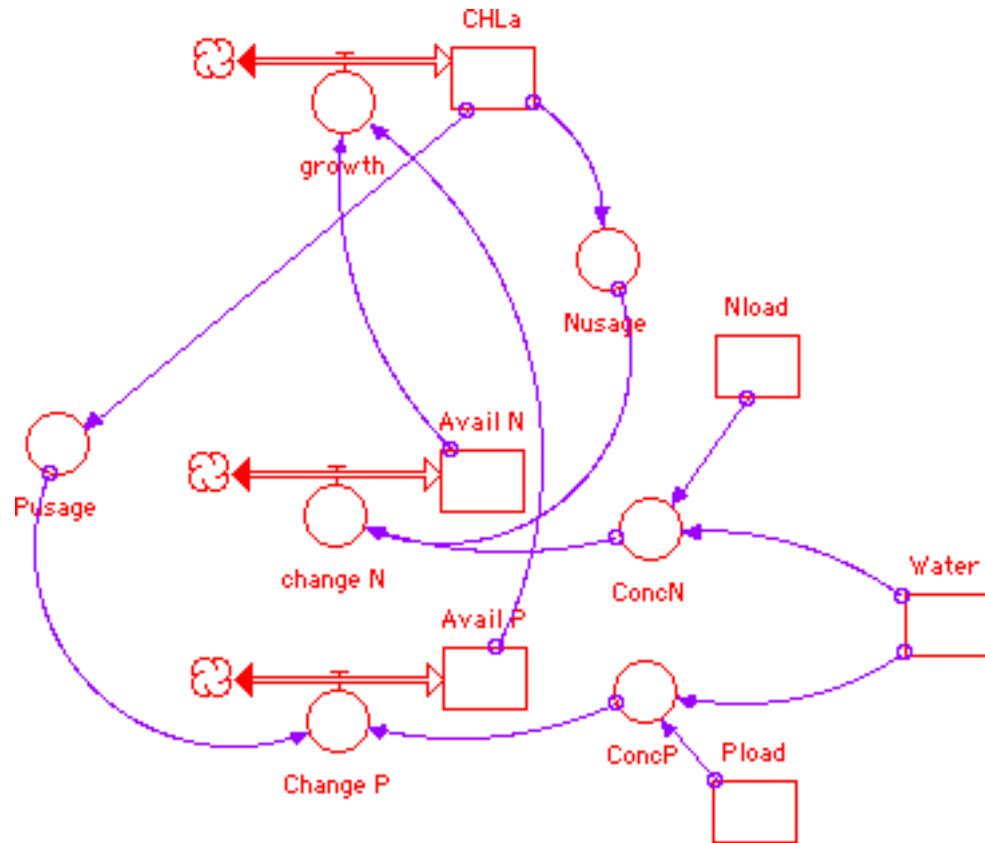


Figure 3.2 Addition of controls for nutrient input

The final model provided a relatively stable and close match to target output system which had been fully tested against expected outcomes.

3.2.6 The Essential Mathematical Relationships

The essential mathematical relationships developed and used in the final version of this model to simulate the development of an algal bloom in a lake such as *Lake Iluka* are set in Appendix 3.10.

The model has three main components, an algal growth equation, a N supply equation and, a P supply equation. Each of these is outlined in detail in this section. Each is interconnected with numerous subsidiary relationships which are also detailed in Figure 3.3 which is a schematic of the final version of the simulation showing the connecting relationships.

As stated in the original design brief outlined in section 3.2.1 of this chapter, the essential driving forces behind the development of an algal bloom are, the presence of sufficient concentrations of nutrients, specifically those which are nitrogen or phosphorous based, sufficient light to support the process of photosynthesis and, a water temperature which is conducive to plant growth. Most of the other factors which are considered to be of any significance are either directly or indirectly related to these driving forces.

A difficulty in the measurement of algal concentration in a water column is the means of its actual measurement. The measure of algal bloom concentration adopted in the model used in this simulation is the concentration of *chlorophyll a* present in the water column. A concentration approaching 55 µg/l or greater is considered to produce significant bloom. In this model, such an output results in the depiction of a significant algal bloom and its associated problems including, oxygen depletion, increase in turbidity and consequent kills of organisms in the lake.

The development of an algal bloom is a function of the factors that directly promote growth and those that promote its natural loss, death and other mechanisms. The inflows for the algal growth equation are shown in Fig 3.3. The factors $N/72$ and $P/6.3$ are taken from the Lake Shagawa model and represent the yield rate of *chlor a*/mg of available nutrient. The initial rate in of *chloro a* is assumed to be zero, although the model does have an initial *Chlor a* input to prime the model. This is preset and not available to the user. The same is the case for the chief nutrients, N and P. An extension of the capabilities of this model at a later date may involve making these controls available to the user. The other inflows to the growth equation are the available light and the water temperature. The factors of available light, temperature, and turbidity are also factored into this growth equation.

Data from all available sources seem to indicate that significant algal bloom will occur when the available concentration of N in the lake water approaches the region of 196 µg/l and for P, 26 µg/l. It is up to the user to explore the relationship between the relative abundances of these elements and its effect on the development of an algal bloom.

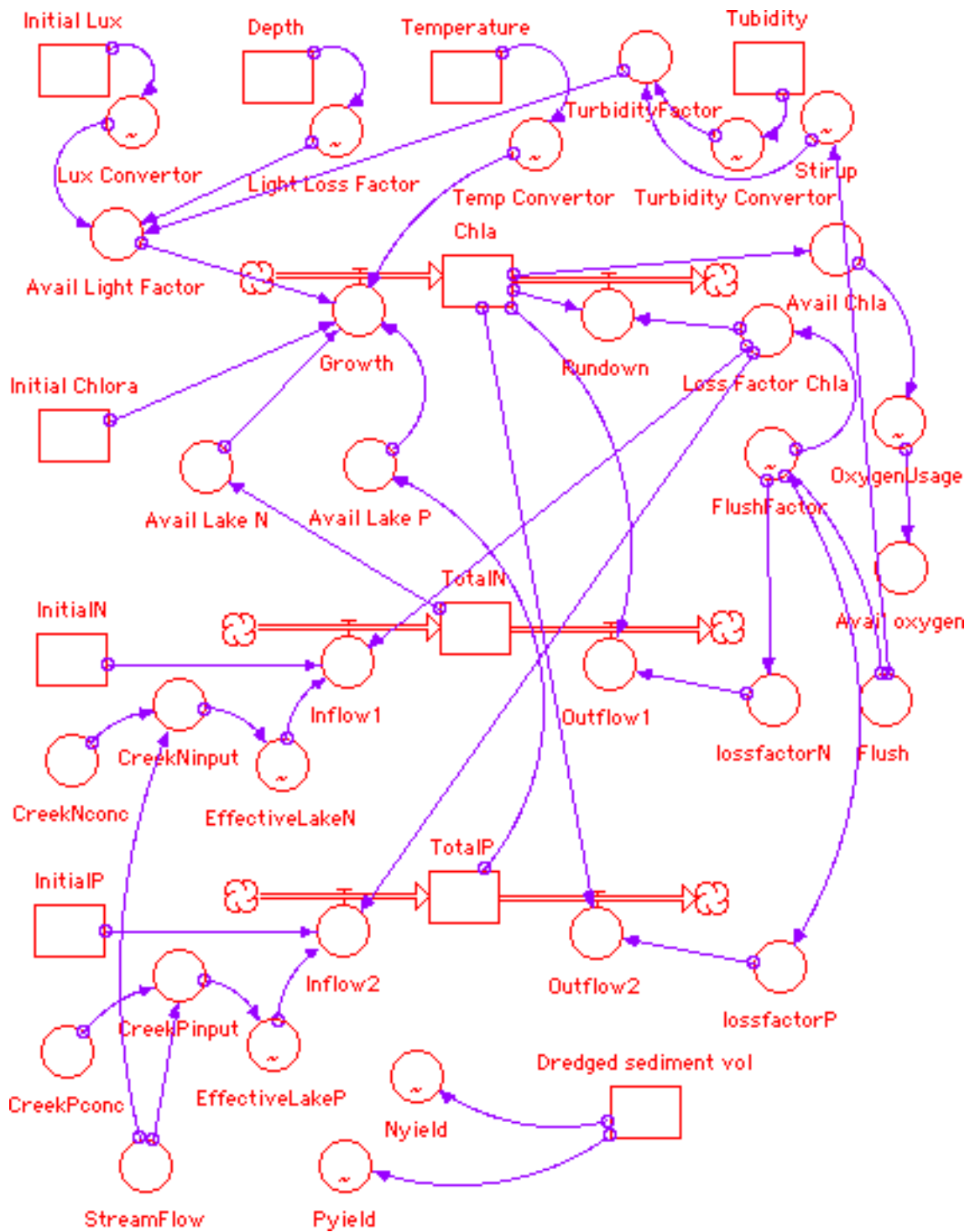


Figure 3.3: Schematic of Final Version- Lake Iluka Model

The rundown equation, which handles the natural process of decay of the blue green algae, is within the section dealing with the equations in the final model elsewhere in this chapter. The value for the *Chla loss factor* (rate at which chlorophyll a is lost from the system through death and decay of the algal mat) is a best estimate developed from the literature. The other two components, the N supply equation and the P supply equation and their associated equations are detailed within the section dealing with the final model equations.

3.2.7 Developing the Accompanying Resources

Among the expected outcomes for the complete *Investigating Lake Iluka* package including the simulation, were the development of higher order skills such as critical thinking, critical appraisal and problem solving techniques. It was essential that the practical, hands on side of the package be backed up by useful and comprehensive resource materials. No details of these resources have been provided here but it should be noted that this feature was incorporated in the design, albeit in a different structure within *Exploring the Nardoo* and as the results of this study show, proved valuable for students in achieving suitable learning outcomes. These materials as well as other resources outlined in a later section of this chapter included in the *Nardoo* package are provided in Appendices 3.1 through 3.7.

An extensive set of audio, video and text based resources covering both theoretical and factual aspects of algal blooms and the social aspects such as human impact on the environment and how this impact on bloom propagation were developed. These materials included, a set of scripts which were to be the basis of a Talk to an Expert function, centred on a series of QuickTime® based video clips, a script for a video clip based Introduction to the Simulation, a set of video scripts (Appendix 3.3), specifically produced to support selected issues and a set of radio scripts (Appendix 3.4), for the audio/visual resource section in the Water Resource Centre, a set of newspaper clippings (Appendix 3.2), based on community issues, and a set of resource notes (Appendix 3.1), based on client supplied official documentation, brochures and fact sheets.

Certain fact sheets (Appendices 3.5 and 3.6) designed to specifically support the algal bloom simulator were also available in the Water Resource Centre.

3.3 Re-purposing the Model for *Exploring the Nardoo*

The model eventually implemented within *Exploring the Nardoo* was a modified version of the final model developed for the package *Investigating Lake Iluka* and described elsewhere in this chapter. As described later in this section, the essential changes involved modifications in collaboration with the client's experts in the area, that would take into account the transfer of a model designed to simulate a lake environment to one which would adequately and accurately simulate a river environment.

The underlying process of Blue-Green Algae growth is essentially the same, being controlled by the interplay of factors such as the concentration of phosphorous and nitrogen in the water, the availability of sufficient light levels and the maintenance of sufficient warmth to activate and maintain this living process.

In the initial stages of redevelopment of the engine for *Exploring the Nardoo*, little information on modelling the process in rivers was available. Based on discussions with subject matter experts employed by the client for whom the package was being developed, a prototype was developed and tested by the client.

A number of modifications were then made to some of the algorithms associated with such aspects as the algal decay rate and its impact on the availability of free nutrients. Some modifications were also needed to the algorithms associated with the effects of light and temperature. More significantly the need to incorporate to a more significant degree the impact of water flow-through was targeted. Water movement within the river has several effects including:

- addition of more nutrients due to the stirring up of nutrient rich sediments;
- an associated increase in turbidity with a resulting loss of light;
- changes in water temperature brought about by natural influx and the more significant and damaging thermal pollution caused by entry of cold water from dams and;
- a wash out and hence diminishing of the deleterious effects of such blooms.

In striving to produce a simulation which provided the closest possible match to the real world, several other features were developed and incorporated within the model. One of the most significant effects of an algal bloom is its ability to lower the oxygen content of water and hence result in significant kills of water born organisms. Associated with this is the release of toxic compounds as a result of the breakdown of the algae as it goes through its life cycle. As a result, algorithms which faithfully replicated these effects (including the natural delay associated with these in nature) were incorporated.

The final model shown schematically in Figure 3.4 represents the result of several iterations of testing and modification in the native development environment (STELLA®) under the guidance of the clients subject matter experts (SME's) and while it is not predictive, it does provide an accurate analogue of the real world process.

3.3.1 Blue-Green Algae Simulator Specifications

The specifications outlined in this section and detailed in Appendices 3.11 through 3.16 provide the detail for the development of the algal bloom simulation tool for *Exploring the Nardoo*. They formed part of the design brief, proof of concept statements and milestone reports provided to the client for approval prior to commencement and during the various stages of development. The documentation represents the proposed structure and function. The actual development was a dynamic process which saw these specifications evolve through consultation and testing in conjunction with fellow members of the design team and the clients SME's into the final tool described in the last section of this chapter. A number of the features outlined in these specifications were not included within the final package due to various constraints. The most notable of these was the provision of feedback using talking heads linked to critical phases of the process. These talking heads, would provide a more personal feedback as to the state of the system being simulated.

They were mooted for inclusion and much of the development work (scripting of voice over was completed) but not implemented because of time and monetary reasons. Plate 3.6 depicts an earlier version of the interface and contains an artifact associated with this talking head feedback.

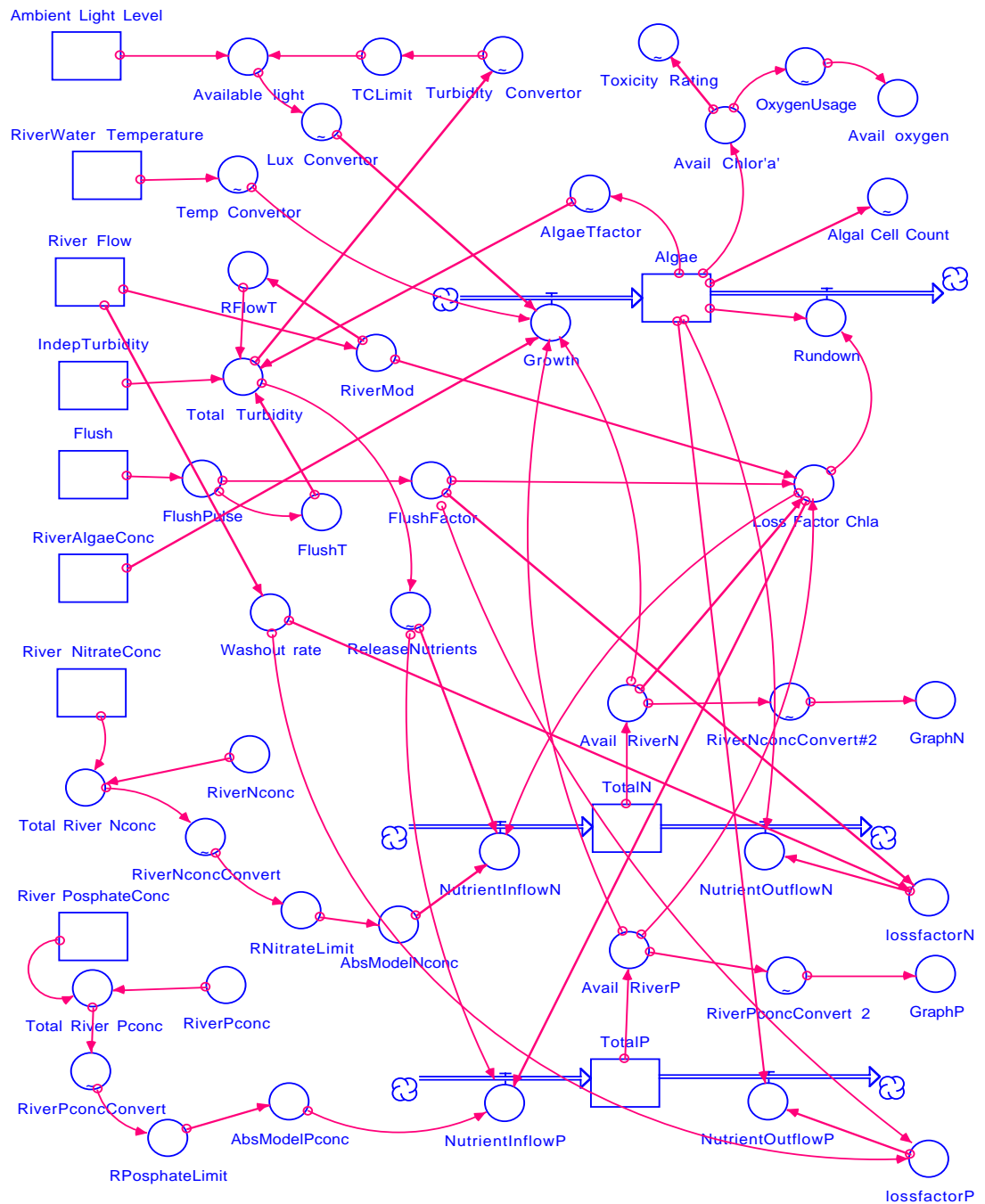


Figure 3.4 Schematic of *Exploring the Nardoo Model*

It was envisaged that the user could elect to turn the feedback on or off using the action buttons. Details of this feedback mechanism are provided in Appendix 3.11.

3.3.1.1 General Interface

The general interface specification set out in Appendix 3.11 provided the client with a reference point for discussion in terms of client needs and the general educational and design principles upon which the development of the package as a whole was based. Issues such as the available screen space, gross simulator functionality, basic navigation, display function and the overall aims and expected outcomes for the design process were addressed. Operational considerations addressed in a general form in this specification included input and output functionality. In terms of the output, details were provided on the function of the various modes of output display and detailed analysis of the expected pattern of use was provided.

3.3.1.2 Detailed Operational Considerations for the Simulator

The blue-green algae simulation tool was to be one of three available for students to use during their investigation of water catchment management issues. The look and feel as well as the functionality of these three tools had to be the same. The details of this section of the specification documentation is set out in Appendix 3.12. It includes the initial state of the proposed generic simulator including aspects of its appearance and automatic introductory sequences the user may see when opening the simulation tool. This section also includes extensive details on required inputs and outputs together with an outline of the expected simulator screen actions for various user interactions.

3.3.2 Model Parameters and Equations

The detailed parameters for model behaviour came from client consultation and testing as well as the initialisation and run time equations upon which the simulation tool is based. The programming notes, originally provided for the programming team members to provide direction in the implementation of the model contain a wealth of information about the process of bloom development and how the factors are inter-related. All of the documentation within this section was supplied in a simplified form as documents in the Filing Cabinet Resource, available to all users of the package.

Use of these could provide sufficient detail for the user to arrive at an understanding of the relationships involved in the process.

3.3.2.1 Basic Model Parameters / Expected maximum and minimum values

Appendix 3.13 sets out the base physical and chemical parameters for the underlying mathematical model as well as the expected range for each of the outputs. This documentation was also provided as an embedded resource within the Water Research Centre in the package.

3.3.2.2 Initialisation Equations

The algorithms developed and utilised in the underlying mathematical model for algal bloom simulator are provided in Appendix 3.14. A number of the relationships within the model are expressed as complex high order polynomials and the corresponding graphs of these relationships are included to assist the readers in their understanding by providing a snapshot of the relationship. The document is set out in sections dealing with each of the principle factors separately for clarity. This document formed the basis of client acceptance of the efficacy of the underlying model.

3.3.2.3 Run time Equations

To facilitate and smooth the process of implementation of the algorithms within the package authoring environment a close liaison between the author and the programmers was supported by two essential sets of documentation. It required a specification for the order of execution and initialisation of the equations. Appendix 3.15 presents this run time equation sequence specification.

3.3.2.4 Equation Programming Notes

It also required supportive documentation in the form of equation programming notes. These notes provide a detailed insight into the algal bloom process and were an essential part of the development process in that they provided a bridge between the authors extensive knowledge of the underlying processes and the less detailed knowledge

of the programmers. Appendix 3.16 provides a stripped down version of the programming notes developed to support the programming team. In this stripped down form, it was part of the documentation provided in the Water Resource Centre within the Filing Cabinet and provided an added resource for users of the package whether they used the simulator or not.

3.4 Phase Two: Developing the tool for *Exploring the Nardoo*.

3.4.1 Overview

The essential purpose for the development and inclusion of the Blue-Green Algal Bloom simulator within *Exploring the Nardoo* was to provide students with an enriched experience. It also enabled better learning outcomes with respect to both the quality of the problem solving process and a deeper understanding of the underlying processes by providing unhindered access to act and become immersed in a real situated process. They could manipulate the various causal parameters and test hypotheses without a real consequence or risk, and in a time frame which was convenient and manageable. Thus “enabling the learner to ground their cognitive understanding in their action in a situation” (Laurillard, 1996).

Users are provided with the facility to solve problems and understand relationships at a deeper level through the testing of their own ‘what-if’ scenarios. This can, during the course of solving problems... “facilitate more detailed exploration and learning by;

- allowing the user to take readings at a sight and study the changes as the simulation runs,
- allowing the monitoring of all parameters while the simulation is running, with the aim of exploring the relationships between them” (Corderoy et al., 1993)

The innovative incorporation of multiple forms of feedback in the simulator has added to its power as a cognitive tool, which supports deeper learning. Data input is simply achieved using slider controls, allowing the user to check the input values against the outcome values at any time during the simulation run. Likewise output data from the simulation is also visible at all times and the format in which it is displayed is user

controlled. Pure numerical data is displayed in the output data windows, while the main screen of the simulator may be toggled between a graphical or animated display of the process.

One of the most important factors in achieving the seamless integration of the various forms of output and the dynamic nature of the output presentation is its development using the University of Wollongong developed authoring software MediaPlant®. This powerful software supports the ‘on-the-fly’ calculation of outputs so that students using the simulation tool are able to see the effects of their interaction with the system immediately. This innovative use of ‘on-the-fly’ calculation provided the user with a continuous time-line depicting the process from start to finish within one window allowed the students to see at a glance the nature of the process over time.

Apart from the key data expected from the simulation, users can select which output data they wish to view during the simulation. In the algal bloom simulator, the algal cell count is considered to be the key output data and is on display at all times. The user may also elect to view the nitrogen and phosphate levels in the water as well as the percent of dissolved oxygen. They may also elect to view a toxicity rating.

3.4.2 Simulator Design

As the Blue-Green Algae simulation tool was one of three, there was a need to provide a generic uniform appearance and functionality to all three. The first version of the interface for the simulation tools was based on the proposed interface for the Lake Illuka implementation of the simulation. Plate 3.2 shows three basic areas of functionality, an input data area, a data display area and a visual output display area. Plate 3.3 shows the mock-up version of the simulator tool interface for *Exploring the Nardoo*.

The look and feel of the final simulator tool module maintained this basic structure. It was designed to provide students with the opportunity to explore; the processes of blue-green algal bloom development in a river; the factors which cause such blooms, and to observe the results of their experimentation in a seamless and easy-to-manipulate way. Output from the simulator was to be provided in three display modes; graphical; animated and numerical.

In the early stages of design, the main visual display window in the simulator tool was to contain a graphical representation of the bloom as it developed, (Plate 3.4) and an ‘insert window’ would simultaneously contain an animated pictorial representation of the bloom development. A reconsideration of the design however led to the separation of display modes so that separate windows were used for the animated and graphical outputs. A toggle switch was implemented to provide the mechanism for changing representation of output data between the graphical mode, (Plate 3.5), and the animated mode, (Plate 3.6). In the case of the display of numerical data in the simulator, a decision was made to limit the automatic display of numerical data so as to minimise the complexity of data presented to the user while at the same time maintaining flexibility in its operation. Only the algal cell count data was displayed automatically (Plate 3.4). Display of the numerical data pertaining to the other variables considered to be of most significance could be activated at will by the user by means of a button located beside the appropriate display window.

3.4.3 Simulator Functionality

3.4.3.1 Using the Algal Bloom Simulator

Users are provided with a short description in the User’s Manual setting out the overall purpose of the simulator and how to get started.

- This simulator illustrates the causes and effect relationships of algal blooms, and helps students determine the relationships between factors contributing to blooms.
- The simulator consists of an output window and a data entry panel which has sliders to allow you to enter values for each variable.
- Users could select the form in which they wished to view the output from the simulator, by clicking the GRAPH or ANIMATE button.

An animated movie illustrates the growth of algae on the river, while the graph form presents data as a continuous graph of variables. To select one or more of the variables phosphorous, nitrogen, oxygen or toxicity, they could click the buttons on the Simulation Output panel.

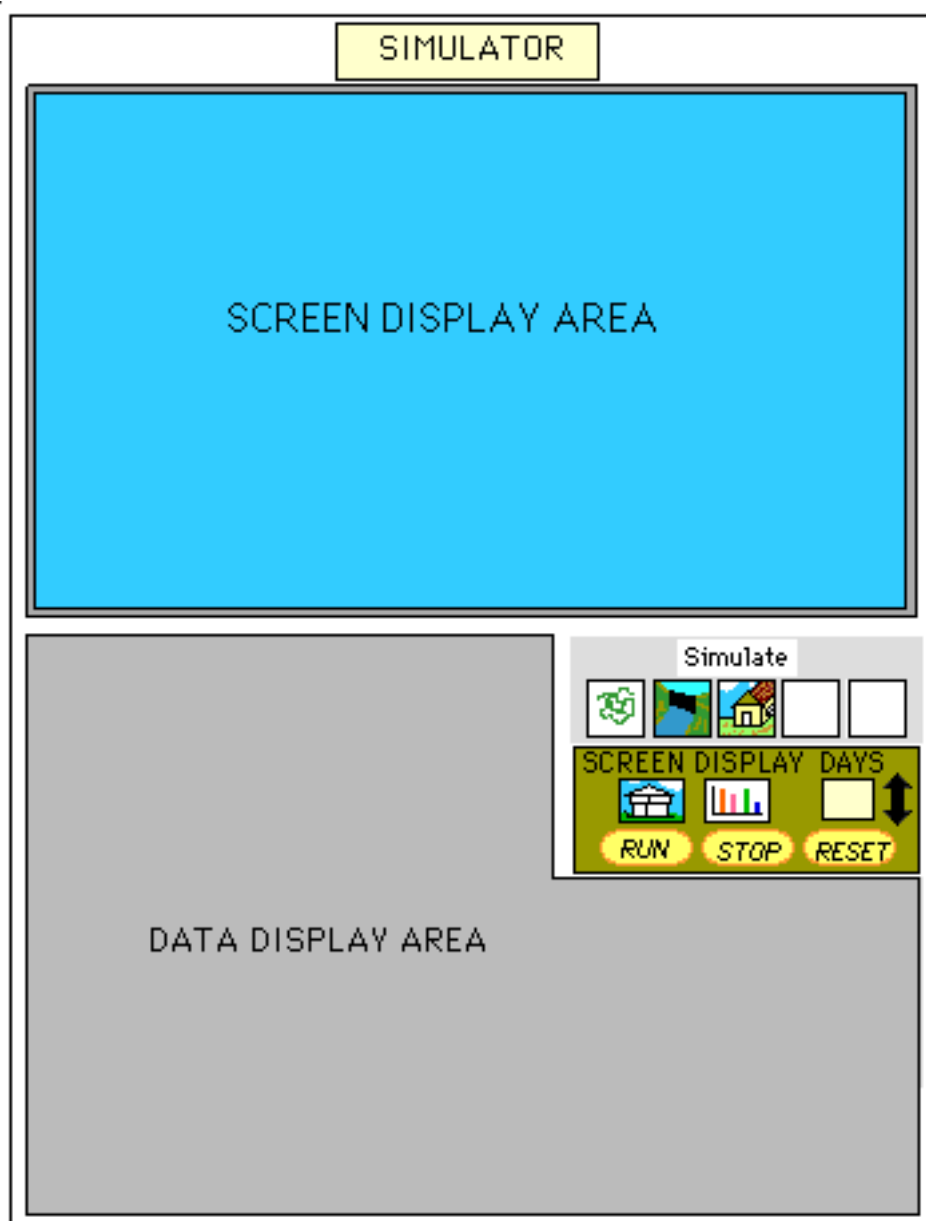


Plate 3.2:
Early Generic Blue-Green Algae Simulation Tool Interface

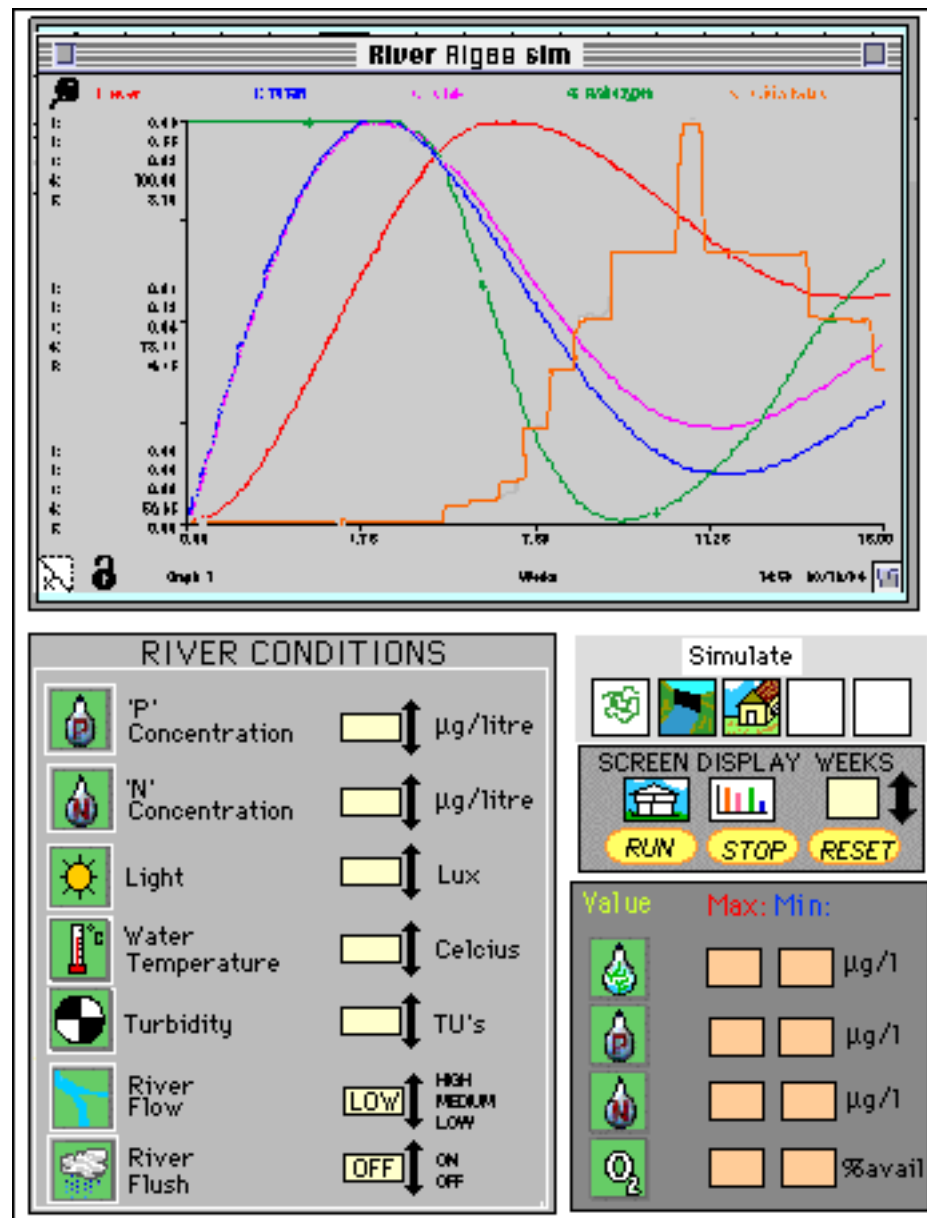


Plate 3.3:
Early Nardoo Blue-Green Algae Simulation Tool Interface

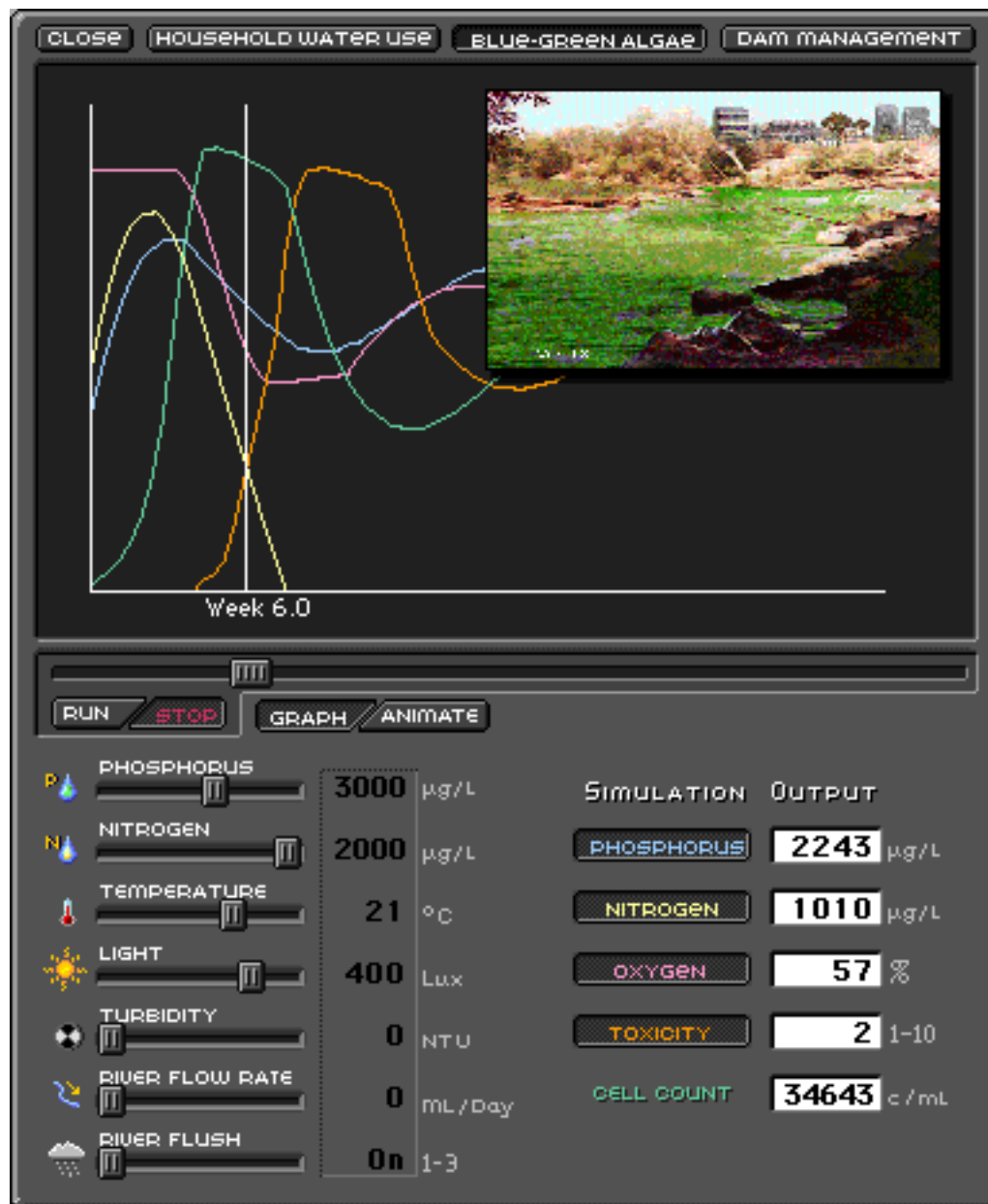


Plate 3.4:
Multiple Representation of Data - Version 1

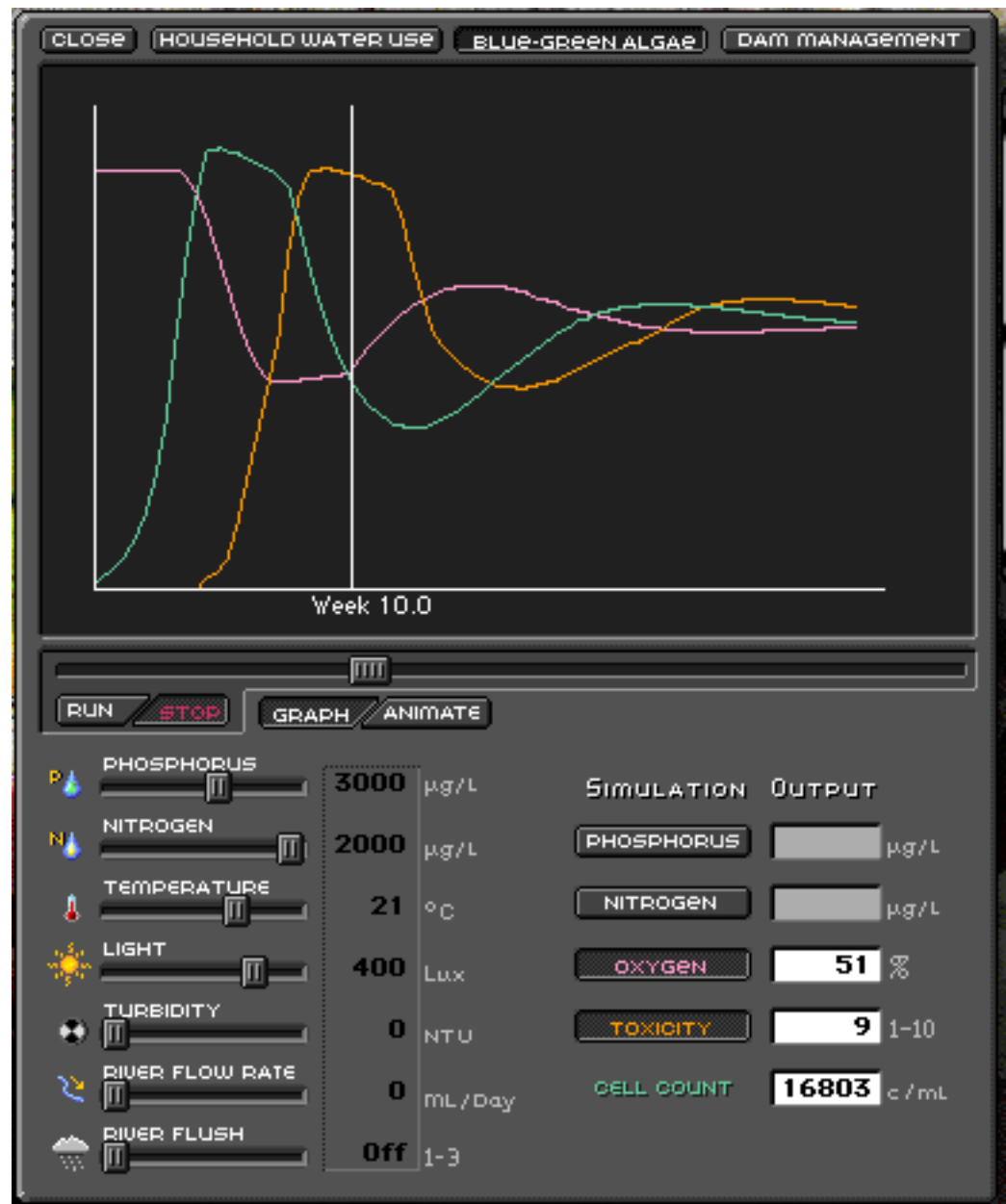


Plate 3.5:
Graphical Presentation Mode



Plate 3.6:
Animated Presentation Mode

- The simulator opens with parameters set to cause a major bloom. To run the simulator, click the RUN button. Click the STOP button to pause the simulation.
- They could alter any of the parameters by using the slide bars.
- The impact of their choices could be viewed at specific points in the bloom's development using the slider at the bottom of the simulator viewing window.

3.4.3.2 Input

Students are provided with control over all the major factors which impinge on the formation of algal blooms including, phosphorous and nitrogen levels, the amount of light penetrating the water, and the temperature of the water. When a student first opens the simulator, the input slider controls which impinge most directly of the development of blooms are set with values which would in the normal course of events produce a significant algal bloom in the river. For clarity, some of these controls are left in the 'off' position.

Altering any or all of these parameters via the slider bars provides immediate feedback on the overall effect on river conditions and consequent bloom development. The 'on-the-fly' calculation mentioned earlier allows the student to move to any section of the process time line and check the output values. The total time over which the simulation runs is set at 30 weeks so that users can obtain a full appreciation for the cyclic nature of such natural systems.

3.4.3.3 Output

It is in the functionality of the output that the tool has its greatest impact. The student is able to select between two visual modes, graph-based or river images. Then by sliding the run tab along the time line, they can toggle between the graph mode or the river image for point on the process time line. By using the run button, they can observe the river images as an animated sequence. This allows them to make a visual connection between the variables they have set on the simulator tool and the effect that bring about in the real world that is *Exploring the Nardoo*. At the same time, the model also outputs numerical data which changes as inputs are changed or the simulator is placed in the run mode.

A feature mentioned elsewhere in this chapter and incorporated within the model but not implemented was the use of talking heads to provide additional feedback on the progress of bloom development, giving the students a more ‘in your face’ indication of what was occurring. This feature was originally designed as part of the *Lake Iluka* model. Appendix 3.7

3.4.4 Resource Materials

In the original design model, the support materials were to be an integral part of the simulation interface itself. In *Exploring the Nardoo*, an extensive set of resources was also developed to compliment and support the learning processes and understandings of students using the simulation tool. The resources included: factual documents on all aspects of river and dam management with respect to the prevention and control of blue-green algae outbreaks; newspaper articles dealing with specific community issues; video and audio resources which dealt specifically with the human aspects of blue-green algae and its effects. The documentation is set out in Appendices 3.1 through 3.4. The factual documents were developed specifically from client-based documentation but others were developed by the design team as support to issues raised elsewhere in the package. All documents were extensively revised by both the client and the design team to ensure that they were accurate and useful.

3.4.5 Using the Simulation Tool

The simulation tool was designed to assist students in solving the problems which were posed by members of a research team in the Water Resource Centre situated within the simulated water catchment area. If students chose to work on the problem of algal bloom in the river, a guide provided them with an outline of the task and some initial suggestions via an audio track about developing a solution. The students may return to the guide to get additional suggestions several time. Each time the guide reveals another level of HELP. (The scripts were developed from a set of suggested expert help scripts developed by the design team, Appendix 3.9)

The design of the simulator interface is such that students should also be able to explore freely the process of blue-green algae development in rivers. The students are able to take measurements from the field and use them to predict river conditions at a location. They could test their hypotheses in terms of the evidence they collected from the simulated environment and resources available. The data collected in the course of this study and reported in chapter 5 suggest that this ability to test hypotheses was considered by the users to be very important in their building of the knowledge and understanding of the process of algal blooms. It also helped them link the process to real world scenarios in the problems presented in the package.

An example is the effect of water flow within the river. One of the related issues involved the question of dams and how the water stored in them could be used to prevent bloom growth. The evidence, in the form of community comment and documentation had two main thrusts. One view presented by proponents of dam development was that the dam would allow a flushing of the river which would remove the growth and solve the problem.

The opposing view was that the river needed to have a continuous flow. Damming the river exacerbate the already poor management of the flow patterns brought about by over- use of the available water resources in the river.

In assessing this proposition and coming to some mental picture of this process for themselves, students could use the simulation tool to test out their mental models. Examination of Plates 3.7a and 3.7b, shows that by providing a continuous flow of water in the river, the level of a bloom is greatly reduced and may in fact prevent further growth.

On the other hand, Plates 3.8a and 3.8b show that, whilst flushing the river initially diminishes the level of bloom by physically removing it, the bloom redevelops. It becomes obvious to the user that flushing is not a long term solution to the essential problem of maintaining low levels of nutrients in the water. The only solution is to maintain a constant flow through of water. Having the ability to observe realistic complex process in real time, interact with and observe the consequences, may be a critical factor in the development of deeper understanding of the process and its impact in a real world environment.

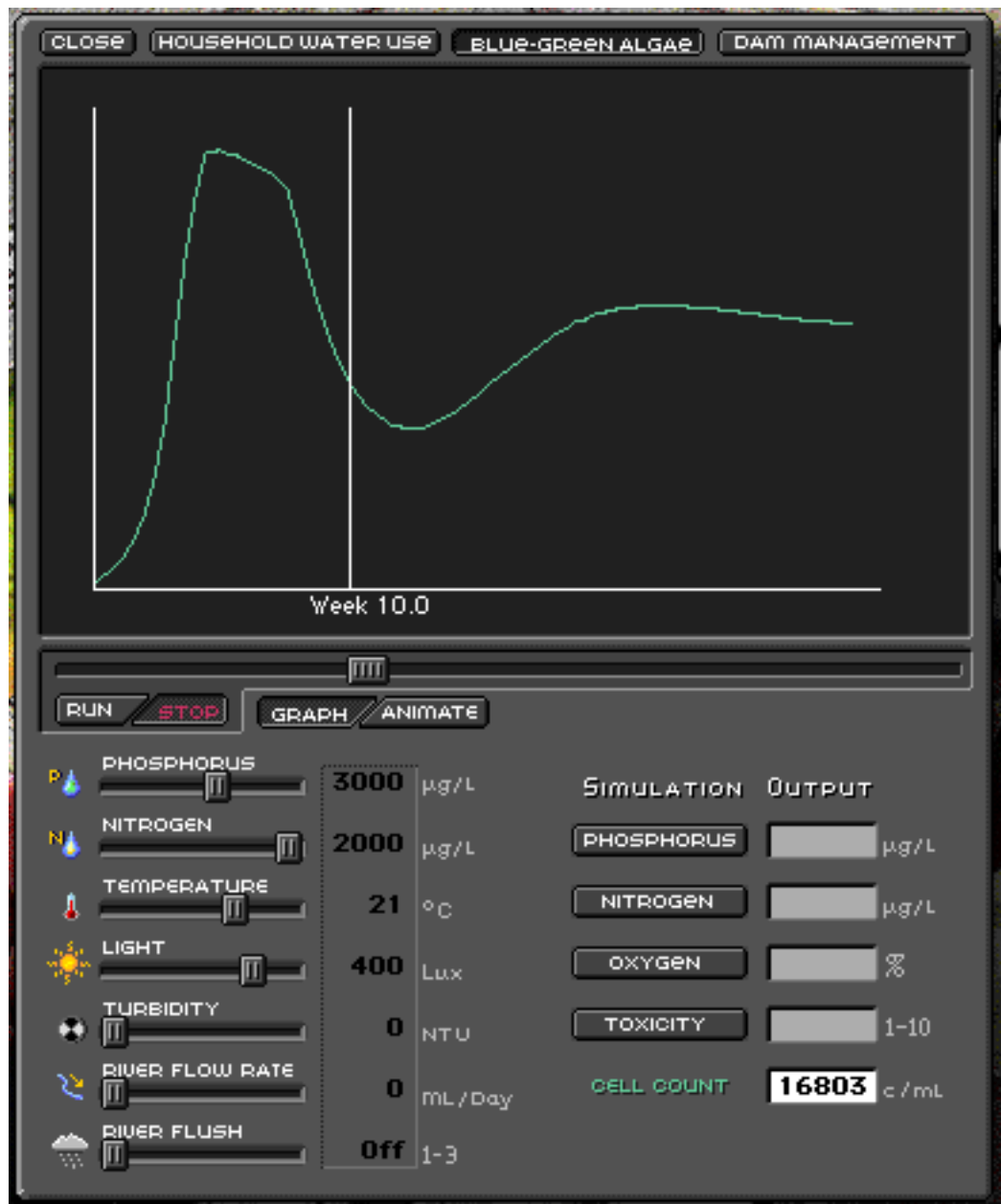


Plate 3.7a:

Testing the Effect of Flow Rate - No flow

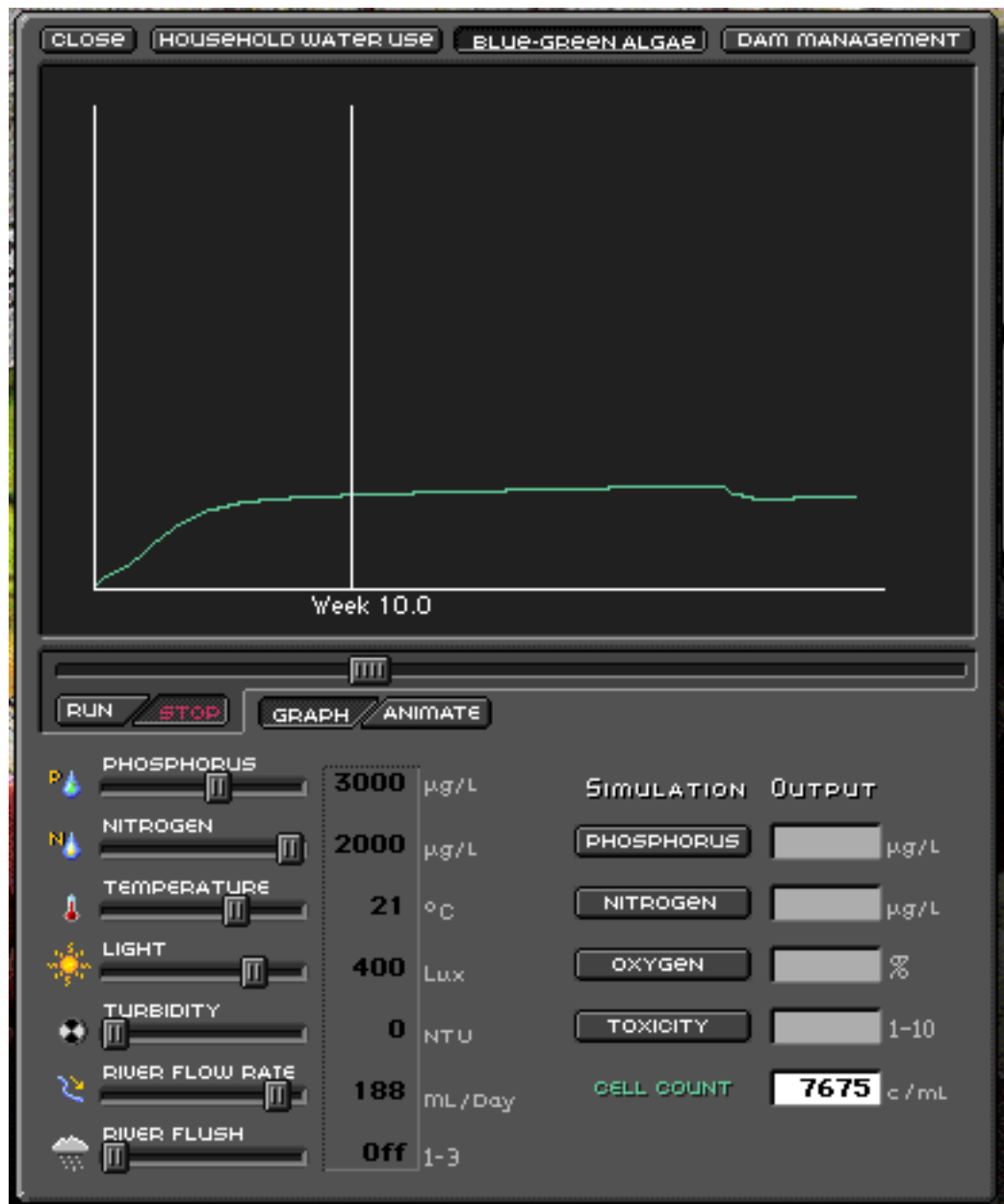


Plate 3.7b:

Testing the Effect of Flow Rate - Continuous Flow

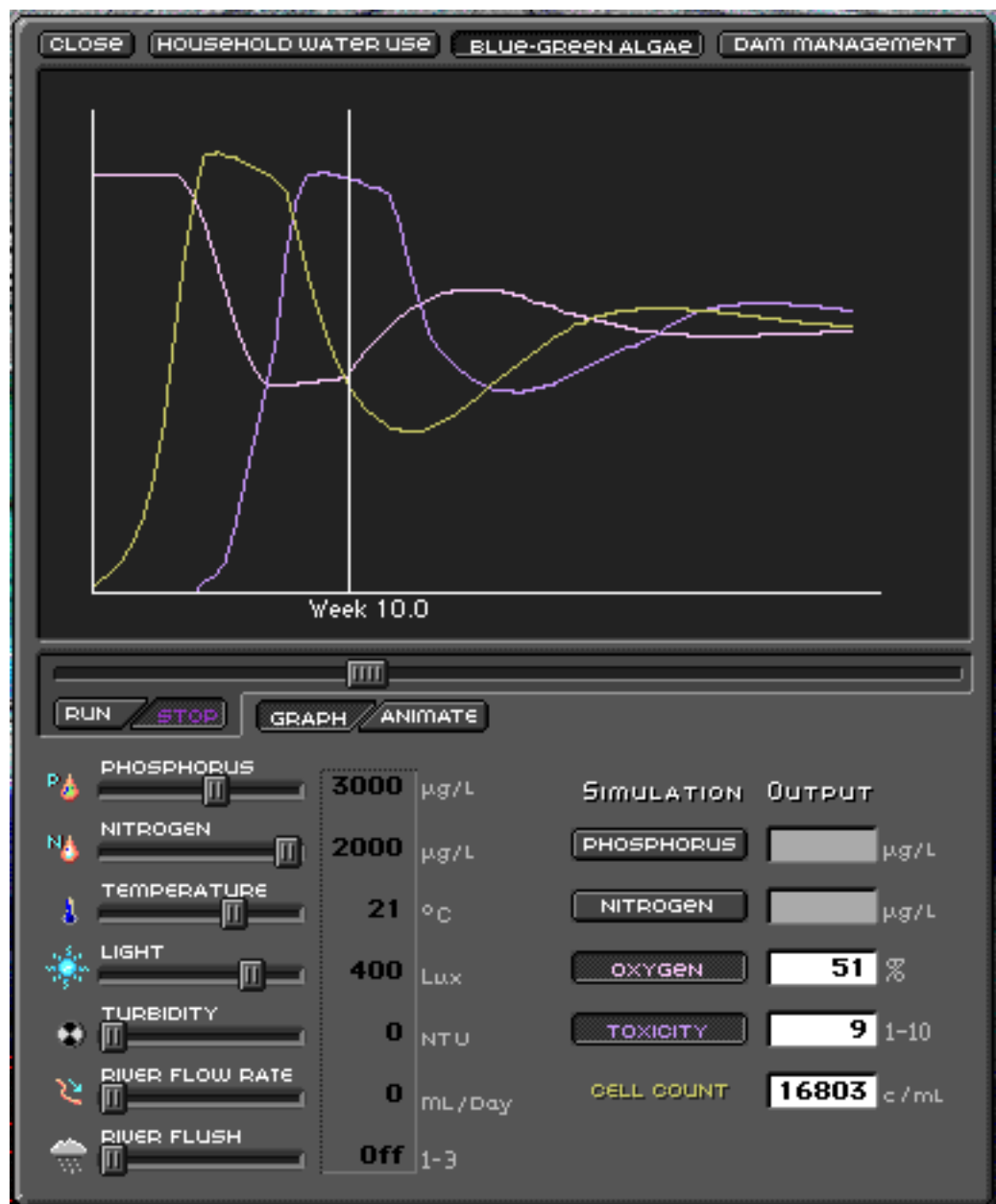


Plate 3.8a:
Testing Effect of Flushing River - No Flow

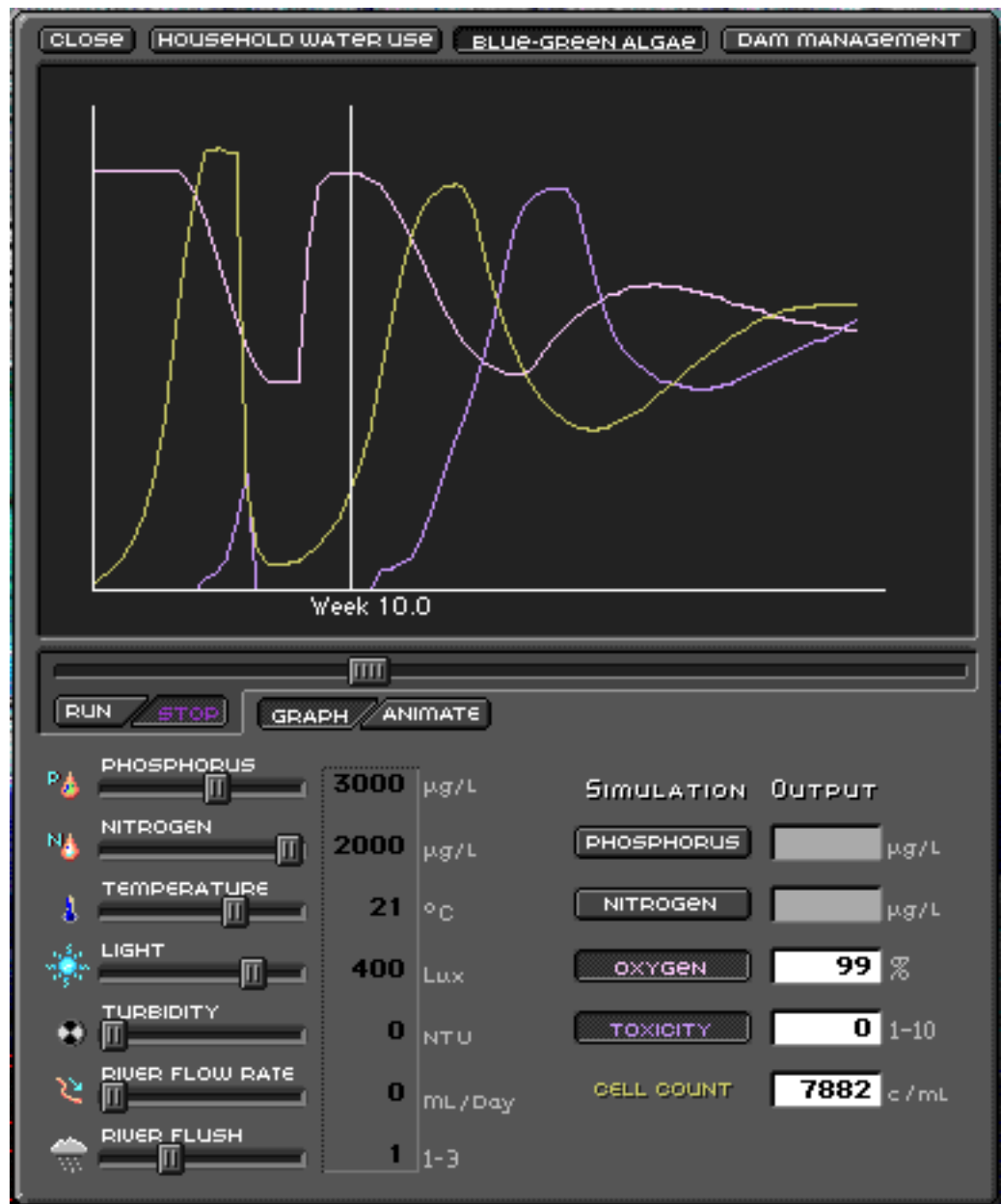


Plate 3.8b:
Testing Effect of Flushing River - Single Flush

3.4.6 Conclusion

The expected essential outcome of the simulation for the student was the development of a deeper understanding not only of the process and its causes, but also the relationships between the various factors contributing to an algal bloom and how environmental changes can influence its growth. They also gained a deeper understanding of the issues involved in whole catchment management that have an influence on bloom development, and how human interaction with the environment impacts on the overall health of the waterway.

CHAPTER 4

Methodology

4.0 Introduction

The underlying rationale of this study was two fold:

- a) to design, develop and implement within the software *Exploring the Nardoo*, an innovative interactive multimedia simulation which not only conformed to ‘best principles’ as described in the current literature, but extended these parameters to incorporate multiple representations of the output as students tested their hypotheses in a resource rich simulated environment and then;
- b) to test the hypothesis that the use of such simulations should provide improve learning outcomes for students using them.

This chapter provides a description of the research methodology adopted for this study. The effectiveness in terms of the acquisition of new knowledge and the ability to recognise and understand cause and effect relationships was achieved through the simulation of Algal bloom within *Exploring the Nardoo*. It details the design of the study, a profile of the operational population for the study, sampling procedures, research instrumentation, data collection and recording, its statistical analysis, and the study limitations.

4.1 The General Research Approach

The design adopted in this study is in the first instance, centred on the analysis of data collected from the administration of a pre- and post-treatment test of Knowledge Acquisition (Appendix 4.1a and 1b). This methodological approach could be described as fitting the classic experimental design and based in the Scientific Paradigm.

In its simplest terms the analysis of the differences in means between the pre and post-test scores were to provide the essential measure of educational effectiveness in terms of the student's knowledge acquisition in the simulation-based treatment.

Overlaying this, data were provided from several other sources based in both experimental design and subjective, analytical survey design. First, a Cause-and-Effects Schedule (Appendix 4.2a and 4.2b), which was designed to give a quantitative measure of the formation of new knowledge links during use of the simulation and the change in conceptual understanding of the processes and relationships between variables controlling algal bloom development.

Second, a User Perceived Value Schedule (Appendix 4.3), was used in an attempt to obtain some subjective data on the overall effectiveness of the package as well as information on general navigational matters and aspects of user behaviour. This involved pathways taken, time spent, problem-solving techniques used, ease of use, and perceptions of the cognitive effort during the use of the both the package and the simulator tool.

Third, direct observations (Appendix 4.4), were made of the users with special interest in general motivation and the will to complete, interaction with others, and general interface interaction. The latter two approaches fit comfortably within the Naturalistic Paradigm, a case study approach which relies on an in-depth study of limited aspects of a problem within a limited time frame.

Finally, as part of the assessable exercise, the students were asked to log the materials/sections they used/visited within the learning environment whilst working through the task. This subjective data constituted an assessable part of the exercise for the purposes of grading the students in the class. A decision was made at an early stage not to track and collect student pathway data directly. Although this subjective data did not form an integral part of the research, it did in some instances add interesting 'comment'. Further, it provided a confirmation that subjects in the control group had actually encountered the resources on Blue-Green Algae that were provided in various media

formats and hence had the opportunity to build on their knowledge and understanding of the relationships without using the simulation tool.

Although the pure experimental approach adopted in this study is essential to the testing of the stated hypotheses, it was the contention of the author that the adoption of some pre-experimental methods as supportive measures would provide a more complete picture of the nature of the user/software interaction particularly with regard to motivational issues, problem solving techniques and the adoption of the expert *modus operandi*. There is continuing debate over the validity of such qualitative research methods centred on the notion that such methods do not have the objectivity, rigour nor control necessary to provide accurate testing of hypotheses and the formulation of reasonable deductions (Kauffman, 1987). However such methods can provide a more balanced overview of the processes and attitudes adopted.

Solomon (1993) also calls for this mixed method approach for understanding user-information system interactions, using a variety of techniques that seek to uncover the “reality of participants”. It is for this reason that the methodology for this research study was based upon a mixed mode approach collecting and analysing both quantitative and qualitative data so that triangulation of findings could be more effectively carried out. In addition this mixed mode approach allowed the researcher to:

- identify overlapping facets of the process;
- add greater depth to the study, often not afforded when purely qualitative measures are used in educational environments and;
- gain the flexibility to view the data from different perspectives.

4.1.1 Research Questions

There has always been a ‘suspicion’ amongst some educators, particularly those who have limited computer literacy, that the platforms of the information technology revolution are simply new toys in the hands of resource developers and researchers, and that the outcome is simply an application of such technologies in the misguided belief that such delivery systems for educational experiences provide some sort of advantage over the more traditional methods. While research evidence does not refute such

notions, it does show that such delivery systems are at least as good as the traditional methods. The value of the delivery mechanism in adding to or facilitating the learning process has long been under debated. While many side with Kozma (1994), accepting that the delivery media is as important as the teaching methods, there are many who are convinced by Clark's (1994) argument that media will never influence learning.

Reiser (1994) and others take the view that the two must work together and that in fact, it is often the media used which facilitates the use of the particular method. As research based in the examination of the cognitive processes invoked during user interaction with appropriately designed systems continues, a clearer picture will emerge suggesting that such delivery systems do have the potential to provide a peculiar enhancement and enrichment of educational environments when they are carefully integrated with the pedagogy.

This study is based on two assertions with regard to the educational effectiveness of simulations in educational environments. First, that to be effective simulations need to have been designed in accordance with contemporary theoretical principles in terms of both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the user may construct knowledge and understanding of complex processes. Second, that students using such simulations will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms the representational media adopted, available resources and teaching methods.

4.2 The Hypotheses

The research hypotheses tested in this study were aimed at providing support for the assertion of improved learning outcomes and deeper understanding from appropriately designed simulations. They are deductive in that they are based on a pre-existing theoretical foundation as opposed to inductive hypotheses which have an observational base.

4.2.1 Learning Outcomes

H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the learning outcomes measure (KAS) than the students who do not.

4.2.2 Development and understanding of Relationships

H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the development of understanding relationships measure (CES) than the students who do not.

4.3 The Research Design

In developing and implementing a research design which will facilitate a meaningful outcome for the research questions, one must ensure that the design meets each of the following basic criteria:

- The design should be appropriate for the task.
- There should be provision for adequate control.
- The design should exhibit validity, both internally and externally.

In order to ensure that the research design adopted in this study met these criteria the following conditions/procedures were adopted.

The measurement of knowledge acquisition, the formation of new knowledge links and, the level of conceptual understanding achieved during the treatment in this study was suited to a quantitative approach for data acquisition and analysis. Consequently, the major part of the research design for this study is based in pure experimental techniques, or positivist paradigm and supported by analytical survey techniques.

The operational population was chosen from the target population by the use of the technique of “cluster sampling” described by Porkess (1988), Borge (1981), Cronbach & Snow (1977) and others. This is a recognised mechanism for appropriating a random sample and was chosen for this study because it was the most effect way of utilising the

available population. The theoretical basis behind this approach is outlined in more detail in section 4.7.2 of this chapter describing the operational population. A control group was used to ensure that any observed differences could be attributed to the treatment and not some other extraneous variable.

Establishing validity is an essential part of any research since validity is the means by which one establishes whether in fact the study actually achieved its objectives. Several procedures were followed to establish both the internal and the external validity of this study. Validity cannot be established unless one can establish the reliability of the instruments. Several steps were taken to establish the reliability of the instruments used.

Apart from the random sampling of the population and the use of the same test for both the pre and post measures, care was taken during the statistical analysis to recognise any unusual data and take appropriate action to negate its effect. The instruments were also tested using Formula 21, the Kuder-Richardson reliability coefficient, often referred to as KR-20. This formula allows the computation of a reliability coefficient simply on the basis of \bar{X} , the number of test items (n) and σ .

Further, the researcher attempted to minimise the effect of the problem of reactivity which arises when using the same questions for the pre and post testing instruments by not indicating that the same test would be used after the completion of the package.

The research design employed for both the pilot and main study is summarised as follows:

Group #1: *Exploring the Nardoo* with Simulator Tool (Experimental Group)

Group #2: *Exploring the Nardoo* **without** Simulator Tool (Control Group)

R (E¹) T₁ x T₂

R (C²) T₁ T₂

4.4 The Variables

The dependent variables in both the pilot and main study were:

- Pre and Post Knowledge Acquisition Schedule scores;
- Pre and Post scores from the Cause and Effect Schedule and;
- Data from User Perceived Value Schedule.

The independent variables or treatments in the **pilot** study were:

- Group #1 (Experimental) -15 females and 5 males)
Exploring the Nardoo with Simulator Tool (20 students) and;
- Group #2 (Control) - 9 females and 11 males)
Exploring the Nardoo **without** Simulator Tool (20 students).

The pilot study sample comprised 40 subjects.

The independent variables or treatments in the **main** study were:

- Group #1 (Experimental) - 51 females and 10 males)
Exploring the Nardoo with Simulator Tool (61 students) and;
- Group #2 (Control) - 44 females and 13 males
Exploring the Nardoo **without** Simulator Tool (57 students).

The total main study sample comprised 118 subjects.

4.5 The Experimental Materials

The experimental materials used in this study comprised the software package *Exploring the Nardoo* and the algal bloom simulation tool embedded within it. The package is an interactive multimedia CD-ROM based learning environment designed with a constructivist approach. It attempts to provide a realistic, risk free information rich learning space in which students may explore, test their understanding issues, and

develop solutions to authentic tasks. The package as a whole, together with the design structure and function of the embedded simulation tool, which was the focus of this study, is fully described in chapter three of this thesis.

4.6 The Treatments

The researcher supervised the administration of this research study and carried out observations. The lecturers whose students were involved were also present on a voluntary basis and acted as research assistants in terms of trouble shooting with technical difficulties encountered by students during the use of *Exploring the Nardoo* when requested by students. They also acted as a *second pair of eyes and ears* in terms of the operation of the treatment. This was particularly important in the pilot study, providing valuable feedback on changes or issues which needed to be addressed.

The subjects in this study were asked to complete an exercise (Appendix 4.0) using the software *Exploring the Nardoo* as part of their subject assessment work within the subject EDUS 301 in the Faculty of Education at the University of Wollongong. The assessment task was given to all subjects after the researcher gave an orientation session. All access to the simulations module was disabled for the control group and it was not mentioned during their orientation session.

All of the subjects in the operational population except for a small percentage noted elsewhere in this chapter, had some exposure to the general principles of the study of ecology and an ecological approach to investigating environments before they took part in this study.

4.6.1 The Control Group

Exploring the Nardoo without algal bloom Simulator:

The subjects in this group worked in pairs to complete the task set out on the exercise sheet (Appendix 4.0). However each student was required to submit their own solutions to the task and completed the pre and post-treatment instruments individually.

The subjects in this group were provided with:

- a brief introductory session at one of their preceding lecture time slots during which a general explanation of the nature of the assessment task and administrative procedures were dealt with;
- administration of pre/post-test instruments (see description elsewhere in this chapter - section 4.8);
- a 1.5 hour orientation session during which the subjects in this group were made aware of all the resources embedded within the learning environment, (see appendices 3.1 - 3.17) except the simulation tool, as well as the general operation of the package using a walk-through presentation. They were also given the opportunity to explore the learning environment. (see description elsewhere in this chapter - section 4.8);
- a CD version of *Exploring the Nardoo* **without the active** simulation tool;
- a blank floppy disk (one each) for saving and working on their materials and;
- support on request during working sessions by the researcher and the lecturer assisting.

4.6.2 The Experimental Group

Exploring the Nardoo with algal bloom Simulator:

The subjects in this group worked in pairs and to complete the task set out on the exercise sheet (Appendix 4.1) in the same manner as the control group.

The subjects in this group were provided with:

- a brief introductory session as described for the control group;
- administration of pre/post-test instruments as for the Control Group (see description elsewhere in this chapter - section 4.8);
- a 1.5 hour orientation session identical to that given to the Control Group (see description elsewhere in this chapter - section 4.8) except that the researcher used a version of the CD which had the active simulator tool to provide the walk through of the package and the simulation tool;
- a CD version of *Exploring the Nardoo* **with a fully active** simulator module;

- a blank floppy disk (one each) for saving and working on their materials and;
- support on request during working sessions by the researcher and the lecturer assisting.

4.7 The Selection Process

In summary, the operational population was a random subset of the target population selected using the cluster sampling technique defined elsewhere in this chapter. Assignment to groups was based on a predetermined division which had been made by the lecturers of the two groups and was not influenced by the researcher in any way.

4.7.1 The Target Population:

The design of *Exploring the Nardoo* is centred on the general principles of ecology study for students in Australian schools K-12 with extension into the earlier years of Higher Education. The areas of interest include, ecological pathways and relationships, together with socio-environmental issues. The nature of the package lends itself to use by almost any group of K-12 students who are studying ecology or who are interested in environmental issues. However some limitations must be recognised especially with regard to the level of competence in language expected of the user and the complexity of some of the problems provided as a mechanism for directed use of the package.

4.7.2 The Operational Population:

The subjects in the main study comprise 118 of the entire student enrolment (138) for the subject EDUS 301 "Science and Technology Investigations" within the Faculty of Education at the University of Wollongong. Burns (1998) suggested that sampling entire natural groups such as this is a common practice in educational research and that it retains the principal of randomness while providing flexibility in research design which may otherwise be curtailed through institutional pressures.

The students were all enrolled in a program of study to enable them to practice within Primary Schools in New South Wales. The subject prepares students to teach in the

area of the Primary Science and Technology Syllabus. Being 3rd year students, the mean age was around 21 years. Approximately 15% of the students in the group were classified as mature age students.

Their science/ecology background, (what they studied in the Science strand in senior high school) was varied. In this study the majority have, through their study of biological based or biased studies, a practical familiarity with the basic principles of ecology.

No Science at matriculation level:	15%
Biology at matriculation level:	65%
General Science at matriculation level:	15%
Other Sciences (Physics/Chemistry/Geology) at matriculation level:	5%

The issue of pre-treatment science background was not incorporated as a variable in this study.

The sample showed a marked gender bias. This was due to the nature of the enrolment currently experienced in primary teacher education courses from which the operational population was drawn. The gender distribution for the combined sample was:

Females subjects	95 (80%)
Male subjects	23 (20%)
Total	118

This gender balance was not unusual. Studies conducted by the New South Wales Department of School Education suggest that many more females than males are training for teaching positions, especially within the Primary School system. This group of Primary pre-service teachers reflected the pattern being experienced within New South Wales Primary schools where the current female to male teacher ratio is similar, in the order of 4 : 1 and as such it is argued that the operational population is a reflection of that target population.

The usual total sample size for experiments involving correlational analysis is, suggest Cronbach and Snow (1977), not less than 100 where practicable. Sample sizes significantly less than this increase the risk of Type 2 errors occurring. It is the contention of the researcher that, given the complexity, duration, and the difficulties related to limited facilities available to the researcher, the sample sizes of 57 for the Control group and 61 for the Experimental group used in this study was sufficient to minimise the risk of Type 2 errors occurring.

4.7.3 Group Allocation:

The student population comprised the entire enrolment for the subject EDUS 301. This cohort of 118 students had been divided into two separate sections for class /lecture/ tutorial purposes at the beginning of the semester by the lecturers responsible for the teaching program and the researcher had no input to this process. Section 1 comprised 61 students and became Group #1 (Experimental) in the study. Section 2 comprised 57 students and became Group # 2 (Control) in the study.

Group #1 (Experimental) - $n = 61$

Students included in study (51 Females and 10 Males)

Group #2 (Control) - $n = 57$

Students included in study (44 Females and 13 Males)

In forming the class sections no divisions were made according to gender, age or science background and this accounts for the unbalanced gender mix. It is assumed that as a result of this random allocation, the mix of science background described earlier in this section is evenly distributed between the two groups and is therefore did not play a significant role in the outcome of this research study.

4.8 Instrumentation

The basic aims of this study are to obtain a measure of the acquisition of knowledge and the associated formation of new links, and the level of conceptual

understanding developed by subjects exposed to the same curriculum materials via different delivery platforms.

The two main instruments providing qualitative data relating to these aims were:

- a 24 question knowledge based schedule and;
- a Cause and Effect schedule.

Allied to these were:

- a 50 question subjective User Perceived Value schedule;
- a record of student self logging of materials/sections used in compilation of solutions to the set problem and;
- a field record of experimenter observations.

The 24 question Knowledge Acquisition Schedule (Appendix 4.1a and b) was designed with careful attention to both the language used and the expected knowledge acquisition by an average user of the target population following exposure to a more conventional delivery. It was designed so that, the majority of questions could be completed with exposure to a standard delivery mechanism making use of all the resources other than the simulator itself, however some simulation specific target questions were included to flag those students who had access to the simulation and took advantage of it.

The purpose of the Cause and Effect Schedule (Appendix 4.2a and b) was to provide data on the conceptual associations, relationships and links and higher order cognitive skills including inference, problem solving and thinking skills which each subject developed to varying degrees during his or her exposure to the experimental environment. Using lines, subjects simply made ‘connections’ between an *effect* on the left of the table with a *process* on the right. While the design of this schedule was ‘open ended’ thus permitting each subject to respond in such a way as to give the experimenter an indication of the level and complexity of the links formed by each subject in their own mental models, the maximum number of ‘recognised’ links, as established by the experimenter, which could be made was 28. While it could be argued that using this approach may not be as robust as requiring the subjects to report directly on predicting results of perturbations and explanations of observed changes, it is argued that the nature of the design of the instrument is such that the subjects are in fact reporting on such

aspects of mental modelling. The instrument was designed to provide useful data in a simple, straightforward and easily manipulated way without the need to decode or analyse text based material. The terms used in each list for the subjects to 'match up' were carefully selected. Subjects needed to have worked at a deeper level in order to be able to make sensible connections that reflected their, metal model development, skills and understanding of the relationships at work. To do this they needed to have developed the ability to use the model to predict and explain observed changes.

The User Perceived Value Schedule (Appendix 4.3) was designed to provide through inference, a user profile with respect to such aspects as, the users preferred learning style, navigational strategies, user comfort, user control, perceived relevance, self confidence, and satisfaction. More general data on design matters including aspects of perception of cognitive loading, appropriate and clear presentation, stimulation and meaningful feedback was also extracted from this schedule.

4.8.1 Instrument Reliability:

As previously stated, without reliability in the instruments, the consistency with which the instrument measures what it is designed to measure, one cannot attain validity. Validity and sampling procedures represent the most critical factors in supporting the findings in any research. The reliability of the research instruments used in this study, particularly the KAS and CES, was established by their careful construction in consultation with two independent colleagues, triangulation and careful assessment of the responses obtained to identify both consistent errors and random errors, if and when they occurred. The instruments were also piloted on a group of subjects belonging to the target population but not involved in the study. The KP-20 statistic was applied to this data. The computed KP-20 values for the KAS and CES respectively were 0.86 and 0.90. These values confirmed that the instruments were reliable and that they did in fact measure the subjects real level of performance in this experiment.

4.8.1.1 Pilot Study

The pilot study enabled;

- the mapping of efficient procedures and processes which would not significantly add cognitive processing load to the experiment, thus clouding the results;
- trialling of the research instruments to minimise the occurrences of unexpected and poor responses;
- testing of the data collection tools to provide the opportunity to check whether the questions would elicit the expected/desired/required data;
- preliminary analysis of the data collected from a pilot study so that unexpected problems with questions or the approach being used could be detected and corrected and;
- data collection to support the case for validity and reliability of the instruments being used.

The pilot study for this research was conducted some 8 months prior to the full scale study.

The population was drawn from students enrolled in a 2nd year Primary Science and Technology program being run within the Faculty of Education at the University of Wollongong. All subjects in the pilot were volunteers and there was an imbalance in the gender mix within the groups. The Control group had a total of 20 subjects (9 females and 11 males) and the Experimental group, 20 subjects (15 females and 5 males). As mentioned earlier in section 4.7.2, this imbalance is a characteristic of population of students who enrol in the Primary pre-teacher service course and therefore is indicative of the target population and does not represent a threat to the inferences drawn from the analysis of the data collected.

The procedure outlined in section 4.9 of this chapter was modelled on the procedure used for the orientation/experimental session/ testing phases of the pilot study. A number of changes were put in place for the main study as a result of data collected in the pilot. A number of questions were re-worded to elicit needed responses. The number of questions used, particularly in the case of the Knowledge Acquisition Schedule was reduced and the instruction for using the Cause and Effect Schedule were

modified to overcome some ambiguity. One of the most important outcomes from the pilot was the development and refining of the answer template for the Cause and Effect Schedule which greatly improved the marking process in the full scale study both in terms of accuracy of data returned and the efficiency of time required for marking.

4.8.2 Instrument Validity:

Instruments are considered valid if they measure what they are designed to measure. Several procedures were followed in order to establish the internal validity of the instruments used in this study including, an assessment of each instrument by colleagues in terms of the degree of correlation between the questions asked and the curriculum materials and package content it was designed to examine. As both groups were given the same pre and post tests, possible problems in terms of internal validity for issues such as testing instrumentation, maturation and mortality were minimised. Further steps included control of extraneous factors which may affect performance during either the use of the package or the completion of the schedules, together with random subject selection. In the case of external validity or generalisation of the results to the target population, the subjects represent a random, representative sample of the target population in every way. Problems such as the Hawthorne effect were minimised by not indicating directly to any of the subjects that they were included in a research study. However, due to the nature of the task and the necessary instructions and directions which were required to 'set the scene' for its successful completion, subjects of this age may have come to the conclusion that they were in fact, involved in a study as a consequence of taking part in the tutorial groups. It is argued however, that these subjects being third year students, were highly motivated to complete the assigned task as part of their contract in completing the course and that such motivation had a greater influence on their performance in the task, than 'pleasing the researcher' with a good performance on the experimental instruments. This is reinforced by the fact that they were fully aware that the scores they obtained on these instruments would neither be counted in nor have any bearing on their final grades in the assigned task. The whole process was simply presented to the students as an assignment to be completed as part of the course.

The post test was administered some days after the treatments to ensure minimisation of the effect of reactivity of the subjects to the tests.

4.9 Procedures

As stated earlier, the researcher supervised the administration of this research study with both groups minimising issues concerned with the impact of history on the study outcomes. The subject lecturers were also present on a voluntary basis and acted as 'research assistants' in terms of trouble shooting with technical difficulties encountered by students during the use of *Exploring the Nardoo* when requested by students. They were rarely called upon in this capacity during both the pilot and main studies. They also acted as a second pair of eyes and ears in terms of the operation of the treatment.

At the outset, in an introductory session which was conducted during a scheduled lecture period prior to the commencement of the experiment, students in each group were given general information about the scheduled prescribed assessment task, the nature of the package which they were going to use in completing the task and an outline of the time line. They were also informed that participation in the tutorials on *Exploring the Nardoo* was voluntary and that they would be neither penalised nor disadvantaged in any way by opting to complete the prescribed assignment by some other means. The assessment task associated with the experiment was devised in such a way as to be non-reliant on the use of the simulation tool or for that matter the software package *Exploring the Nardoo*. The rich resources presented in the various media formats within *Exploring the Nardoo* provided all subjects including those in the control group, with ample opportunity to learn about blue-green algae. The subjects in both groups were made aware of these resources during subsequent pre-experimental sessions. To ensure that no students were disadvantaged by being forced to use the package to complete the assignment, it was emphasised to the subjects that the task could also be successfully completed using library based research if they elected not to take part in the computer based tutorial sessions. Further it was made clear that participation in either group would not have any bearing on the actual assessment mark that the students gained for their grading in the subject.

Finally, they were assured of anonymity of collected data once its compilation had taken place.

The outcome of these assurances was to have all students accept initial participation however as the data records indicate, some 20 odd students either failed to continue in the group as subjects for the study after the initial orientation session, or for one reason or another missed either the pre or post data collection sessions.

4.9.1 Pre-study Orientation

Both the experimental and the control groups were exposed separately, to a 1.5 hour orientation session to introduce them to the *Exploring the Nardoo* package. During this session they were given some verbal information about the software to be used such as its central theme and its overall structure. The researcher used on-screen walk through's of each of the major sections of the package, describing what they were, how to use them and where they fitted within the overall scheme of the learning environment *Exploring the Nardoo*. Care was also taken to ensure that the students were aware of the extensive resources in various media formats available to them. Time was also spent in discussing functionality issues such as, extraction of data from the system, saving files, reloading and working on them away from the experimental site. The students were told that the work sessions would be run in pairs and that they were free to choose their own partner. The students pair were able to spend some 40-50 minutes gaining 'hands on experience' with software during their introductory session. Each pair of students was given its own 'appropriate' CD version of *Exploring the Nardoo*.

A concern expressed by many including Ring et al., (1994) is that the user must have adequate time to advance past the learning how the system works stage before they attempt to use software to work on a set task. For effective learning to take place it is vital that all of their time and cognitive effort can be spent learning from the system rather than about the system. It has been suggested that under ideal conditions this getting to know the system time period could be as high as 10 hours. Given the make-up of the operational population in this study and the fact that they were provided with a period of guided instruction as well as a hands on period mentioned earlier in this section to

become familiar with the software, the researcher believes that the groups were sufficiently familiar with the software for it not to impact significantly on the outcome of this study.

This was supported by responses to questions within the User Perceived Value Schedule (Appendix 4.3) which suggested that little time was spent learning how to use the system because of its well designed interface and structure. A number of students also provided feedback by way on comments during use and in response to questioning after completing the task to the effect that they had not found difficult to learn how to use. (Appendix 4.4).

4.9.2 Variations to Orientation Sessions

The two groups were inducted into the study in a similar fashion except that the experimental group needed to be made aware of the simulation tool as a resource to be used to complete the task.

4.9.2.1 Experimental Group

During this session, a CD version of *Exploring the Nardoo* which had the simulations activated was used and its function was pointed out by the researcher as part of the overall description of the package.

4.9.2.2 Control Group

During this session, a CD version of *Exploring the Nardoo* was used which had the simulations functionality disabled to the extent that the button placed in the Water Resource Centre used to activate them was deactivated and gave no indication of any functionality.

4.9.3 The Pre-Treatment Data Collection

Each of the groups was given the pre-treatment instruments to complete at the beginning of the orientation session. The format for this initial collection of pre - treatment data session was the same for both groups in the study. The subjects were

each given a copy of the Pre-Test for Knowledge Acquisition Schedule (Appendix 4.1a and b) and a copy of the Pre-Test Cause and Effect Schedule. (Appendix 4.2a and b). They were then given enough time for all students to finish filling out the schedules in what ever order they wished. This freedom to complete both simultaneously was implemented following comments made by students in the pilot study.

At then end of the orientation session, the students were each given a copy of the assignment task (Appendix 4.0) ready for the next session. They were told that during the next two lecture periods, they would be given 3 hours in each session to complete the assigned task and reminded that it would be part of their overall assessment for the subject but that, the criteria for marking would exclude any influences which may relate to the study group in which they were working. At this time they were also given an outline as to the best way to approach the task in terms of use of time in sessions and they were told that after the end of the experimental period, they would have several days to work on the materials they had collected before being required to hand-up their solution.

4.9.4 The Treatment Sessions (2 x 3 Hours)

The subjects in both the Control and Experimental group were given a total of 6 hours hands on (2 x 3 hours sessions) to complete the task as well as the initial 40-50 minutes hands on orientation. As mentioned earlier, the orientation period appeared to provide ample training in the use of the software so that the 6 hours spent working on the task was quality time with respect to task completion. There was a limitation placed on the times when each group could work on the computers due to the fact they must fit this time spent in the study into a tight set semester time line. The researcher was mindful of the possible limitation placed on the study by virtue of the need to conduct the treatment sessions over a two week period. This may have acted to lessen the effects or perhaps wipe some out. It may also have been compounded by the one week delay between the last treatment session and the completion of the post-test by both groups.

However, with due consideration given to time and equipment limitations, it is suggested that the total treatment time of 6 hours falls within acceptable minimum limits for there to be a measurable effect. Cronbach and Snow (1977), suggest that treatment

duration may range from a few minutes to many years, however they point out that where research involving measurement of improvement in education is concerned, the duration should be such as to take into account the phenomenon known as learning to learn and allow for the perturbation that occurs in performance as the student becomes familiar with the environment. “A period of habituation is probably necessary before the student is working with full effectiveness” (Cronbach & Snow 1977).

A key consideration for the design of effective computer based educational environments is the recognition that individuals learn at different rates, and in different ways. It has been suggested by some researchers that in order to properly measure performance improvements, one should use an open ended treatment time so that each individual may reach the same end point. However such an attempt to accommodate these differences may be counter productive in that the experiment is not holding constant the amount learned. Rather, the time of exposure should be kept constant so that “how much a student learns ... over a fixed number of hours of work, meaningfully indicates the effectiveness of a treatment” (Cronbach & Snow, 1977).

At the commencement of each session for each group, the subjects were asked to form pairs and were given a copy of the CD appropriate to the group involved. To provide some direction as to how they should best use their time, they were advised to spend most of the time in the first session exploring the available material, collecting what they thought they needed to complete the assigned task. They should then take that away to work on and use the second session as a refining/enriching and extra exploration session. At the end of the second experimental session the subjects were again instructed to use the period between lecture periods (4 days) to complete the write-up of their solutions to the task at home and hand it in at the next lecture.

4.9.5 Post-Treatment Data Collection

At the next lecture session, (4 days after the last experimental session), the subjects handed in their completed task as an assignment and in the last part of the lecture period completed a Post-Test Knowledge Acquisition Schedule and a Post-Test Cause and Effect Schedule (Appendix 4.1a and b and 4.2a and b) which were identical to those

completed before the experiment started except that they had the identification as Post-Test.

As the students left the lecture session, they were handed a copy of the User Perceived Value Schedule (Appendix 4.3) and asked to return it on a voluntary basis at their next tutorial. As can be seen from the data analysis, the percentage of subjects who returned this form fell to about 52%. As this schedule was a voluntary instrument to be filled in away from the formal setting, it was expected that there would be a significant dropout in returns.

4.10 The Experimental Site

All sessions except for the pre and post treatment data collection, were carried out in a dedicated computer laboratory. The Faculty of Education at the University of Wollongong has a Macintosh teaching laboratory attached to its main research laboratory, the Interactive Multimedia Learning Laboratory, where *Exploring the Nardoo* was developed. The laboratory comprised 20 Macintosh computers, all of which were PowerMacs with sufficient RAM to ensure trouble free operation on the software. Such a facility was essential as the package relies heavily on media clips which cannot really be run successfully on slower machines.

Each machine had the ability to save students work out to floppy disk and the engine within *Exploring the Nardoo* itself did so as a text file which could be edited on any home based word processor. The room also has a data projector which was used during the orientation sessions to *walk* the subjects through the basic structure of the package.

4.11 Data Collection

Data collection was somewhat simplified by the fact that all subjects were from the same institution and subject cohort. The data collected fell into two categories and was comprised of:

Non Parametric:

- Ordinal:
- Data obtained from researchers personal field observations.
 - Subjective data from student self-log pathway data.

Parametric:

- Interval:
- Scores by individuals in the pre/post tests.
 - Scores by individuals in the Cause and Effect Schedule.
 - Data obtained from the User Perceived Value Schedule.

In this study, all data marking and compilation was carried out by a third party (a PhD student based in the Faculty of Education at the University of Wollongong).

The marker had a background in science at matriculation level and was also conducting research on aspects of student learning using *Exploring the Nardoo*. This aspect of her background was particularly important in her ability to assess data in the Cause and Effect Schedule. She was involved in data collection and carried out the marking in the pilot study and so was very familiar with the materials and had an excellent understanding of the cause and effect relationships at the time of data collection in the full study.

Prior to marking in the pilot study, the researcher went through the instrument with the marker, indicating the correct answers in the case of the Knowledge Acquisition Schedule (KAS) and the expected responses for the Cause and Effect Schedule (CES). To facilitate a smooth marking process, the researcher supplied the marker with templates for both the KAS and the CES. In the case of the KAS, this template comprised an overlay of the answer sheet with the correct responses punched out. This template was the same as that used in the main study. It facilitated the fast and accurate compilation of results for the KAS.

In the case of the CES, the template used for the pilot study contained those responses which the researcher and marker agreed represented the expected responses for the pre-treatment condition. The purpose of this was to ensure that the obvious responses were easily identified and counted and to minimise the complexity of the template until the marker became more comfortable in recognising relationships.

Students were allowed to make as many connections as they thought existed when completing the schedule. The task of sorting the 'good' from the 'bad' was slow and tedious as great care was taken to ensure that any legitimate relationships were counted.

The CES template used for the main study was a modified version of the pilot study template. It included the many more subtle relationships which would be expected. The students were asked to indicate whether they had used the simulator or not on the Cause and Effect Schedule pro forma so as to ensure that data entry was accurate in terms of the groups. To ensure objectivity in the marking of the CES, the response sheets from both groups were marked as one unidentifiable batch. This was achieved by the researcher mixing the sheets and then numbering them sequentially. The name, group and identification number were then recorded and became the basis of the scores database. Before handing the sheets to the marker, the top section of each sheet containing the name and group identify was simply cut off.

4.12 Data Processing and Statistical Analysis

This section of the chapter outlines the procedures used to analyse both the data collected from both the pilot study and the main study. Tables 4.1 and 4.2a-d provide a quick overview of the protocol used to collect data and statistical analyses carried out on the data pertaining to each of the hypotheses under testing.

4.12.1 Pilot Study

The data collected during the pilot study was not subjected to extensive analysis as its purpose was to provide a guide as to the suitability of the instruments and techniques employed in running the experiment. The data collected using the KAS and CES was analysed using standard statistical techniques including the calculation of the mean (\bar{X}) and the standard deviation (σ). An initial two tail paired 't' test was also carried out on the small sample. Table 4.1 summarises the analysis techniques applied to this data.

Hypothesis	Protocol used	Data collected	Analysis Applied
Learning Outcomes Key Hypothesis: H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the 'learning outcomes' measure (KAS) than the students who do not.	Pre KAS	Pre scores	Mean, σ , Paired 't', ANOVA
	Post KAS	Post scores	Mean, σ , Paired 't', ANOVA
	UPS	Likert Scale	% distribution Mean, σ , ANOVA
	Field Observations/ notes/interviews	Text	Peer/supervisor
Development of Understanding Key Hypothesis: H_0 : Students who use the simulation tool to solve a set problem will not score significantly higher on the 'development of understanding relationships' measure (CES) than the students who do not.	Pre CES	Pre scores	Mean, σ , Paired 't', ANOVA
	Post CES	Post scores	Mean, σ , Paired 't', ANOVA
	UPS	Likert Scale	% distribution Mean, σ , ANOVA
	Field Observations/ notes/interviews	Text	Peer/supervisor Review

Table 4.1: Pilot Study – Statistical Analysis Summary

The data collected using the first version of the User Perceived Value Schedule (UPS) used in the pilot study was examined in broad terms by the researcher, supervisor and colleagues with a view to ensuring that the instrument elicited the data expected and covered all the aspects of interest to the researcher. Apart from the obvious need to shorten the number of questions it became apparent that some of the questions required modification as the data they returned was not providing sufficiently clear information. In redeveloping the UPS, the suggestions of colleagues and the guidelines in Bell (1995) were invaluable.

4.12.2 Main Study

The processing of the data obtained from the main study had several phases. The compilation of non parametric data including, field notes and observations was followed by a subjective assessment and analysis by the researcher, supervisor and colleagues to identify and consider issues which impact on both the outcomes in terms of the hypotheses being tested and the more general issues of design and user interaction.

Data from the User Perceived Value Schedule was also initially subjectively assessed and then coded for parametric analysis. This coding was done using a scoring pattern based on a 5 point Likert scale. Table 5.27 in chapter 5 sets out the allocation of 'points' for each of the responses to the questions. The compilation of the parametric data from the pre and post tests, Knowledge Acquisition Schedule and the Cause and Effect Schedule was followed by their statistical analysis using Statview 4 for the Macintosh (1992).

In the first instance, the basic statistical analysis of the data involved the calculation of the group means (\bar{X}) and standard deviations (σ) for each of the pre and post test KAS and CES instruments. This was then followed by the application of statistical techniques including initially, two tail paired 't' tests and then one and two way ANOVA's to test each the stated working hypotheses.

Although the paired 't' test and ANOVA are essentially functionally equivalent for hypothesis testing, the revelation by the initial 't' tests of differences between pre-test scores, particularly in the case of the KAS pre-test scores, dictated the application of ANOVA testing. The use of a 2-way ANOVA allows such initial differences to be taken into account so that they do not interfere with the analysis of the end results. Consequently, the essential statistical test planned and executed on the KAS and CES data collected in this study was the 2-way ANOVA, treatment vs. pre/post scores. In all of these calculations the confidence level was set at 95%. Table 4.2a, b, c and d provide summaries of the analysis techniques applied to the data collected from the main study.

Hypothesis	Protocol used	Data collected	Analysis Applied
Homogeneity of Population H_0 : The operational population comprising the experimental and control groups had the same entry level of knowledge and understanding of cause and effect relationships in the process of algal bloom development.	Pre KAS for Experimental and Control groups	Scores	Mean, σ , Paired 't', ANOVA

Table 4.2a: Operational Population Homogeneity

The KAS was administered as a pre and post treatment instrument and except for the inclusion of a post treatment header, was the same test in each case. The answer sheet used for each of the tests was also identified as pre or post test. They were passed to the independent marker upon completion. The marker was supplied with a punched template (described earlier in this chapter) that could be laid over the answer sheet to identify correct answers. The raw data and the answer sheets were returned to the researcher, checked for marking accuracy and adjustments made. These were verified and approved by the marker.

The raw data was analysed in terms of the general statistical measures of mean (\bar{X}) and Standard Deviation (σ) and the results were considered by both the researcher and the marker. The agreed data set was then analysed using the techniques set out in the summary table 4.2b.

Hypothesis	Protocol used	Data collected	Analysis Applied
Learning Outcomes			
Operational hypotheses: H ₀ : Control Group. Access to the resources only within the <i>Exploring the Nardoo</i> environment will produce no significant change in the learning outcomes for the students, using the difference between pre and post scores on the KAS as a measure of learning outcomes.	Pre/Post KAS	Scores	Mean, σ , Paired 't', ANOVA
H ₀ : Experimental Group. Access to the algal-bloom simulation (treatment) as well as the other resources within the <i>Exploring the Nardoo</i> environment will produce no significant change in the learning outcomes for the students, using the difference between pre and post scores on the KAS as a measure of learning outcomes.	Pre/Post KAS	Scores	Mean, σ , Paired 't', ANOVA
H ₀ : Experimental vs Control. Access to all resources within the <i>Exploring the Nardoo</i> environment including the algal-bloom simulation for the experimental group will produce no significant difference in mean post scores on the KAS between the experimental and control group members	Post KAS for Experimental and Control groups	Scores	Mean, σ , Paired 't', ANOVA

Table 4.2b: Learning Outcomes Analysis Summary

Hypothesis	Protocol used	Data collected	Analysis Applied
Development of Understanding			
Operational hypotheses: H ₀ : Control Group. Access to the resources only within the <i>Exploring the Nardoo</i> environment will produce no significant difference in the students understanding of the cause/effect relationships in the process of algal bloom development, using the difference between pre and post scores on the CES as a measure.	Pre/Post CES	Scores	Mean, σ , Paired 't', ANOVA
H ₀ : Experimental Group. Access to the algal-bloom simulation (treatment) as well as the other resources within the <i>Exploring the Nardoo</i> environment will produce no significant difference in the students understanding of the cause/effect relationships in the process of algal bloom development, using the difference between pre and post scores on the CES as a measure.	Pre/Post CES	Scores	Mean, σ , Paired 't', ANOVA
H ₀ : Experimental vs Control. Access to all resources within the <i>Exploring the Nardoo</i> environment including the algal-bloom simulation for the experimental group will produce no significant difference in mean post scores on the CES between the experimental and control group members.	Post CES for Experimental and Control groups	Scores	Mean, σ , Paired 't', ANOVA

Table 4.2c: Development of understanding Analysis Summary

The CES was administered as a pre and post treatment instrument and except for the inclusion of a post treatment header, was the same test in each case. The procedure for marking was similar to that for the KAS. However, the task of marking was much more complex. The method of filling in the sheets involved the student drawing lines to connect cause and effect sets. This in itself had the potential to create very complex responses from

students who could make many connections. The marker used the *expected* or most obvious responses template detailed earlier for the pre-test marking and had several conversations with the researcher as to other less obvious responses that might be acceptable. During the marking process, the marker was able to check with the researcher when unsure of response acceptability. The markers background, mentioned earlier in this chapter, together with the pre-marking discussions resulted in very little need for further consultation. At the completion of the marking process, the researcher checked the answer sheets with the marker to identify any missed correct responses or incorrect responses that had been passed.

The marking process for the post-test was more complex as more *connections* were identified by most students. However as outlined earlier, the marker had become very skilled at identifying correct and incorrect responses and the processes of reconciliation on completion of marking resulted in very few changes. The agreed data set was then analysed using the techniques set out in the summary table 4.2c.

The UPS questionnaires were returned directly to the researcher. They were processed by the researcher in the first instance in terms of the number of responses to each possible response for each question and these were tabulated as a percentage of the total return for each question. This provided a basic 'picture' of the agreement or disagreement of targeted questions. This initial analysis was completed in two stages, the responses of both the control and experimental groups on the common questions and the responses of the experimental group on the simulation tool specific questions.

The common question set was then re-coded assigning values to each of the Likert scale steps. An ANOVA was carried out on the resulting data set, identifying questions which were significant in terms of the responses of the control group as opposed to those of the experimental group. The final data sets and the trends apparent in the initial analysis of them was discussed with the supervisor and the marker for the KAS and CES responses. The techniques used for analysis of the UPS data is set out in summary table 4.2d

Purpose	Protocol used	Data collected	Analysis Applied
Common Questions (Both groups) Learning outcomes/Development of relationships; General Functionality; User Control; Navigation; Multiple representations; Broad Issues	UPS	Likert Scale	% distribution
	UPS	Coded scores	Mean, σ , ANOVA
Simulator Specific Questions (Experimental group only) Learning outcomes/Development of relationships; General Functionality; User Control; Broad Issues; Multiple representations;	UPS	Likert Scale	% distribution
	UPS	Coded scores	Mean, σ , ANOVA
Enhancement of other data sources	Field Notes/ Observations/ interviews	Text	Peer/supervisor review

Table 4.2d: UPS Statistical Analysis Summary

During the pre-experimental familiarisation sessions and the experimental sessions, the researcher made edited field notes on the conduct of the sessions, comments made by students to other students and comments made to the researcher. This process is divergent with the normal practice of making some form of recording and then transposing the record later. This was a deliberate action driven by the desire to collect this form of data but with minimal effort and reduced bulk. At the end of sessions where the lecturer had been present, the researcher debriefed the lecturer and made edited notes. At the end of the experiment after the completed work had been handed in and the UPS had been returned, a random selection of students (10 from the control group and 12 from the experimental group) were interviewed briefly (15 minutes) during which time edited data was collected in the form of notes. The questions asked are provided in Appendix 4.4

4.13 Limitations

The fact that the population had an average age of 21 years where as the software is essentially designed for the K-12 New South Wales school population (5 - 18 years of age) and is chiefly used by students in that group in the age group of 14-18 years of age, may act to compromise and limit the degree of transferability to the target population of the inferences drawn from this study.

This type of sampling was forced on the study by the limited time span available for access to the operational population.

Participation in this research meant that many of the “subjects were taken out of their natural environment” (Porter 1988). For a number of the subjects in this study, the computer environment is very unnatural. It is suggested by the researcher that this may in fact have produced some pressures which may have lead to a modification of the normal processes of learning, thus producing spurious outcomes.

One of the challenges for developers of computer driven delivery systems is the variation in the level of computer literacy which users present. The operational population in this study, being 3rd year students operating within an university environment which promotes the use of technology in teaching and learning would be expected to have a higher level of computer literacy than the average student in the target population. As the research literature shows this variation can have drastic effects on the outcomes achieved for each individual. In a worst case scenario it may mean an aversion by the subject to using the interface altogether. More realistically, it may simply mean an inhibiting of the achievement in some of the expected outcomes. There may have been a bias towards ‘better performance’ in the subjects exposed to the more normal delivery system, which needs to be carefully considered when making inferences about the target population.

4.14 Conclusion

The methodological approach adopted for this study was of a classic experimental design (pre/post-test) and based in the Scientific Paradigm. Such a pure experimental approach was essential to testing the stated hypotheses, however in order to provide a

more complete picture of the nature of user/software interactions, a hybrid quantitative/qualitative approach was used. The data set on which the analysis of the study was based was collected using researcher designed instruments; a Knowledge Acquisition Schedule (KAS), a Cause and Effect Schedule (CES) and a User Perceived Value Schedule (UPS). Subjective information in the form of field observations and comments records were also collected. The use of a quantitative approach supported by additional qualitative data with a purposive group of participants provided a context in which the research question could be tested and considered while maintaining the necessary research rigour.

The following chapters examine the statistical analysis of the collected data and set out the findings from these analyses with respect to the research question, and provide an overview of the essential outcomes for the study.

CHAPTER 5

Results and Findings

5.0 Overview

The collection of data to test the research hypotheses involved a pilot study and later, a full study conducted in the light of the experiences and observations from the pilot study. Details of the processes and procedures adopted and applied for both of these studies are described in full in chapter 4 of this thesis.

The purpose of the pilot study was to gain a feel for the population characteristics and their reactions to the conduct of the experiment. It also provided an opportunity and a means of validating the instruments and flag possible problems and deficiencies before using them in the full study. At the completion of the full study, the analysis methodology proposed and detailed in chapter 4 was applied to the data.

This chapter reports on the results of the analysis of the data collected in both the pilot and main studies and details the findings arising from the interpretation of these results in turn.

5.1 Pilot Study

The Pilot study, described in chapter 4, was conducted under similar conditions to the main study with regard to selection of the operational population, and was described in detail in the methodology, chapter 4. The general characteristics of the pilot population are also detailed in that chapter.

5.1.1 Results: Pilot Study - KAS/CES Parametric Data

In addition to the general descriptive statistics presented in tables 5.1 and 5.2 several other statistical tests were conducted on the parametric data collected from the Knowledge Acquisition Schedule (KAS) and the Cause/Effect Schedule (CES).

The results of these tests are presented below. It should be noted that unless otherwise stipulated all tests were conducted at the 5% significance level.

5.1.2 Pilot Study: Summary of General Statistics

The data set collected on the pre and post treatment administration of both the Knowledge Acquisition Schedule (KAS) and the Cause/Effect Schedule (CES) for the **Control group** is presented in full in Appendix 5.1 and for the **Experimental Group** in Appendix 5.2. They show the total number of subjects in the population (n), the gender distribution (M/F%) and the means (\bar{X}) and standard deviations (σ) for each group. Table 5.1 below provides a statistical summary of the KAS (Pre/Post) data set for both the Control and Experimental groups in the Pilot study.

X₁ : Con_Pre_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
14.4	2.6	.6	6.8	18.1	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
9	18	9	287	4247	0
X₂ : Con_Post_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
15.1	1.7	.4	3	11.5	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
13	19	6	301	4587	0
X₃ : Exp_Pre_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
12	3.5	.8	12.2	29.1	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
5	19	14	240	3112	0
X₄ : Exp_Post_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
16.7	2.5	.6	6.2	14.9	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
10	20	10	334	5696	0

Table 5.1: Pilot Study: Control /Experimental (KAS data set)-Statistical Summary

Table 5.2 below provides a statistical summary of the CES (Pre/Post) data set for both the Control and Experimental groups in the Pilot study.

X₁ : Con_Pre_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
8.2	3.4	.8	11.4	40.8	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
1	16	15	165	1577	0

X₂ : Con_Post_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
9.2	2.5	.6	6.3	27.2	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
4	13	9	184	1812	0

X₃ : Exp_Pre_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
8.3	4.1	.9	16.9	49.5	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
3	17	14	166	1698	0

X₄ : Exp_Post_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
14	4.9	1.1	24	35	20
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
4	25	21	280	4376	0

Table 5.2: Pilot Study: Control /Experimental (CES data set)-Statistical Summary

5.1.3 Analysis of Variance (Repeated Measure) - KAS

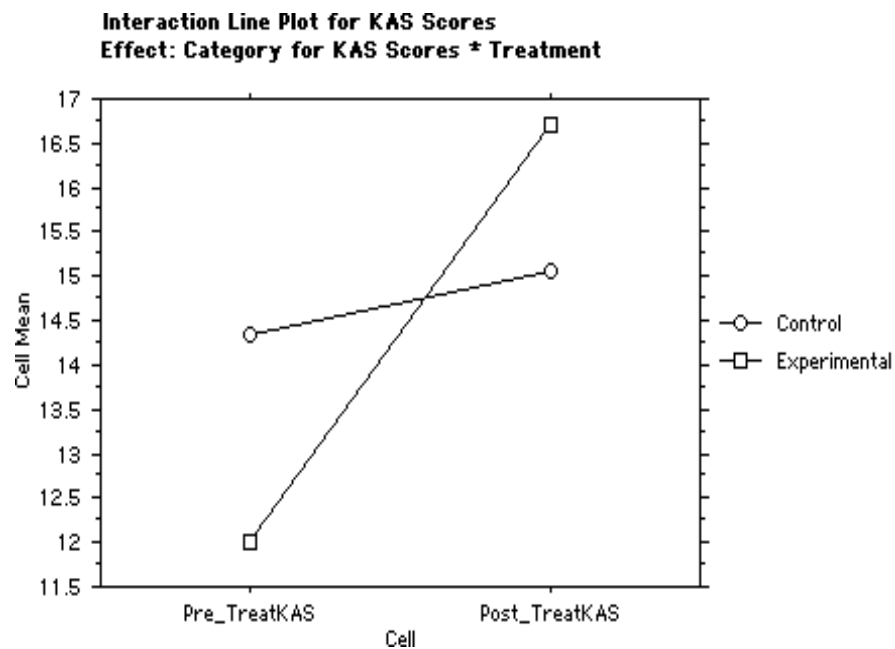
For completeness, 't' tests were applied to the KAS data and these are presented in Appendices 5.3 and 5.3a. Appendix 5.3a presents the results of a 't' test on the Treatment vs degree of change in mean scores for the KAS data. To enhance the statistical 'picture', a repeated measure ANOVA for Treatment vs KAS pre/post mean scores was carried out on the KAS data. Table 5.3 below presents the result of this ANOVA.

ANOVA (Repeated Measure) Table for KAS Scores

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	2.450	2.450	.284	.5970
Subject(Group)	38	327.500	8.618		
Category for KAS Scores	1	145.800	145.800	26.611	<.0001
Category for KAS Scores * Treatment	1	80.000	80.000	14.601	.0005
Category for KAS Scores * Subject(Group)	38	208.200	5.479		

Table 5.3: Pilot Study: ANOVA - Summary of Pre/Post KAS Mean Scores

Graph 5.1 below presents the interaction line plot for the Treatment vs KAS Pre/Post mean scores ANOVA.



Graph 5.1: Pilot Study: Interaction - Treatment vs KAS Pre/Post Mean Scores

In order to clarify the results presented in Graph 5.1, the variable KAS_Diff (Post mean KAS scores - Pre mean KAS scores) was created to test whether the experimental group's mean KAS scores changed more than those of the control group. This data was tested using a one factor ANOVA and the results are presented in table 5.4 below.

ANOVA Table for KAS_Diff

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	160.000	160.000	14.601	.0005
Residual	38	416.400	10.958		

Model II estimate of between component variance: 7.45

Means Table for KAS_Diff

Effect: Treatment

	Count	Mean	Std. Dev.	Std. Err.
Control	20	.700	2.849	.637
Experimental	20	4.700	3.715	.831

Scheffe for KAS_Diff

Effect: Treatment

Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Control, Experimental	-4.00	2.12	.0005

Table 5.4: Pilot Study: ANOVA-Treatment vs Pre/Post KAS Mean Score Differences

5.1.4 Analysis of Variance (Repeated Measure) - CES

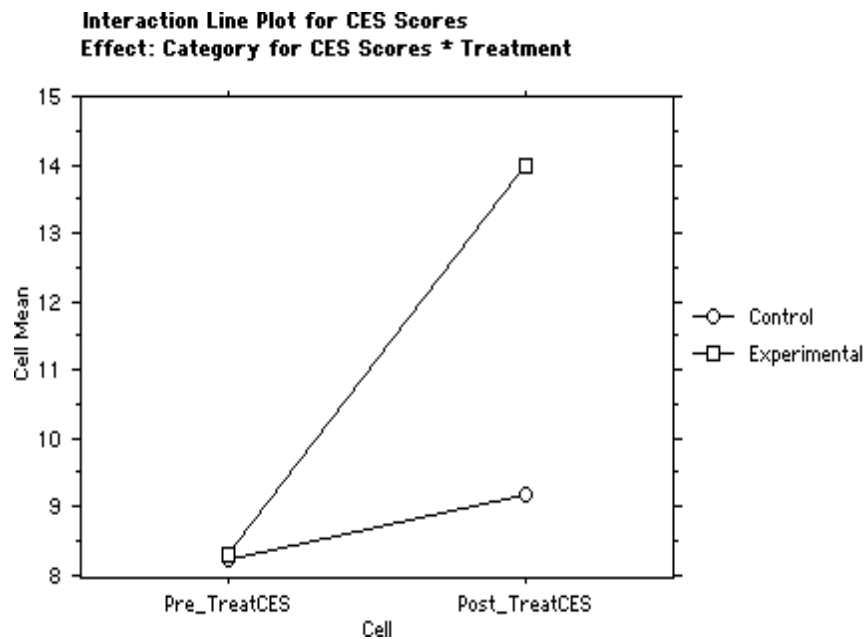
For completeness, 't' tests were applied to the CES data and these are presented in Appendices 5.3 and 5.3a. Appendix 5.3a presents the results of a 't' test on the Treatment vs degree of change in mean scores for the CES data. To enhance the statistical 'picture', a repeated measure ANOVA for Treatment vs CES pre/post mean scores was carried out on the CES data. Table 5.5 below presents the result of this ANOVA.

ANOVA (Repeated Measures) Table for CES Scores

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	117.612	117.612	5.070	.0302
Subject(Group)	38	881.575	23.199		
Category for CES Scores	1	221.112	221.112	36.599	<.0001
Category for CES Scores * Treatment	1	112.812	112.812	18.673	.0001
Category for CES Scores * Subject(Group)	38	229.575	6.041		

Table 5.5: Pilot Study: ANOVA - Summary of Pre/Post CES Mean Scores

Graph 5.2 below presents the interaction line plot for the Treatment vs KAS Pre/post mean scores ANOVA.



Graph 5.2: Pilot Study: Interaction Line Plot for CES Scores

In order to clarify the results presented in Graph 5.2, the variable CES_Diff (Post mean CES scores - Pre mean CES scores) was created to test whether the experimental group's mean CES scores changed more than those of the control group. This data was tested using a one factor ANOVA and the results are presented in table 5.6 below.

ANOVA Table for CES_Diff

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	225.62	225.62	18.67	.0001
Residual	38	459.15	12.08		

Model II estimate of between component variance: 10.68

Means Table for CES_Diff

Effect: Treatment

	Count	Mean	Std. Dev.	Std. Err.
Control	20	.95	3.02	.67
Experimental	20	5.70	3.88	.87

Scheffe for CES_Diff

Effect: Treatment

Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Control, Experimental	-4.75	2.23	.0001 S

Table 5.6: Pilot Study: ANOVA-Treatment vs Pre/Post CES mean score Differences

5.1.5 Findings: Pilot Study

5.1.5.1 Procedural Aspects

The rationale for and outcomes from the conduct of the pilot study are reported on in detail in chapter 4 of this thesis. The Pilot study provided information on the efficacy of the proposed main study in terms of the hypotheses; the instruments designed to collect data to test these hypotheses and the research design. As a result of the pilot study a number of changes to the orientation session, the conduct of the experimental sessions and the research instruments were made.

It was noted that a significant number of students spent considerable amounts of time coming to terms with the task and its connection with the learning environment. The time set aside for the orientation period was by necessity quite short, allowing only a brief *tour* covering the aspects of the learning environment and no consideration of 'house keeping' issues such as saving files, loading files and organisation of collected materials. All of these issues created anxiety and delay in starting on the task. As a result, the orientation session for the main study was extended and an attempt was made to cover every aspect of the learning environment.

For the experimental group, this included some exposure to the simulator and how to use it. Although sufficient CD-ROM's were produced to allow for individual work on the task, the students naturally gravitated to working in pairs and the decision to run the full study as a collaborating pairs experimental environment was made at this stage. In terms of the hypotheses, a very broad and general hypothesis was used as the starting point but it became obvious after discussion with colleagues that the aspects of learning outcomes and the understanding of the process, in terms of the student's ability to apply the new knowledge to a set task, needed to be looked at separately. The decision was also made to produce a series of working hypotheses, which were called Operational Hypotheses. These helped in clarifying the analysis process and the synthesis of the findings for both the researcher and the reader.

One of the most useful aspects of the pilot study was the highlighting of the need to re-assess the data gathering tools. Although the statistical analysis of the data collected showed a measurable effect for the students using the simulation tool as opposed to those

who did not, it was decided to make several changes to the instruments before using them on the much larger main study groups.

The number of questions used, particularly in the case of the KAS was reduced and the instructions, together with the methods of making connections for relationships, were modified in the CES. Some of the questions in the original KAS were also determined by colleagues who reviewed the tools as not being suitable due to ambiguity, inappropriate structure or 'too simulator tool dependent' and were either removed or modified to address these concerns. This was done with due consideration of the effects observed in the analysis of the pilot data so as to avoid diminishing or enhancing the effect.

Feedback from the Pilot study students also indicated that the User Perception Schedule (UPS) and the Cause and Effect Schedule (CES) had too many questions, some stating that they would not have bothered to finish them had they been in a normal classroom situation. It was noted that the control group showed little change in their KAS score from pre to post treatment and this could have been significant in terms of the structure of the questions being asked to target this aspect of the learning experience had it not been for the fact that the experimental group did show a change.

As mentioned elsewhere, in the early phases of the development of a methodology, consideration was given to tracking the students movement through the package. It became apparent from the pilot study, that observations by the researcher had the potential to throw more light on the outcomes particularly in terms of the design of both the simulator and the complete integrated package than student tracking data.

The complete data set collected from the Knowledge Acquisition Schedule (KAS) which provided a measure of learning outcomes is presented in Appendix 5.1. The complete data set for the Cause/Effect Schedule (CES) which was to provide a measure of the depth of learning in that it 'tested' the students ability to understand and recognise relationships rather than just simple facts is presented in Appendix 5.2. Tables 5.1 and 5.2 provide basic statistical analysis of these data sets.

5.1.5.2 Pilot Study: Homogeneity of Population

The assumption was made that the two groups had very similar entry status both in terms of their knowledge base and ability to draw out relationships. This was based on the fact that the cluster samples were the two classes that comprised the total student enrolment for the subject, created for administrative purposes on a random basis without regard to their backgrounds.

The general statistical analysis of the pre KAS mean scores presented in Tables 5.1 and 5.2 suggest that in terms of the pre KAS, the control group ($\bar{X} = 14.2$, $\sigma = 2.6$) performed better than the experimental group ($\bar{X} = 12.0$, $\sigma = 3.5$). In the case of the pre CES mean scores, the control group ($\bar{X} = 8.3$, $\sigma = 3.4$) and the experimental group ($\bar{X} = 8.3$, $\sigma = 4.1$) had an equal entry status in terms of their level of understanding of relationships between the competing variables. To test whether in fact there were any significant differences between the two groups both in terms of pre KAS and pre CES mean scores, the scores were subjected to 't' tests. Repeated measure ANOVA's conducted as part of the overall KAS/CES measures data set analysis provided corroborative evidence in support of the results of these 't' tests. The ANOVA results are presented in Tables 5.3 - 5.6 and Graphs 5.1 - 5.2.

Appendix 5.3 presents the results of paired two-tail 't' tests ($df = 19$, $t_{\text{Critical}} = 2.09$, $p = 0.05$) carried out on both the pre KAS and pre CES mean scores for the Control vs Experimental groups. With $t_{\text{Obtained}} = 2.18$, and $p = 0.0418$, these tests confirm that the control group KAS mean score was *borderline* significantly better than the experimental group KAS mean score suggesting that their entry knowledge of algal growth was slightly better than that of the experimental group. This difference was also highlighted by the repeated measure ANOVA's (Table 5.4 and Graph 5.1) and is further reported in more detail on page 5-11 of this chapter. In terms of the pre CES mean scores, a $t_{\text{Obtained}} = 0.05$, and $p = 0.9629$ confirms that both groups would seem to have a similar entry level understanding of cause and effect relationships involved in the process of algal growth. As the only statistically significant result (for the KAS) was borderline, it was considered that re-assessing and the consequent re-structuring of the instruments in the manner outlined earlier in this chapter, together with the use of a much larger

sample ($n = 18$) in the main study would be sufficient to ensure that differences in entry status of the subjects would be minimised.

5.1.5.3 Pilot Study: KAS/CES Measures

Briefly, the pilot study showed that although both the control and experimental groups showed improvement in post treatment measures of both knowledge acquisition (KAS) and understanding of relationships (CES) Appendix 5.3, the experimental group which had access to the simulation tool, showed a significantly better performance on both these measures in comparison to the control group, particularly in the case of the developing of an understanding of the relationships.

Appendix 5.3 presents evidence to support this assertion in terms of paired two-tail 't' tests ($df\ 19$, $t_{\text{Critical}} = 2.09$, $p = 0.05$) carried out on both the post KAS and post CES mean scores for the Control vs Experimental groups. The variables KAS_diff and CES_diff (post mean scores – pre mean scores) were created to further test this in the light of the differences found between the populations in terms of entry status.

Appendix 5.3a presents the results of paired two-tail 't' tests ($df\ 19$, $t_{\text{Critical}} = 2.09$, $p = 0.05$) carried out on both the Experimental vs Control group KAS_diff and CES_diff mean scores. Clearly with $t_{\text{Obtained}} = 4.1$ for each test and $p = 0.0007$ and 0.0006 respectively, the mean scores changed significantly more for the experimental groups over the control group on both the KAS and the CES. The simulation tool provided them with the opportunity to test out relationships and through the use of multiple representations of the data, see the interactions between variables, reinforcing their understanding.

To further distill the data and at the same time limit the possible effects resulting from the differences in the entry status of the two groups, a repeated measure ANOVA ($F_{\text{Critical } 1, 38} = 4.1$ and $p = 0.05$) was carried out on both the KAS and CES data sets. Such repeated measure testing takes into account the variations in the initial status of the populations with regard to the measures being investigated and increases the overall sample size, thus adding power to the analysis.

In terms of the KAS, the ANOVA summary table of pre/post KAS mean scores (Table 5.3) supports the earlier finding that there was a significant difference between the experimental and control pre and post KAS mean with an $F_{\text{Obtained } 1, 38} = 26.61$ and $p = < 0.0001$. The summary table also reports a significant interaction between the KAS mean scores and the treatment with an $F_{\text{Obtained } 1, 38} = 14.60$ and $p = 0.0005$.

The nature of this interaction is shown in Graph 5.1 which illustrates it as a line plot, depicting both the significant difference in post KAS mean scores and the pre KAS mean scores. The plot also illustrates the marginal change in the control group's pre and post KAS mean scores, the plotted line being almost horizontal. One would expect that given the nature of the resources in the package, there should be a change in the knowledge acquisition for both groups independently of the access to the simulation tool. This anomaly in the control groups performance could probably be attributed to some transient factor such as the circumstances (time constraint and associated pressure to complete) under which the post test was carried out or sampling error, rather than a problem with the research instrument itself.

Table 5.4 presents the results of a one factor ANOVA on the created variable KAS_diff. With an expected an $F_{\text{Obtained } 1, 38} = 14.60$, and $p = 0.0005$ clearly the KAS mean scores for the experimental group changed significantly more than for the control group. In terms of the learning outcomes as measured by the KAS, the experimental group has had a significantly better outcome.

A similar pattern is evident in the CES scores. The ANOVA summary table of pre/post CES mean scores (Table 5.5) supports the earlier finding that there was a significant difference between the experimental and control pre and post CES mean scores with an $F_{\text{Obtained } 1, 38} = 36.599$ and $p = < 0.0001$. The summary table also reports a significant interaction between the CES mean scores and the treatment with an $F_{\text{Obtained } 1, 38} = 18.673$ and $p = 0.0001$.

The nature of this interaction is shown in Graph 5.2 which illustrates it as a line plot, depicting the significant difference in post CES mean scores. It also clearly shows that in terms of the CES mean scores and the entry status of the two groups, there was no significant difference in the pre treatment scores. Table 5.6 presents the results of a one

factor ANOVA carried out on the created variable CES_diff. With an $F_{\text{Obtained } 1, 38} = 18.67$ and $p = 0.0001$ clearly the CES mean scores for the experimental group changed significantly more than for the control group.

In terms of the development of an understanding of the relationships between the competing variables (a measure of the depth of learning) as measured by the CES, the experimental group had a significantly better outcome.

5.2 Results: Main Study - KAS/CES Parametric Data

5.2.1 Main Study Data Sets

The operational population comprised 118 third year students enrolled in the subject EDUS 301 'Science and Technology Investigations', a subject in the program of study for pre-service K - 6 teachers. As third year students their average age was around 21 years, with a modal age of approximately 20 years, with 15% of the students in the group being classed as mature age students. No official data was collected on their pre-experience in the area of ecological study nor their computer literacy.

Only a small number of the members population had no science background at matriculation level and for the purposes of this study it assumed that the majority, through their study of biological-based studies would have a good knowledge of the basic principles of ecology. The efficacy of this assumption is validated elsewhere in this chapter.

In terms of the possible impact of significant variations in computer literacy within the population comprising the control and experimental groups, it is assumed that there was no significant difference in the levels of computer literacy. This assumption is based on the fact that the University has a strong emphasis on the use of technology in teaching and learning and all students are expected to have reached a target level of literacy in computers before they graduate. Most students through a need to operate effectively within such an environment achieve this level early in their programmes of study.

5.2.2 Main Study: Summary of General Statistics

The data set collected on the pre and post treatment administration of both the Knowledge Acquisition Schedule (KAS) and the Cause/Effect Schedule (CES) for the **Control group** is presented in full in Appendix 5.4 and for the **Experimental Group** in Appendix 5.5. They show the total number of subjects in the population (n), the gender distribution (M/F%) and the means (\bar{X}) and standard deviations (σ) for each group.

Table 5.7 below provides a statistical summary of the pre/post KAS data set for both the Control and Experimental groups in the main study.

X₁ : Con_Pre_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
10.9	3.3	.4	10.6	29.7	57
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
3	18	15	623	7401	4

X₂ : Con_Post_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
13.7	3.3	.4	10.6	23.8	57
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
1	19	18	782	11324	4

X₃ : Exp_Pre_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
12.3	2.8	.4	8	22.9	61
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
6	18	12	751	9723	0

X₄ : Exp_Post_KAS					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
16.8	1.8	.2	3.3	10.9	61
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
12	21	9	1023	17355	0

Table 5.7: Main Study: Control/Experimental (KAS data set)-Statistical Summary

Table 5.8 below provides a statistical summary of the pre/post CES data set for both the Control and Experimental groups in the main study.

X₁ : Con_Pre_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
6.1	2.5	.3	6.3	40.8	57
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
1	13	12	349	2487	4

X₂ : Con_Post_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
9	3.1	.4	9.6	34.2	57
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
1	16	15	515	5189	4

X₃ : Exp_Pre_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
5.2	3.1	.4	9.9	60.4	61
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
0	14	14	318	2252	0

X₄ : Exp_Post_CES					
Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
13.3	3.6	.5	13.3	27.3	61
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
6	20	14	812	11604	0

Table 5.8: Main Study: Control/Experimental (CES data set)-Statistical Summary

5.2.3 Main Study: Testing The Homogeneity of the Operational Population

To test for the degree of similarity between the control and experimental population with respect to:

- their knowledge of the processes involved in algal bloom development and;
- their ability to recognise cause and effect relationships in the process,

prior to exposure to experimental treatment conditions involved in this study two statistical tests were carried out.

A series of 't' tests examining Treatment vs pre/post KAS mean scores and Treatment vs pre/post CES mean scores were conducted. The results of these test are presented in Appendix 5.6. Within group (experimental pre vs experimental post KAS mean scores) 't' tests were also conducted and the results for these test are presented in Appendix 5.7.

These data were also subjected to a one factor ANOVA and the results are presented in table 5.9 below.

One Factor ANOVA X_1 : Treatment Y_1 : PreKAS

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	56.2	56.2	6.1
Within groups	116	1068.8	9.2	p = .0149
Total	117	1125.1		

Model II estimate of between component variance = .8

One Factor ANOVA X_1 : Treatment Y_1 : PostKAS

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	274.3	274.3	40.1
Within groups	116	794.3	6.8	p = .0001
Total	117	1068.6		

Model II estimate of between component variance = 4.5

One Factor ANOVA X_1 : Treatment Y_1 : PreCES

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	24.4	24.4	3
Within groups	116	944.4	8.1	p = .0862
Total	117	968.8		

Model II estimate of between component variance = .3

One Factor ANOVA X_1 : Treatment Y_1 : PostCES

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	538.9	538.9	47
Within groups	116	1331	11.5	p = .0001
Total	117	1869.9		

Model II estimate of between component variance = 8.9

**Table 5.9: Main Study:
One Factor ANOVA- Treatment vs Pre/Post KAS and CES Mean Scores**

5.2.4 Main Study: KAS Scores (Learning Outcomes Measure)

In addition to the general descriptive statistics presented in tables 5.7 and 5.8 several other statistical tests were conducted on the parametric data collected from the Knowledge Acquisition Schedule (KAS). The results of these tests are presented below. It should be noted that unless otherwise stipulated all tests were conducted at the 5% significance level.

5.2.4.1 Analysis of Variance (Repeated Measure) - KAS

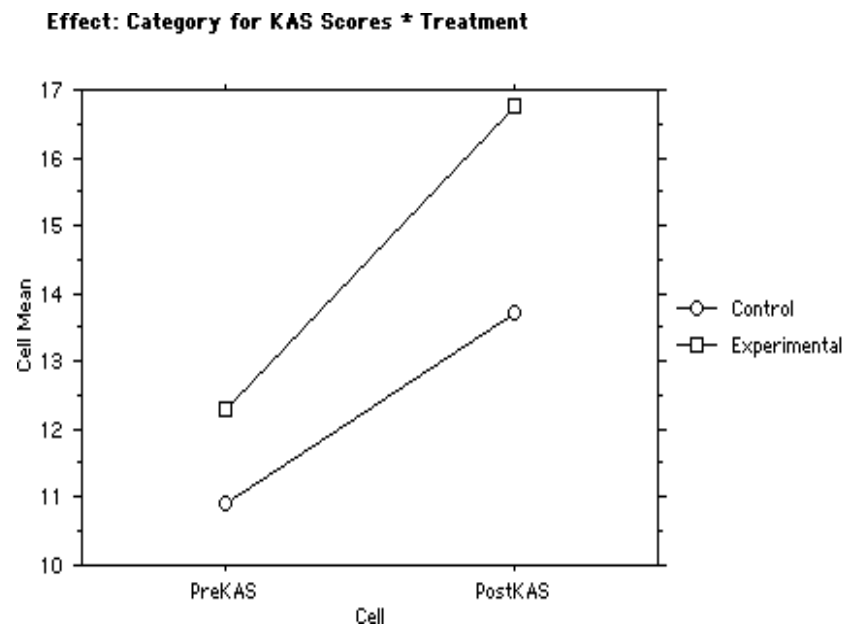
For completeness, ‘t’ tests were applied to the KAS data and these are presented in Appendices 5.6 and 5.8. Appendix 5.8 presents the results of a ‘t’ test on the Treatment vs the degree of change in the mean scores on the KAS. To enhance the statistical ‘picture’, a repeated measure ANOVA for Treatment vs KAS pre/post mean scores was carried out on the KAS data. Table 5.10 below presents the result of this ANOVA.

ANOVA Table for KAS Scores

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	289.506	289.506	27.691	<.0001
Subject(Group)	116	1212.786	10.455		
Category for KAS Scores	1	787.123	787.123	140.404	<.0001
Category for KAS Scores * Treatment	1	41.067	41.067	7.325	.0078
Category for KAS Scores * Subject(Group)	116	650.311	5.606		

Table 5.10: Main Study: ANOVA - Summary of Pre/Post KAS Mean Scores

Graph 5.3 below presents the interaction line plot for the Treatment vs KAS Pre/Post mean scores ANOVA.



Graph 5.3: Main Study: Interaction - Treatment vs KAS Pre/Post Mean Scores

In order to add clarity to the results presented in Graph 5.3 above, the variable KAS_Diff (Post mean KAS scores - Pre mean KAS scores) was created to test whether the experimental group's mean KAS scores changed more than those of the control group. This data was tested using one factor ANOVA and the results are presented in table 5.11 below.

ANOVA Table for KAS_diff

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	82.133	82.133	7.325	.0078
Residual	116	1300.621	11.212		

Model II estimate of between component variance: 1.2

Means Table for KAS_diff

Effect: Treatment

	Count	Mean	Std. Dev.	Std. Err.
Control	57	2.789	3.858	.511
Experimental	61	4.459	2.790	.357

Fisher's PLSD for KAS_diff

Effect: Treatment

Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Control, Experimental	-1.67	1.22	.0078

Table 5.11: Main Study: ANOVA-Treatment vs Pre/Post KAS Mean Score Differences

5.2.5 Main Study: CES Scores (Understanding Relationships Measure)

In addition to the general descriptive statistics presented in tables 5.7 and 5.8 several other statistical tests were conducted on the parametric data collected from the Cause/Effect Schedule (CES). The results of these tests are presented below. It should be noted that unless otherwise stipulated all tests were conducted at the 5% significance level.

5.2.5.1 Analysis of Variance (Repeated Measure) - CES

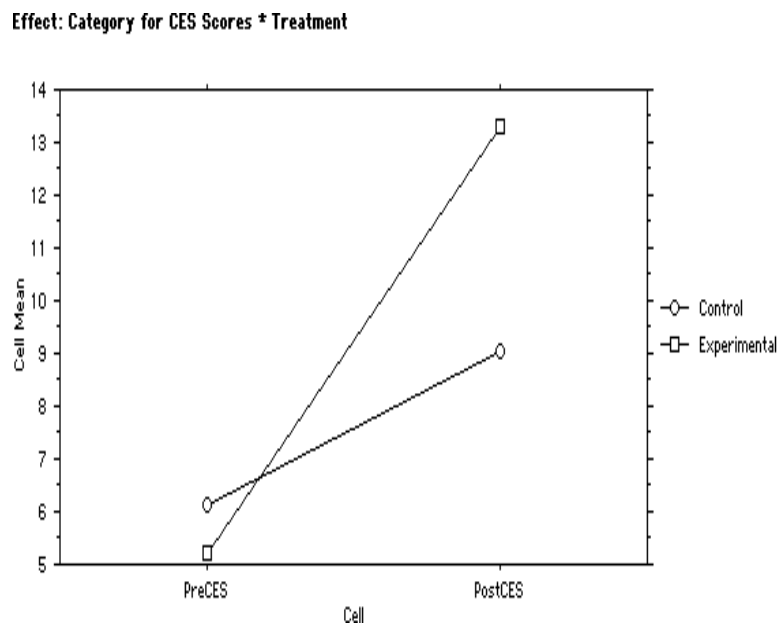
For completeness, ‘t’ tests were applied to the CES data and these are presented in Appendices 5.6 and 5.8. Appendix 5.8 presents the results of a ‘t’ test on the Treatment vs the degree of change in the mean scores on the CES. To enhance the statistical ‘picture’, a repeated measure ANOVA for Treatment vs CES pre/post mean scores was carried out on the CES data. Table 5.12 below presents the result of this ANOVA.

ANOVA Table for CES Scores

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	166.994	166.994	12.211	.0007
Subject(Group)	116	1586.396	13.676		
Category for CES Scores	1	1845.763	1845.763	310.759	<.0001
Category for CES Scores * Treatment	1	396.252	396.252	66.714	<.0001
Category for CES Scores * Subject(Group)	116	688.986	5.940		

Table 5.12: Main Study: ANOVA Summary of Pre/Post CES Mean Scores

Graph 5.4 below presents the interaction line plot for the Treatment vs CES Pre/post mean scores ANOVA.



Graph 5.4: Main Study: Interaction- -Treatment vs CES Pre/Post Mean Scores

In order to add clarity to the results presented in Graph 5.4 above, the variable CES_Diff (Post mean CES scores - Pre mean CES scores) was created to test whether the experimental group's mean CES scores changed more than those of the control group. This data was tested using one factor ANOVA and the results are presented in table 5.13 below.

ANOVA Table for CES_diff

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	792.503	792.503	66.714	<.0001
Residual	116	1377.971	11.879		

Model II estimate of between component variance: 13.25

Means Table for CES_diff

Effect: Treatment

	Count	Mean	Std. Dev.	Std. Err.
Control	57	2.912	2.530	.335
Experimental	61	8.098	4.122	.528

Fisher's PLSD for CES_diff

Effect: Treatment

Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value
Control, Experimental	-5.19	1.26	<.0001 S

Table 5.13: Main Study: ANOVA-CES_diff Score

5.3 Findings: Main Study

The purpose of this study was:

- to design, develop and implement a simulation tool based on contemporary theoretical design and pedagogical directions;
- to test its efficacy using the two research hypotheses restated below using data collected from 3 main instruments, a Knowledge Acquisition Schedule (a measure of learning outcomes), a Cause and Effect Schedule (a measure of the development of understanding relationships within the process), a User Perceived Value Schedule (UPS) and;
- to confirm and expand where possible the current knowledge base on simulation development with respect to design and pedagogical issues.

5.3.1 Restatement of the Research Hypothesis

As stated in chapter 1, in order to better focus the study, the general hypothesis set out in Chapter 1 was divided into two definitive research hypotheses:

5.3.1.1 Learning Outcomes

H_o : Students who use the simulation tool to solve a set problem will not score significantly higher on the learning outcomes measure (KAS) than the students who do not.

5.3.1.2 Development of understanding of Relationships

H_o : Students who use the simulation tool to solve a set problem will not score significantly higher on the development of understanding relationships measure (CES) than the students who do not.

The instruments used to test these hypotheses included:

- A Knowledge Acquisition Schedule (KAS) - Scores from which constitute a measure of Learning Outcomes;
- A Cause and Effect Schedule (CES) - Scores from which constitute a measure of development of understanding of relationships between contributing variables, and;

- A User Perceived Value Schedule (UPS) - Additional data (both parametric and nonparametric in format) to gather user perceptions of the learning experience and outcomes which will add support to the findings associated with the parametric data and the issues for design in terms of functionality, the pedagogical approach and user interaction.

5.3.2 Operational Hypotheses

To facilitate the analysis of the data collected from the instruments used in this study, a series of operational hypotheses were drawn up and tested against the data. All were stated in terms of the null (H_o), that is, that the outcomes for both the experimental and control groups would be the same for all aspects tested in this study. The hypotheses were:

- **$OH_{[1]}$ Homogeneity of Operational Population**

H_o : The operational population comprising the experimental and control groups have the same entry levels of knowledge and understanding of cause and effect relationships in the process of algal bloom development.

- **$OH_{[2]}$ Control Group: Learning outcomes**

H_o : Access to the resources only within the *Exploring the Nardoo* environment will produce no significant change in the learning outcomes for the students using the difference between pre and post mean scores on the KAS as a measure of learning outcomes.

- **$OH_{[3]}$ Experimental: Group Learning outcomes**

H_o : Access to the algal bloom simulation (treatment) as well as the other resources within the *Exploring the Nardoo* environment will produce no significant change in the learning outcomes for students using the difference between pre and post mean scores on the KAS as a measure of learning outcomes.

• **OH_[4] Control Group: Developing understanding of Relationships**

H₀: Access to the resources only within the *Exploring the Nardoo* environment will produce no significant difference in the students understanding of the cause and effect relationships in the process of algal bloom development using the difference between pre and post mean scores on the CES as a measure.

• **OH_[5] Experimental: Developing understanding of Relationships**

H₀: Access to the algal bloom simulation (treatment) within the *Exploring the Nardoo* environment will produce no significant difference in the students understanding of the cause and effect relationships in the process of algal bloom development using the difference between pre and post mean scores on the CES as a measure.

• **OH_[6] Learning Outcomes: Control vs Experimental**

H₀: Access to all resources within the *Exploring the Nardoo* environment including the algal bloom simulation for the Experimental group will produce no significant difference in mean post scores on the Knowledge Acquisition Schedule (KAS) between the experimental and control group.

• **OH_[7] Understanding of Relationships: Control vs Experimental**

H₀: Access to all resources within the *Exploring the Nardoo* environment including the algal bloom simulation for the Experimental group will produce no significant difference in the mean post scores on the Cause/Effect Schedule for experimental and control group members.

5.4 Findings: Main Study - Based on KAS and CES Research Instrument Data

In this section, the findings will be presented briefly in terms of the basic statistical measures, Mean (\bar{X}) and Standard Deviation (σ) and then in terms of the data obtained from the repeated measure ANOVA's and 't' tests for each of the Operational Hypotheses in turn.

5.4.1 General Statistical Measures

The basic statistical measures (Tables 5.7 and 5.8) point to a measurable differences between the pre and post treatment performance of the control and experimental groups in terms of their mean scores on the KAS (a measure of learning outcomes) and the CES (a measure of the development of understanding) after using the package *Exploring the Nardoo*.

In terms of the KAS, both the control and experimental group showed an increase in their pre vs post mean scores. The control group's post KAS mean score ($\bar{X} = 13.7$, $\sigma = 3.3$) when compared to the pre KAS mean score ($\bar{X} = 10.9$, $\sigma = 3.3$) showed a 2.5 point improvement. The experimental group's post KAS mean score ($\bar{X} = 16.8$, $\sigma = 1.8$) when compared to the pre KAS mean score ($\bar{X} = 12.3$, $\sigma = 2.8$) showed a 4 point improvement. The results of a paired 't' test results table presented in Appendix 5.7 indicates that in both cases, these differences were significant. Since the design of the package was such that factual knowledge about the process was available in many representational forms, this was not unexpected.

More importantly, the experimental group's post KAS mean score ($\bar{X} = 16.8$, $\sigma = 1.8$) compared to the control group's post KAS mean score ($\bar{X} = 13.7$, $\sigma = 3.3$) showed a 3 point difference. The results of a two tail paired 't' test ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on this difference and presented in Appendix 5.8, indicated that this difference was significant ($t_{\text{Obtained}} = 2.8$ and $p = 0.0074$) and this significance was also confirmed by the results of an ANOVA analysis conducted on the KAS data (Table 5.11). One can conclude from this that there were improved outcomes for both groups and that the experimental group's improvement was significantly greater than that of the control group.

In terms of the CES, a similar pattern emerged. Both groups showed an improvement on their pre treatment mean scores as in deed would be expected with exposure to the rich learning environment. The experimental group's post CES mean score ($\bar{X} = 13.3$, $\sigma = 3.6$) when compared to the pre CES mean score ($\bar{X} = 5.2$, $\sigma = 3.1$) showed an 8 point improvement. The control group's post CES mean score ($\bar{X} = 9.0$, $\sigma = 3.1$) when compared to the pre CES mean score ($\bar{X} = 6.1$, $\sigma = 2.5$) showed a 3 point improvement. The results of a paired 't' test results table presented in Appendix 5.7

indicates that in both cases, these differences were significant. As was the case for the KAS results, the difference between the experimental group's post CES mean score ($\bar{X} = 13.3$, $\sigma = 3.6$) compared to the control group's post CES mean score ($\bar{X} = 9.0$, $\sigma = 3.1$) proved to be significant, ($t_{\text{Obtained}} = 8.0$ and $p = 0.0001$) (Appendix 5.8). Again this significance was also confirmed by the results of the ANOVA analysis conducted on the CES data (Table 5.13). One can conclude from this that both groups improved in their understanding of the relationships involved in the process of algal growth, but that the experimental group exhibited as significantly greater improvement.

5.4.2 Findings for each of the Operational Hypotheses

The Operational Hypothesis:

H_o: The operational population comprising the experimental and control groups have the same entry levels of knowledge and understanding of cause and effect relationships in the process of algal bloom development.

The nature of the selection and the make up of operational populations has been set out in chapter 4 in some detail. The use of the “cluster sampling” technique imposed several unusual characteristics on the nature of the groups including a gender bias towards females and an unequal distribution in terms of the areas of science previously studied in high school. From the outset of this study, the issue of Gender and its possible influence was not considered as part of the focus for this study due mainly to this heavy bias towards female participants in the sample (75% total sample).

Further, as no specific testing was done to determine the level of science knowledge in each group it is important that the relationship between these two populations with regard to their entry status in terms of both their knowledge and understanding of relationships in the process of algal bloom development be established in order to rule out the influence of substantially higher levels of prior knowledge and understanding by either group on the findings of this study.

The basic assumption with regard to the homogeneity of population in the conduct of the main study was the same as that made in the pilot study, essentially the control and

experimental populations were equivalent in terms of their entry status with regard to their levels of knowledge of and understanding of relationships associated with algal growth processes. With the changes made in the instruments and the larger sample it was assumed that the small differences noted in the pilot study would not impact unduly on the main study.

The general statistical analysis of the pre KAS mean scores presented in Tables 5.7 and 5.8 suggest that the experimental ($\bar{X} = 12.3$, $\sigma = 2.8$) performed marginally better than the control group ($\bar{X} = 10.9$, $\sigma = 3.3$) on the pre KAS. In the case of the pre CES mean scores there also appears to be only a marginal difference between the control group's ($\bar{X} = 6.1$, $\sigma = 2.5$) and the experimental group's ($\bar{X} = 5.2$, $\sigma = 3.1$) performances on the pre CES.

Testing for significance of these differences was carried out using paired two tail 't' tests ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$). Repeated measure ANOVA's conducted as part of the overall KAS/CES measures data set analysis provided corroborative evidence in support of these 't' tests.

5.4.2.1 Experimental vs Control (Pre Treatment KAS Mean scores)

With a $t_{\text{Obtained}} = 2.0$ and $p = 0.0479$ (Appendix 5.6), the H_0 was rejected and the conclusion reached that there was in fact a significant difference, in favour of the **experimental group**, between the entry status of the two groups in terms of the knowledge mean scores (KAS).

Similarly, a one factor ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$) conducted on the same data yielded an $F_{\text{Obtained } 1,116} = 6.1$ and $p = 0.0149$ (Table 5.9). Again based on this data, the H_0 was rejected. It should be noted however that these results, particularly in the case of the 't' test, are borderline. With a t_{Obtained} only marginally greater than the critical value in the case of the 't' test, p values in the order of 0.04 and with an 'estimated between component variance' = 0.8, the chance that the difference is in fact due to chance rather than the treatment cannot be ruled out at the $p = 0.05$ level.

5.4.2.2 Experimental vs Control (Pre Treatment CES Mean scores)

With a $t_{\text{Obtained}} = 2.2$ and $p = 0.0333$ (Appendix 5.6), the H_0 was rejected and the **control group**, between the entry status of the two groups in terms of the understanding of the relationships mean scores (CES).

However, a one factor ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$) conducted on the same data yielded an $F_{\text{Obtained } 1,116} = 3.0$ and $p = 0.0862$ (Table 5.9). Based on this outcome, the H_0 was not rejected and hence one concludes that there was in fact no significant difference between the entry development of understanding (CES) mean scores of these two groups. Examination of the interaction plot, Graph 5.4 illustrates the similarity, and when error bars are added, there is almost complete overlap.

The assumption of equal entry status in terms of the level of both knowledge (KAS) and understanding of the relationships between the factors involved in the development of algal blooms (CES), is essentially confirmed. Although the experimental group's KAS mean scores are shown to be significantly better than the control group's, the significance is borderline and as such the impact on the final outcome of the study is probably minimal.

In the case of the CES mean scores, although the 't' test pointed to a significant difference in favour of the control group, the ANOVA indicated that there was no significant difference. This result probably more accurately reflects the true situation. It will be argued in the course of analysis of the KAS and CES data that the anomalies revealed in the course of the testing for homogeneity will not influence the final analysis as the use of 2-way ANOVA as the main statistical tool, takes such differences into account. Further, it will also be argued that these differences will be outweighed by the significant improvements in the post KAS and CES mean scores not only within each group but in the experimental group over the control group.

5.4.3 Learning Outcomes (Control Group)

The Operational Hypothesis:

H_o : Access to the resources only within the Exploring the Nardoo environment will produce no significant change in the learning outcomes for the students using the difference between pre and post mean scores on the KAS as a measure of learning outcomes.

A paired two tail 't' test ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on the pre/post KAS mean score data for the control group yielded a $t_{\text{Obtained}} = 5.5$ and $p = 0.0001$ (Appendix 5.7) and hence the H_o was rejected. The control group's post KAS scores were significantly improved following the treatment.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$), Treatment vs pre post KAS mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 140.4$ and $p = < 0.0001$ (Table 5.10) and again the H_o was rejected. With values of $p = 0.0001$, the decision to reject the H_o has a very high probability of being correct.

The conclusion to be drawn from these tests is that the control group's improvement in KAS score (a measure of learning outcomes) from having access to the package *Exploring the Nardoo* is reflected in an improvement in learning outcomes for them. This is illustrated in interaction plot (graph 5.3), the slope of the pre/post KAS plot for the control group being quite steep.

5.4.4 Learning Outcomes (Experimental Group)

The Operational Hypothesis:

H_o : Access to the algal bloom simulation (treatment) as well as the other resources within the Exploring the Nardoo environment will produce no significant difference in the learning outcomes for students using the pre and post mean scores on the KAS as a measure of learning outcomes.

A paired two tail 't' test ($df = 60$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on the pre/post KAS mean score data for the experimental group yielded a $t_{\text{Obtained}} = 12.5$ and $p = 0.0001$ (Appendix 5.7) and hence the H_0 was rejected. The experimental group's post KAS scores were significantly improved following exposure to the treatment.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$), Treatment vs pre post KAS mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 140.4$ and $p < 0.0001$ (Table 5.10) and again the H_0 was rejected. With values of $p = 0.0001$, any chance of the difference observed being due to chance rather than the treatment is extremely low.

The conclusion to be drawn from these tests is that the experimental group's improvement in KAS score (a measure of learning outcomes) from having access to the package *Exploring the Nardoo* is reflected in an improvement in learning outcomes for them. This is illustrated in interaction plot (graph 5.3), the slope of the pre/post KAS plot for the experimental group being steep.

5.4.5 Developing Understanding of Relationships (Control Group)

The Operational Hypothesis:

H_0 : Access to the resources only within the Exploring the Nardoo environment will produce no significant difference in the students understanding of the cause and effect relationships in the process of algal bloom development using the difference between pre and post mean scores on the CES as a measure.

A paired two tail 't' test ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on the pre/post CES mean score data for the control group yielded a $t_{\text{Obtained}} = 8.7$ and $p = 0.0001$ (Appendix 5.7) and hence the H_0 was rejected. The control group's post CES scores were significantly improved following participation in the experiment.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$), Treatment vs pre post KAS mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 140.4$ and

$\rho = < 0.0001$ (Table 5.12) and again the H_0 was rejected. With values of $\rho = 0.0001$, confidence in rejecting the H_0 is very high, there being little possibility that the observed difference is due to chance rather than exposure to the treatment.

The conclusion to be drawn from these tests is that the control group's improvement in CES score (a measure of development of understanding of relationships) from having access to the package *Exploring the Nardoo* is reflected in an improvement in their understanding of the cause and effect relationships operating in the algal bloom process for them. This is illustrated in interaction plot (graph 5.4), the slope of the pre/post KAS plot for the experimental group being quite steep.

5.4.6 Developing Understanding of Relationships (Experimental Group)

The Operational Hypothesis:

H_0 : Access to the algal bloom simulation (treatment) within the Exploring the Nardoo environment will produce no significant difference in the students understanding of the cause and effect relationships in the process of algal bloom development using the difference between pre and post mean scores on the CES as a measure.

A paired two tail 't' test ($df = 60$, $t_{\text{Critical}} = 2.00$, $\rho = 0.05$), conducted on the pre/post CES mean score data for the experimental group yielded a $t_{\text{Obtained}} = 15.3$ and $\rho = 0.0001$ (Appendix 5.7) and hence the H_0 was rejected. The experimental group's post CES scores were significantly improved following exposure to the treatment.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $\rho = 0.05$), Treatment vs pre post CES mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 310.75$ and $\rho = < 0.0001$ (Table 5.12) and again the H_0 was rejected. With values of $\rho = 0.0001$, confidence in rejecting the H_0 is very high, there being little possibility that the observed difference is due to chance rather than exposure to the treatment.

The conclusion to be drawn from these tests is that the experimental group's improvement in CES score (a measure of development of understanding of relationships) from having access to the package *Exploring the Nardoo* is reflected in an improvement in their understanding of the cause and effect relationships operating in the algal bloom process for them. This is illustrated in interaction plot (Graph 5.4), the slope of the pre/post CES plot for the experimental group being steep.

5.4.7 Learning Outcomes (Control vs Experimental)

The Operational Hypothesis:

H_o : Access to all resources within the *Exploring the Nardoo* environment including the algal bloom simulation for the Experimental group will produce no significant difference in mean post scores on the Knowledge Acquisition Schedule (KAS) between experimental and control group members.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$), Treatment vs pre/post KAS mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 7.325$ and $p = 0.0078$ (Table 5.10). On this basis the H_o was rejected. An ANOVA conducted on the variable KAS_Diff (Post mean KAS scores - Pre KAS scores) to test whether the experimental group's mean KAS scores changed more than those of the control group (Table 5.11) indicated that there was a significant difference between the experimental group's post KAS scores and those of the control group, with the experimental group's scores changing significantly more than those of the control group. With a value $p = 0.0078$, the probability that this difference is due to chance rather than exposure to the treatment is very low.

This finding was further supported by the use of a paired two tail 't' test ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on a Treatment vs post KAS mean score basis. The test yielded a $t_{\text{Obtained}} = 6.3$ and $p = 0.0001$ (Appendix 5.6) and hence the H_o was rejected.

The interaction plot (Graph 5.3) illustrates that the post KAS scores for the experimental group are higher than those for the control group.

An ANOVA conducted on the created variable KAS_diff (Table 5.11) confirms that the difference is significant.

The conclusion to be drawn from this is that the control and experimental group's improvement in the post KAS score (a measure of learning outcomes) resulting from access to the package *Exploring the Nardoo* (including the simulation tool for the experimental group) is reflected in an improvement in the learning outcome for both groups. However in terms of the knowledge component of the experience, there was a significant difference between the post KAS mean scores for both groups, the experimental group's scores changing significantly more than those of the control group. One must therefore conclude that the simulation tool may have had a positive influence on the acquisition of knowledge about algal growth.

5.4.8 Developing Understanding of Relationships (Control vs Experimental)

The Operational Hypothesis:

H_o : Access to all resources within the *Exploring the Nardoo* environment including the algal bloom simulation for the Experimental group will produce no significant difference in the mean post scores on the Cause/Effect Schedule for experimental and control group members.

A repeated measures ANOVA ($F_{\text{Critical } 1,116} = 3.92$ and $p = 0.05$), Treatment vs pre/post CES mean scores, conducted on the data yielded an $F_{\text{Obtained } 1,116} = 66.7$ and $p = < 0.0001$ (Table 5.12). On this basis the H_o was rejected. An ANOVA conducted on the variable CES_Diff (Post mean CES scores - Pre CES scores) to test whether the experimental group's mean CES scores changed more than those of the control group (Table 5.13) indicated that there was a significant difference between the experimental group's post CES scores and those of the control group, with the experimental group's scores changing significantly more than those

of the control group. With a value $p = < 0.0001$, the probability that this difference is due to chance rather than exposure to the treatment is extremely low.

This finding was further supported by the use of a paired two tail 't' test ($df = 56$, $t_{\text{Critical}} = 2.00$, $p = 0.05$), conducted on a Treatment vs post CES mean score basis. The test yielded a $t_{\text{Obtained}} = 5.9$ and $p = 0.0001$ (Appendix 5.6) and hence the H_0 was rejected.

The interaction plot (Graph 5.4) illustrates that the post CES scores for the experimental group are higher than those for the control group and in fact suggests that the experimental group's mean scores changed more than those for the control group. An ANOVA conducted on the created variable CES_diff (Table 5.13) confirms that the difference is significant.

The conclusion to be drawn from this is that the control and experimental group's improvement in the post CES score (a measure of development of understanding of relationships) from having access to the package *Exploring the Nardoo* (including the simulation tool for the experimental group) is reflected in an improvement in the understanding of relationships between contributing factors for both groups. However, in terms of the development of an understanding of the relationships involved in the process, the experimental group's post CES score was significantly better than the control group's and this reflects a significant advantage afforded the experimental group by having access to the simulation tool.

5.5 Results: Main Study - Based on User Perception Schedule

This tool has been described in Chapter 4 of this thesis and it is included within this volume as Appendix 4.3. The data from this schedule was processed in two stages. The initial stage involved analysis of the responses to the 5 point Likert scale for each question in terms of frequency of each 'point' and a breakdown of the responses was developed in terms of the percentage of respondents who fell into each of the five scale 'slots' for each question.

Appendix 5.9 presents the paired responses for each of the common questions in the User Perception Schedule (UPS) expressed in terms of the percentage responses for each of the steps on the Likert scale. These questions were asked of both the control and experimental groups and they focused on the learning preferences and general design issues such as user control, general functionality and information representation. For each question, the number of responses and its expressed percentage of the whole group in each of the 5 Likert divisions is set out for the control group and experimental group separately. The percentage response which represented the largest number of students is also indicated for each group.

Appendix 5.10 presents the paired responses for each of the simulation specific questions (Experimental group responses) in the User Perception Schedule (UPS) expressed in terms of the percentage responses for each of the steps on the Likert scale. These questions focused more on the aspects of the simulation tool, its functionality, value to learning and ease of use. For each question, the number of responses and its expressed percentage of the whole group in each of the 5 Likert divisions is set out for the control group and experimental group separately. The percentage response which represented the largest number of students is also indicated for each group.

In stage two, the responses were ‘re-coded’ using the ‘scoring’ pattern shown below in Table 5.14.

Scale Score	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
	5	4	3	2	1

Table 5.14: Likert ‘Scores’

The resulting data sets were then analysed to provide the general statistical measures Mean (\bar{X}) and Standard Deviation (σ) for two combinations of the data, namely the experimental groups responses to the simulation specific questions which only they answered and the responses of both the experimental and control groups to the *common* questions in the schedule. A two factor ANOVA for Treatment vs Common Questions was also conducted on the responses of the two groups to the common questions in the schedule.

5.5.1 Main Study: UPS Responses for Common Questions (\bar{X} and σ)

Table 5.15 below presents the responses for each of the common questions in the User Perception Schedule (UPS) expressed in terms of mean (\bar{X}) and standard deviation (σ).

These questions were answered by both the control and experimental group members. For each question, the number of responses and its expressed percentage of the whole group in each of the 5 Likert divisions is set out for the control group and experimental group separately. The response which represented the largest number of students is also presented for each group.

Q	Question Issue/Concept Specific Grouping	Control Group (n=24)		Experimental (n=53)	
		Mean	St. Dev	Mean	St. Dev
Learning Outcomes/Development of Relationships					
3	I think this kind of computer based CD-ROM package makes learning easier.	3.88	0.74	4.04	0.78
10	I think that the facility to measure various features including levels of nutrients in the river was helpful in learning about the role of such factors in the development of algal blooms.	3.75	0.94	3.91	0.74
27	I feel that simulating the "real world" is a more interesting way to learn about things than simply reading about them or being told about them.	4.00	0.78	4.08	0.81
29	I think that I have learned more about ecology in general from the package than I would have learned if I studied the work in the normal classroom or using textbooks.	3.46	1.06	3.72	0.77
General Functionality					
24	I needed quite a deal of help from the teacher to get started on this package.	2.00	0.72	2.51	1.15
25	The teacher had difficulty in showing us how to use this package and in helping us with problems we had.	1.33	0.48	1.62	0.77
46	I became frustrated and didn't work through all the sections of this package because it did not interest me.	2.04	0.75	2.23	0.70
User control					
38	I found the layout in this package confusing because there were too many choices and pathways. I didn't know where to start.	2.25	0.53	2.74	0.98
39	I looked at all the video clips before I looked at anything else.	1.83	0.82	2.02	0.77
40	I browsed through the whole package so that I would not miss anything. Then I worked on researching the set problem.	2.58	1.18	2.75	1.14
45	I became frustrated and didn't get round to completing all the sections because I found it difficult to find the materials I needed to answer some of the parts of the set problem.	1.75	0.61	2.17	0.83
Navigation					
4	I didn't need to use the help function very often to complete the problem.	4.21	0.88	4.19	0.83
22	I found that I got lost while working my way through the package and often needed to access the help function.	1.42	0.50	2.06	0.93
33	I found the layout in the package easy to follow and had no trouble finding my way around.	4.25	0.53	3.74	0.98
36	I think the package was too detailed and complex. I didn't know where to start or how to go about solving the problem.	1.92	0.83	2.21	0.95
Multiple Representations					
17	I prefer learning using visual media/representations such as, video clips, graphs, pictures etc.	3.33	0.76	3.85	0.79
39	I looked at all the video clips before I looked at anything else.	1.83	0.82	2.02	0.77
44	I think most of the media materials were very useful and provided good support in solving the set problem.	4.04	0.75	4.06	0.63
Broad Issues					
2	I don't enjoy researching materials from textbooks.	2.83	1.24	3.08	1.05
7	The filing cabinet in the water research centre provided me with more information about the causes of algal growth in the river than any of the other available resources.	4.33	0.82	3.92	0.73
15	Learning by using computer software packages is easier than reading a textbook or listening to a teacher.	3.33	0.96	3.51	1.05
23	I prefer using text based materials to collect information about a topic.	2.88	0.90	2.77	1.09
32	I think the best thing about the Exploring the Nardoo package in general is that it lets you explore and choose your own areas to research if you wish.	4.42	0.58	4.36	0.48
37	A good feature of this package was that the graphics were clear and easily understood.	4.21	0.51	4.09	0.71
50	I had no difficulty in obtaining enough information to solve the problem from the filing cabinet, video clips, radio reports and the newspaper articles.	4.46	0.51	4.21	0.77

Table 5.15: Main Study: Experimental/Control Responses- UPS Common Questions

5.5.2 Main Study: UPS Responses for Simulation Specific Questions (\bar{X} and σ)

Table 5.16 below presents the responses for each of the simulation specific questions in the User Perception Schedule (UPS) expressed in terms of mean (\bar{X}) and standard deviation (σ).

Q	Question Issue/Concept Specific Grouping	Experimental	Group (n=53)
		Mean	St. Deviation
Learning Outcomes / Development of Relationships			
1	I learned the most about the growth of algae in the package by running the simulation.	3.32	1.17
8	I preferred using the simulator to discover the causes and effects of algal blooms in rivers than any of the other resources available to me in the package.	2.94	1.01
12	I learned more about algal growth by reading the references and using the media sections of this package than I did by using the simulator.	3.26	1.06
13	My understanding of the process of algal growth in rivers was improved by “ seeing it happen before my eyes” in the simulator.	3.75•	0.73
18	I experimented with the different controls on the simulator before I tried to use it to research to problem.	3.79•	0.91
21	Simulating the conditions that may produce blue-green algal blooms gave me a better understanding of the process of blue-green algal over-growth in rivers.	3.96•	0.73
28	I think that the blue-green algae simulator helped me to understand the causes and effects of excessive algal growth in the Nardoo river.	3.91•	0.71
47	I don’ t think you can fully understand the processes involved in the development of blue-green algal blooms without using the simulator in this package.	2.77	0.95
General Functionality			
20	I am good at maths but found the simulator too difficult to use.	2.25•	0.87
31	The function of each of the controls on the simulator was clear.	3.58	0.80
User control			
5	While using the blue-green algae simulator I felt that I had control over its operation.	3.47	0.95
6	The controls on the simulator were easy to use.	3.94•	0.79
11	I found using the simulator was very simple and easy.	3.53	0.93
16	I was not able to gain useful information from the simulator until I had used the help section.	2.32•	0.80
Broad Issues			
9	I found using the simulator confused me rather than helping me.	2.36•	0.86
19	I had access to the simulator but did not even try to use it because I am not good on computers.	1.85•	0.82
30	I think using the blue-green algae simulator is essential to understanding algal blooms.	2.89	0.95
34	I don’ t think it necessary to use the simulator to fully understand the causes and effects of algal blooms.	3.51	0.91
35	Some of the problems could not be answered fully unless you used the simulator.	2.68•	0.85
43	I feel that the blue-green algae simulator is an important part of the whole package.	3.57	0.82
Multiple Representations			
14	When using the blue-green algae simulator, I preferred to use it in the ‘ graph mode’ rather than the animate mode’ .	3.21	0.91
26	I could understand the process of blue-green algal blooms more easily by looking at the output from the numerical data windows in the simulator.	2.91	0.90
41	The ability to swap between the different kinds of output from the simulator, graphic, animation and numeric, was useful and helped me better understand the process at work.	3.72	0.66
42	I think the graphs produced by the algal bloom simulator helped me most in understanding the process.	3.09	1.02
48	I found the animated output, (depiction of algal growth as it occurred), from the simulator helped me to best understand the process.	3.02	0.82
49	I found the graphical output generated in the simulator helped me most in understanding the process.	3.02	0.95
Grand Mean		3.18	0.57
Means marked (•) represent those which fall in the top and bottom 10% of the Grand Mean distribution.			

**Table 5.16: Main Study:
Experimental Group Responses UPS Simulation Specific Questions**

These questions were applicable only to members of the experimental group. Students in the control group were able to select a Not Applicable (NA) option for these questions. For each question, the number of responses and its expressed percentage of the whole group in each of the 5 Likert divisions is set out for the control group and experimental group separately. The response which represented the largest number of students is also presented for each group.

5.5.3 Main Study: ANOVA (Common Question Responses)

5.5.3.1 Treatment vs Question 'scores'

Based on the (\bar{X}) and (σ) for the responses from the control group and experimental groups to some of the common questions, several questions were identified as having the potential to contribute to discussion of the issues in this study. A one factor ANOVA (Treatment vs Question 'scores') was carried out on the re-coded UPS responses for all questions to tease out possible interactions. Six questions were flagged as exhibiting significant interaction and for ease of data presentation, they have been grouped as pairs.

Table 5.17 below sets out the results of this ANOVA for question 7 and 17.

Question 7: The filing cabinet in the Water Resource Centre provided me with more information about the causes of algal growth in the river than any of the available resources.

Question 17: I prefer learning using visual media/representations such as video clips, graphs, pictures etc.

One Factor ANOVA X_1 : Treatment Y_4 : q7

Analysis of Variance Table				
Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	2.8	2.8	4.8
Within groups	75	43	.6	p = .0314
Total	76	45.8		

Model II estimate of between component variance = .1

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	-.4	.4*	4.8*	2.2

* Significant at 95%

One Factor ANOVA X_1 : Treatment Y_7 : q17

Analysis of Variance Table				
Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	4.4	4.4	7.1
Within groups	75	46.1	.6	p = .0092
Total	76	50.5		

Model II estimate of between component variance = .1

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	.5	.4*	7.1*	2.7

* Significant at 95%

Table 5.17: Main Study: UPS Common Questions - ANOVA (Questions 7 & 17)

Table 5.18 below sets out the results of this ANOVA for question 22 and 24.

Question 22: I found that I got lost while working my way through the package and often needed to access the help function.

Question 24: I needed quite a deal of help from the teacher to get started on this package.

One Factor ANOVA X₁: Treatment Y₈: q22

Analysis of Variance Table				
Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	6.8	6.8	10
Within groups	75	50.7	.7	p = .0022
Total	76	57.4		

Model II estimate of between component variance = .2

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	.6	.4*	10*	3.2

* Significant at 95%

One Factor ANOVA X₁: Treatment Y₁₀: q24

Analysis of Variance Table				
Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	4.3	4.3	4
Within groups	75	81.2	1.1	p = .0503
Total	76	85.5		

Model II estimate of between component variance = .1

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	.5	.5	4*	2

* Significant at 95%

Table 5.18: Main Study: UPS Common Questions -ANOVA (Questions 22 & 24)

Table 5.19 below sets out the results of this ANOVA for question 33 and 45.

Question 33: I found the layout in the package easy to follow and had no trouble finding my way around.

Question 45: I became frustrated and didn't get round to completing all the sections because I found it difficult to find the materials I needed to answer some of the parts of the set problem.

One Factor ANOVA X₁ : Treatment Y₁₆ : q33

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	4.4	4.4	5.8
Within groups	75	56.8	.8	p = .0188
Total	76	61.2		

Model II estimate of between component variance = .1

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	-.5	.4*	5.8*	2.4

* Significant at 95%

One Factor ANOVA X₁ : Treatment Y₂₅ : q45

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	2.9	2.9	5
Within groups	75	44	.6	p = .0288
Total	76	46.9		

Model II estimate of between component variance = .1

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Experimental vs. Control	.4	.4*	5*	2.2

* Significant at 95%

Table 5.19: Main Study: UPS Common Questions - ANOVA (Questions 33 & 45)

5.5.4 Main Study: ANOVA (Simulation Specific Questions)

A one factor ANOVA (Gender vs Question ‘scores’) was carried out on the re-coded UPS responses by the experimental group members to the simulation specific questions to ensure that no effects were missed. None of the questions in this analysis were flagged as significant.

5.5.5 Main Study: Other Data Sources

The researcher remained with the both the control and experimental groups as they worked, observing and noting aspects of their general approach to using the package, their interaction/conversation with each other and the researcher when necessary. A selection of these interactions is provided.

5.5.5.1 Student Field Comments - Control & Experimental Groups

“... great the way you can change the amount of light and temperature there is and see what happens and see how each one controls the whole process”.

“ ... I think that you need to look at the three kinds of numbers coming out of the simulator so that it makes sense”

“ ... kids could use this to see what happens when someone empties pollution into the river ... they could work out what things caused the most damage”

“ ... the best thing as far as I’m concerned is the way the simulator shows me on a graph what happens ... the numbers don’t mean much to me ... maybe they might if I knew more about it”

“ ... it was great to see the river change when you moved the controls”

“ I did badly I think when we did the test the other day ... I didn’t do Biology so I don’t know anything about algae ... I think I know a lot more now about why algae grows”

“ ... the videos of people telling about what has happened were good”

“... this would be good for kids ... they could see what happens to the river when people live in the area”

“... I only had a quick look at the sim ... it just confused me ... it was quicker to get the stuff from the filing cabinet.”

5.5.5.2 Researcher's Field Observations

- Some of the students worked by themselves by choice and they seemed to need more assistance than the others.
- A number of students are still into just grabbing stacks of data and then walk away to process elsewhere ... treating it as no more than a database ... and electronic book.

5.6 Findings: Main Study: User Perceived Value Schedule (UPS)

The User Perceived Value Schedule (UPS) was designed to gather data on the students perception of their experience in using the package *Exploring the Nardoo* in relation to:

- their perception of their level of achievement in relation to learning outcomes;
- their perception of their level of achievement in relation to the development of an understanding of the relationships involved and;
- their perception of the quality of design and how it impinged on their experience.

The schedule was designed to facilitate this in the simplest way possible, providing in the same schedule, questions which pertained to the design of the overall package and the resources available to both groups as well as experimental group specific questions on the algal bloom simulation tool (Appendix 4.3). As noted earlier, the control group students were given the option to indicate [NA] for the questions, which did not pertain to their group. A check was made when coding these completed schedules, that students in the control group did not inadvertently answer questions which pertained to issues specific to the experimental group. There were four cases where experimental group specific questions were answered by control group respondents. Three of these related to question 1 which targeted the experimental group. This design fault in the instrument did

not become apparent in the pilot study otherwise the first question would have been a common question. These four cases were ignored during the processing of the data and not included in the data set.

It is important to consider the nature of the whole package *Exploring the Nardoo* when interpreting the perceptions of the students. *Exploring the Nardoo* is in itself a simulation, in the broadest sense, of a real world environment which contains a number of supportive tools, one of which is a simulation tool designed to model a specific process integral to the processes at work in the whole environment. Consequently, a number of the questions which were asked of both the control and experimental provide data which pertains to the design of simulations in this broad sense as well as the specific simulation tool, the subject of this study.

5.6.1 Common Questions (Control and Experimental)

The analysis that follows is based on the responses of students from both the control and experimental groups to questions in the User Perception Schedule (UPS) which were common to both groups, dealing with general aspects of the package *Exploring the Nardoo* and the learning experience from a user's point of view. For clarity of presentation (Table 5.15) and reporting, the questions and their responses were grouped into several broad categories but it should be noted that a number of questions have considerable overlap.

Learning outcomes/Development of Relationships

Questions: 3, 10, 27 and 29

Broad Issues

Questions: 2, 7, 15, 23, 32, 37 and 50

General Functionality

Questions: 24, 25 and 46

User Control

Questions: 38, 39, 40 and 45

Navigation

Questions: 4, 22, 33 and 36

Multiple Representations

Questions: 17, 39 and 44

5.6.1.1 Learning Outcomes and Understanding Relationships

In terms of the overall package, there was a perception by all the participants that their learning experience had been improved or positively influenced by the use of the simulation *Exploring the Nardoo*. This is supported by the response breakdown data presented in Table 5.15. Question 3 asked directly whether they thought that this type of CD ROM package makes learning easier. In response, both the control group mean ($\bar{X} = 3.88, \sigma = 0.74$) and experimental mean ($\bar{X} = 4.04, \sigma = 0.78$) groups indicated strong agreement. When this response is compared with a verification question 15, which asked whether using the software made learning easier, the mean response for both groups suggests that there is less strong agreement as to the value of the package itself. This may be a reflection of the subtle difference in the question, suggesting that in question 3, CD- ROM based learning in general is being tested while in question 15, the specific software *Exploring the Nardoo* is in question.

Both groups showed a strong agreement with the proposition presented in question 27 (control mean $\bar{X} = 4.00, \sigma = 0.78$) and experimental mean ($\bar{X} = 4.08, \sigma = 0.81$) that simulating the real world is a more interesting way to learn, supporting the accepted notion that learning is more effective when it's placed in a context which means something to the learner.

Question 29 provided an insight into ecological education in general. Both the control and the experimental groups agreed that they thought that they had learned more from the package about ecology than they would have using normal classroom delivery techniques, however the with a (σ) = 1.06 the control groups responses were much less decisive than those of the experimental group (σ) = 0.77.

Question 32 provides insight into the aspect of multiple pathways and the freedom to explore. With means (\bar{X}) > 4.0 and (σ)'s = 0.5 for both the control and experimental groups, there was strong agreement with the proposition that the freedom to explore and select their own pathways through the package was valuable to their learning outcomes.

Both groups agreed that ability to take measurements in the field was a significant factor. (Question 10). With a mean (\bar{X}) = 3.91 and a (σ) = 0.74 the experimental group compared to the control group mean (\bar{X} = 3.75, σ = 0.940) shows a firmer agreement with this proposition and this is probably a function of the reinforcement they may have had through the recognition that these measurement are the same as those used in the simulation. It may also be significant that, hints to take such measurement are given within the guided help scripts.

The particular suggestion occurs at the second level of help. If students in the control group progressed without accessing this level, they may not have made any attempt to take measurements.

A similar response was noted for the control group on question 40. As for the experimental group, most worked directly on the problem rather than browsing. The suggestion that this may be the result of being given too much direction in the orientation phase has been made but it may also be a reflection of the limited time frame in which the students were required to gather, analyse and synthesise their solutions to the set problem. There must obviously be a connection between this strategy and their learning styles but it was not the intention to include this variable in this study. The response to question 44 suggests that both groups (control mean (\bar{X}) = 4.04, σ = 0.75 and experimental group mean (\bar{X}) = 4.06, σ = 0.63) found the different media useful and supported them well in developing solutions to the problem presented.

There is evidence for the proposition that the control groups equally good improvement in performance on the post KAS may be a reflection of the extensive and well structured theoretical materials in the filing cabinet, question 7. A one factor ANOVA (Treatment vs Questions 'scores') indicated that there was a significant difference in the responses of the two groups ($F_{\text{Obtained } 1,75} = 4.8$, $p = 0.0314$), with the control group indicating greater level of agreement with the proposition. Their poorer performance on the post CES is perhaps a reflection of their lack of access to the simulation tool which provided the experimental group with the ability to explore and 'test' relationships between factors.

5.6.1.2 Other Issues

Responses to question 2 showed that both groups did not show a leaning towards researching on computers instead of more traditional approaches (books), the control group ($\bar{X} = 2.83$, $\sigma = 1.24$) exhibiting a stronger disagreement to the proposition than the experimental group ($\bar{X} = 3.08$, $\sigma = 1.05$).

Responses to question 23 indicated that both groups did not have a preference for collecting information from text based materials. It is clear from the data however that the experimental group ($\bar{X} = 2.77$, $\sigma = 1.09$) is in greater disagreement with the proposition than the control group. Examination of the percentage distribution of responses for both groups (Appendix 5.9) confirms this. It could be suggested from these figures that the experimental group may have in fact been more suited to working with the simulation tool than the control group had they been given the opportunity. Data from questions 24 and 25 suggest that both groups entered the experience equally prepared in terms of the pre-treatment sessions and their overall knowledge of the package and what was required.

In terms of general statistical measures, question 17 provides evidence for both groups having a leaning towards a preferred visual representation of information in learning environments. In a one factor ANOVA (Treatment vs Questions) conducted on all the common questions, question 17 showed a significant interaction, $F_{\text{Obtained } 1,75} = 7.1$, $p = 0.0092$, the experimental group showing a significantly greater preference for working visually. This preference is further reinforced by the responses to question 39, where again, the experimental group ($\bar{X} = 2.02$, $\sigma = 0.77$), tends more towards visual representations than the control group ($\bar{X} = 1.83$, $\sigma = 0.82$).

The data from question 46 indicates that students in both the control group ($\bar{X} = 2.04$, $\sigma = 0.75$) and the experimental group ($\bar{X} = 2.23$, $\sigma = 0.70$) completed the task and did not become frustrated through a lack of interest. This may have several implications for this study. It could be a function of good design, or the 'pressure' to complete the task as it formed part of their course work or perhaps reflects the fact that the problem was presented in a context that had meaning for them.

5.6.1.3 General Package Design

The findings in this section are based on the broader responses of both groups to the common questions. These questions were targeted to the more general look, feel and behaviour of the entire package. In a number of questions the word simulation was used, but in the broad context outlined elsewhere and in the next section.

5.6.1.3.1 Overall Package Design

As mentioned earlier, *Exploring the Nardoo* simulates a whole catchment environment using a combination of resources based in text, various media and cognitive tools (including the algal bloom simulator) designed to support the learning process. The common questions within the User Perceived Value Schedule (UPS) provided data on the success of the package as a whole in terms of design and the findings are set out below.

5.6.1.3.2 General Design/Functionality/Navigation

In general terms few students had difficulty using or moving around in the package *Exploring the Nardoo*. A total of only 15% (n=10) students (Appendix 5.9) across both the control and experimental groups indicated in their response to question 36 that the overall package was too complex. This was supported by the response to question 33. Within the control group, there was 100% agreement ($\bar{X} = 4.25$, $\sigma = 0.53$) that the layout was easy to follow and resources were easy to find and use. The results for the experimental group were less positive ($\bar{X} = 3.74$, $\sigma = 0.98$), 73% agreeing with the proposition put by the question.

There was a significant undecided factor and the 16% disagreement registered by the experimental group may be the result of the extra layer of complexity placed on the task by those using the simulation tool. This possibility is further reinforced in results from a one factor ANOVA (Treatment vs Questions) conducted on all the common questions. Questions 22, 33 and 45 all registered significant interaction and all deal either directly or indirectly with the issue of navigational difficulties. Question 22 which probed the issue of getting lost while working in the package produced an $F_{\text{Obtained } 1,75} = 10.0$, $p = 0.0022$ (Table 5.18), indicating a significant difference in the responses of the two

groups such that more participants in the experimental group felt they got lost. Question 33 probed package layout and the ease with which participants could move through it. An $F_{\text{Obtained } 1,75} = 5.8$, $p = 0.0188$ indicated that a significant proportion of the control group found the layout more easy to follow than the experimental group. Question 45 also dealt with aspects of moving through the package and finding materials and again, a significant proportion of the experimental group $F_{\text{Obtained } 1,75} = 5.0$, $p = 0.0288$ (Table 5.18), found it more frustrating in finding materials needed to complete the task. An explanation for this may lie in the increased cognitive load placed on some members of the experimental group in dealing with the extra complexity imposed through having access to the simulation tool. Although it is reported in the section dealing with the experimental groups responses that the responses indicated that the simulation tool was considered to be easy to use, it would appear that this may be true in isolation. However, when considered as a complete package some users were more taxed than others.

This aspect is again probed with question 38 which puts the proposition that the layout of the package was confusing because there were too many choices and pathways. The control group strongly disagreed ($\bar{X} = 2.25$, $\sigma = 0.53$) as did the experimental group ($\bar{X} = 2.74$, $\sigma = 0.98$). Generally for the majority, the user perception that the package was well laid out is reinforced.

5.6.1.3.3 Ease of use/User control

Although the aspects of ease of use are closely related to the previous section, the researcher has separated them out for clarity of presentation and analysis. The responses to question 4 (control group $\bar{X} = 4.21$, $\sigma = 0.88$) and (experimental group ($\bar{X} = 4.19$, $\sigma = 0.83$), showed that most of the students in both groups found the package easy to use. This response most likely reflects the preparation of the groups prior to commencement of the study.

As mentioned elsewhere in this chapter, one of the outcomes of the Pilot study was to provide a more detailed orientation session before commencement of the study. A significant problem in the pilot study arose from the need for students to spend an

inordinate amount of their on task time becoming familiar with the system. Providing more time for the on task portion of the study was not a possibility due to time tabling restrictions. The solution adopted in an attempt to ameliorate this limitation of time was to provide each group with a more extensive and detailed orientation session. If this has been excessive, it may well have clouded the results with respect to these aspects however, without further investigation, the researcher assumed that in this study the effect of more intense preparation has been negligible on the outcomes.

The most important aspect however, the need for equality in terms of extent and quality of this orientation session for both groups was achieved. A small number of experimental group members did agree with the question. They are probably representative of the few students who could not manage the added complexity of the simulation tool alluded to earlier. (See also comment in section 5.5.5.2, *Other Data Sources-Researcher's Field Observations*).

The responses to question 24 which probed the level of help user requested of the instructor showed a marked difference between the two groups, with the experimental group indicating that they generally required more help to get started. A one factor ANOVA (Treatment vs Questions) was conducted to test the significance of the difference in response of the two groups (Table 5.18). With an $F_{\text{Obtained } 1,75} = 4.0$, $p = 0.0503$ the difference was determined to be significant.

5.6.1.3.4 Multiple Perspectives/Representations

One of the essential design features of the package *Exploring the Nardoo* as a whole is that it provides students with multiple perspectives to the embedded problems through multiple representations of the available resources. Both the experimental and control groups responded to question 44 very positively with similar means ($\bar{X} > 4.0$) and similar standard deviations.

Question 40 probed their pattern of attack for accessing resources to complete the task set. For the control group, most indicated that they spent little time looking at the complete package and instead immediately went about researching a solution to the problem. The experimental group indicated that about half of the group looked at the

complete package before tackling the problem. This is an interesting but not unusual occurrence when students use resources that are computer based and provide ‘open pathways’ for access.

5.6.1.3.5 Resources

The package *Exploring the Nardoo* has a rich and extensive resource base. There is an extensive collection of text based materials in the filing cabinet and this provides easy access to information on all aspects of the problems embedded in the learning environment. Approximately 50% of the control group strongly agreed that they relied heavily on the filing cabinet text based materials while this dropped to 19% for the experimental group. This difference was found to be significant and was reported on earlier (question 7).

The responses to question 50 showed that both the experimental ($\bar{X} = 4.21$, $\sigma = 0.77$) and control ($\bar{X} = 4.46$, $\sigma = 0.51$) groups were in strong agreement with the proposition that there were more than enough resources available in the complete package to solve the set problems. This would support the reported statistical outcomes earlier in this chapter, which showed that both groups significantly improved on their pre, and post learning outcomes measure (KAS). The knowledge component was there and freely available for all. The change in level of understanding of relationships was much less significant between the groups however without the added ability to test out relationships using the simulation tool.

5.6.2 Simulation Specific Questions (Experimental Group)

The analysis that follows is based on the responses of students from the experimental group to questions in the User Perception Schedule (UPS) which were specific to the simulation tool available to them within the package *Exploring the Nardoo* dealing with its impact on the learning experience from a user’s point of view. For clarity of presentation (Table 5.16) and reporting, the questions and their responses were grouped into several broad categories but it should be noted that a number of questions have considerable overlap.

Learning outcomes/Development of Relationships

Questions: 1,8,12,13,18,21,28, and 47

Broad Issues

Questions: 9,19,30,34,35 and 43

General Functionality

Questions: 20 and 31

User Control

Questions: 5,6,11 and 16

Multiple Representations

Questions: 14, 26,41,42,48 and 49

It should be noted also that in terms of the mean response for each question, a number of questions did not show a clear cut agreement or disagreement with their means responses clustered around the center of the 5 point scale. To clarify and simplify the analysis, a grand mean was calculated for this set of questions and only those questions whose mean fell within either the bottom 10% or top 10% range of the grand mean were considered. There were a few exceptions to this. Examination of the percentage breakdown of responses in Appendix 5.10 shows that in some questions, an otherwise skewed result was masked in the process of mean calculation. In one or two cases, questions which shed light on the arguments presented in this thesis are lost to the analysis if this strict 10% rule was rigorously applied.

5.6.2.1 Learning Outcomes and Understanding of Relationships

The overall trend in terms of the participants perceived learning outcomes was that the use of the simulation tool resulted in a greater knowledge of the process both in terms of the factual information and the interaction or relationships between factors that are involved.

In question 21 ($\bar{X} = 3.96$, $\sigma = 0.73$), most of the respondents agreed that the simulation tool resulted in them having a better understanding of the process (factual knowledge of the process) and the result for question 13 ($\bar{X} = 3.75$, $\sigma = 0.73$) adds further support to this. In terms of developing a better understanding of cause and effect

relationships several questions in this grouping provided supporting evidence. Question 28 ($\bar{X} = 3.91, \sigma = 0.71$) indicates that the group found the tool helped them to do this and this was reflected in the quality of the solutions to the task handed up as the formal outcome of the exercise. The experimental groups significantly greater improvement over the controls group in the post CES mean scores also supports this finding.

Question 18 ($\bar{X} = 3.79, \sigma = 0.91$), indicates that most (87%) of the experimental group respondents did not just see the exercise as a collection of information, but rather a exploration of the process in that they experimented with the simulation tool before attempting to utilise it. An important design feature of the simulation tool was the inclusion of the ability of the users to easily consider the information from different perspectives using different representation modes and the responses to question 41 ($\bar{X} = 3.72, \sigma 0.66$), whose mean falls just outside the targeted range for this analysis, suggest that a large proportion of the group found that this ability to swap between display modes helped them in gaining greater knowledge of both the process and the relationships. This finding is reinforced by the response to question 13 ($\bar{X} = 3.75, \sigma 0.73$), 72% suggesting that *seeing it happen* helped them.

5.6.2.2 Broad Issues relating to Learning Outcomes/Understanding Relationships

A number of the questions in the UPS had a broader application to the issues detailed in the previous section. In terms of the tool itself and the learning experience, there are a number of instances of support for the notion that the tool was an essential part of the whole simulated environment in terms of the overall learning experience. In responding to question 43, approximately 61% of the respondents felt that the simulation was an essential part of the whole package however, it is very that the students did not consider that the tool was essential to completion of the task as indicated by the responses to question 30 ($\bar{X} = 2.89, \sigma = 0.95$).

Examination of the results of the basic statistical measures (Appendix 5.10) shows that 45% of the students disagreed and a further 19% were undecided. Question 35 ($\bar{X} = 2.68, \sigma = 0.85$) supports this in that almost half the students disagreed

with the proposition that some of the problems could not be answered fully without using the simulator, with a further 37% being undecided. The nature of the responses to these two questions could be attributed to that extent and quality of the other resources that provided an alternative pathway to the development of a solution to the task. What is clear from the responses to a number of questions is that the design of the package as a whole is such that there are sufficient resources of quality other than the simulation tools to complete the task. This may have clouded their memories after the event when responding to the UPS.

Questions 9 ($\bar{X} = 2.36, \sigma 0.86$) and 19 ($\bar{X} = 1.85, \sigma 0.82$) reinforce the assertion that the design of the simulation tools was such that it was user friendly and provided users with positive support in the development of an understanding of the process.

5.6.2.3 Design Quality – Simulation Tool

How well does the design of this simulation tool fit the contemporary theoretical principles enumerated earlier and how did it impinge on their experience? The simulation tool itself was designed to have the following broad characteristics based on the contemporary theoretical principles examined and summarised in chapter 2:

- A clean and easy to navigate and operate interface.
- Provides the user with multiple perspectives on the learning task through multiple representations of the resources available to complete the task.
- Provides the ability to flip between these perspectives/representations.
- Provides user with control of the system to test hypotheses quickly and conveniently.
- Provides instant feedback to the user on the results of their actions in the system using ‘on the fly’ calculation and dynamic representation, no need for a run button.
- Provides user with option to review the process using a slider control, to look back at the process in a step by step fashion.

5.6.2.3.1 General design/Functionality

In general terms, the students in the experimental group found the simulation tool to be easy to use, intuitive in its operation and provided a good level of user control. Question 31 probed in terms the overall functionality With a mean (\bar{X}) = 3.58 and a (σ) = 0.80, it is apparent that most agreed that the functionality was good, with controls that had a clear function. The raw data (Appendix 5.10) suggests that some were undecided clouding the issue slightly. This group may represent a small group of less able students with respect to computer literacy however there is no hard evidence to support this. In responding to question 20 (\bar{X} = 2.25, σ = 0.87), most found the simulator easy to use but 8% of the users indicated that they thought the simulation tool was too difficult to use effectively. Significantly, this small undecided group is probably a subset of the undecided group alluded to in question 31.

5.6.2.3.2 Ease of use/ User control over the system

A number of the questions asked in the UPS targeted this aspect directly. The majority of the users in the experimental group indicated that the simulator was simple and easy to use (question 11) and that they had control over its operation. Question 6 (\bar{X} = 3.94, σ = 0.79), probed the issue of simulator control directly and indicates that most found it easy to control. Likewise, question 16 (\bar{X} = 2.32, σ = 0.80), which tests the reliability of earlier responses by checking their need to use the help function indicates that the students were able to use the simulator intuitively (an indication of overall design quality), not withstanding their introduction to it at the orientation session.

5.6.2.3.3 Multiple perspectives/representations of information

There were a number of questions designed to elicit details on how the design feature of the simulator, which allowed students to flip between various data representation modes, worked for them.

Several questions probed their preference for one presentation mode over another. In general however, although a number indicated a preference for the graphical mode over

the animate mode (question 14 $\bar{X} = 3.21$, $\sigma = 0.91$), no clear preference for one presentation mode over another emerged (Appendix 5.10). Question 42 ($\bar{X} = 3.09$, $\sigma = 1.02$) requires comment. Although there is a larger agree component, the response is not clear cut as there is a significant undecided component of (23%). This perhaps an expression of a misunderstanding in the meaning of the use of the term *numerical window*, as being both the *graphical display window* and actual numerical output.

Although outside the lower 10% -Upper 10% target range set for this analysis, question 41 ($\bar{X} = 3.72$, $\sigma = 0.66$) to which 73% of the respondents indicated that the ability to change output helped them in their understanding of the process also requires comment. Taking into account some of the comments made by students and recorded elsewhere in this chapter, it would seem that it is in fact the ability to be able to combine and flip between modes that is most critical factor in terms of information representation rather than any particular format.

5.6.2.3.4 Navigation

The majority of students had little difficulty moving between screens (flipping between different representations of data) in the simulator. Where icons were used to represent variables or other features, there seemed to be from the researcher's field observations, little difficulty for students in identifying them and using the simulator effectively.

5.6.3 Other Data Sources: Findings

As stated earlier, the researcher collected data based on observations of the groups during their working sessions, noting aspects of their interactions with the software, other students and the instructor when necessary and some of these were detailed earlier in this chapter. They provided some useful insights into the overall issues of design and how the package is used in the classroom as well as supporting some of the findings based on the other data sources.

The general thrust of the student based comments is to support the positive impact which multi-representation of data has on the experience. Many students commented on

how it helped them understand the process and how it might support students in the classroom. There was also strong support for the value of the mechanisms used to place the learning in a real context, using real people to provide information and feedback as well as relating the whole exercise to real world problems and locations.

The observation that some students preferred working as individuals was highlighted by the need to provide more help for those who did. There were more in the control group (5) who elected to do this than in the experimental group (3). The observation that some students in both groups approached the exercise by simply grabbing chunks of information suggests that the pressure to satisfy the requirements and move on must not be discounted in this type of study. The students were asked to provide an audit trail of the materials they collected along with their solution to the task. Analysis of these indicated that in the case of the experimental group, only approximately 20% appeared collect content in an unstructured way in an effort to ensure they found what they needed. This figure rose to an estimated 35% in the control group.

5.7 Summary of Main Study Findings

The essential aims of this study were to:

- to design, develop and implement a simulation tool;
- to test its efficacy in terms of the two research hypotheses stated elsewhere and;
- to add to the knowledge base of the application of simulations in educational environments,

using data obtained from specially designed instruments designed to provide both parametric and nonparametric data for analysis.

5.7.1 KAS and CES data

Analysis of the parametric data using the general statistical measures of (\bar{X}) and σ , two tailed paired 't' tests and repeated measure ANOVA's where applicable, together with collation and analysis of the data which provided a student perception of the outcomes indicated that there were improvements in the parameters nominated to measure the success or otherwise of the implementation.

5.7.1.1 The Hypotheses

In summary, the findings pertaining to main study data are as follows:

- One of the underlying assumptions in this study was that the two groups had identical entry characteristics in terms of the principal measures used, the KAS and CES scores. On the basis of the analyses reported, there were some differences between the two groups of subjects in this study. In particular, the experimental group showed a marginally significantly better entry knowledge based on the KAS scores. It is argued however, that this difference does not compromise the overall analysis and outcome of this study because the principal statistical test applied, namely 2-way ANOVA, allows initial differences to be taken into account in the analysis. In the light of the complete analysis of both the KAS and CES data sets, it is argued that for the purposes of this study, the control and experimental groups could be considered as essentially equivalent in terms of their entry status and that any inconsistencies presented by the analysis with regard to this conclusion have had a minimal impact on this study and do not compromise the overall outcome. For both the KAS and CES measures, the experimental group's improvement in post treatment mean scores was significantly greater than that of the control group.

- For participants in both the control and experimental groups, the within group scores in the KAS (a measure of learning outcomes) after exposure to the treatment improved. This would have been expected as all participants were exposed to factual information within the package which should have increased their knowledge and they entered the treatment with a similar knowledge of the process under study as has been shown elsewhere in this chapter and care was taken to select a task for the participants to solve which could be solved using either the resource base of the *Exploring the Nardoo* package with or without the simulation tool. Care was also taken with the design of the questions used in the KAS to measure knowledge acquisition so that the answers were not dependent on the use of the simulation tool.

- Participants in both groups also improved their within group scores on the CES (a measure of development in understanding relationships) after exposure to the treatment. Again this was not unexpected given the measures taken to ensure that successful completion of the set task was not simulation tool dependent and the nature of much of the information within the package which would afford some development of understanding of the relationships if participants gave some thought to the problem.
- Detailed statistical analysis of the parametric data confirmed that these improvements in the KAS and CES scores within groups were significant and not due to chance or some other variable.
- In comparing the KAS post mean scores between groups, the statistical analysis indicated that they were significantly different, in favour of the experimental group. The essential purpose of the simulation tool was to allow participants to test ‘what if’ situations in order to fully explore the variables in operation and how they interact with one another to influence the process. Perhaps the simulation tool had an added influence on their acquisition of knowledge about the process by assisting them in transforming better understandings of cause and effect into knowledge about the process, supporting the re-working and confirmation of their mental models.
- In comparing the between group CES post treatment mean scores, the difference in the mean scores of the control and experimental groups proved to be significant and favoured the experimental group, despite that fact that the control group may have had a better entry understanding. This is a reflection of the fact that the instrument was designed to measure the participants understanding of how different factors interact. This understanding could be developed by very careful analysis of the data available within the package (including simulation data output within the main text based resource, the filing cabinet). It could also be developed relatively quickly by using the highly visual multi-representational simulation tool to hypothesise about

and then test relationships. Participants within the experimental group who had access to this tool developed a better understanding of the relationships than those in the control group as evidenced by their significantly better scores on the CES.

5.7.2 UPS data

Analysis of the data obtained from the User Perceived Value Schedule (UPS) not only provided supportive evidence for the findings from the two parametric instruments but also proved a rich source of information on the more general aspects of simulation design and implementation which will be reported on in the concluding chapter.

Generally, both the control and experimental group participants had the perception that using *Exploring the Nardoo*, provided them with a more interesting and profitable learning experience than traditional methods of studying ecological and land management issues. The experimental group participants also suggested that the simulation tool was an integral part of the package and experience, providing them with a tool to gain a better understanding of the process rather than just better factual knowledge.

The findings from this data source fall into two divisions, those which come from the questions that were common to both control and experimental group participants and those which come from the simulation specific questions completed by the experimental group participants only.

5.7.2.1 The Common Questions

Some of the key findings were:

- The students enjoyed using the software and in general felt comfortable using the technology for learning.

(Questions: 3, 15, 27 and 32)

- There was no clear preference for any particular learning style over another however most agreed that a strength of the systems was the visual nature of the content.

(Questions: 17, 37 and 44)

- Participants had the perception that they had learned more using the package than if they had used a more traditional method.

(Questions: 3, 10 and 29)

- There was general agreement that the package as a whole was well designed in terms of ease of use, ease of data access, ease of navigation, multi-representation of the data and interface issues.

(Questions: 4, 7, 32, 33, 38 and 50)

- Many students believed the highly visual nature of the package was a significant factor in their learning outcome.

(Question: 10)

- Most thought that placing the learning of new and complex processes like algal blooms in a familiar setting helped them learn and understand.

(Question: 27)

5.7.2.2 The Simulation Orientated Questions

The general feeling of the participants who had access to the simulation tool is that its use improved their understanding and knowledge of the process of algal bloom development.

- Many agreed that the simulation of the processes involved was an essential part of the package and would be an advantage to understanding the process.

(Questions: 13, 18,19, 21, 28, 30, 34 and 43)

- Most thought that the simulation was well designed.

(Questions: 5, 6, 20 and 31)

- Most thought that the ability to flip between representations of the data produced by the simulation tool helped them learn and understand.
(Questions: 41, 42, 48 and 49)
- Most indicated that none of the formats in themselves were more useful than another, rather it was the combination which was the key.
(Questions: 14, 26, 42, 48 and 49)
- The quick feedback of the users actions on the system was another feature singled out as important. This instant feedback was a function of the ability of the simulator to calculate and display ‘on the fly’ so that the user was able to see the results of their interactions reflected instantly. The impact of this on the learning outcome one would suspect would be that the participant is more likely to persist with the task and explore options, making changes and testing hypotheses because of the feel of dealing with a real system as opposed to a *plug in the value and see the result* system.
(Question: 13)
- Most felt the simulation was easy to control and manipulate.
(Questions: 6 and 31)
- More importantly, most felt that they were in control. This the researcher feels is highly significant because it provided an incentive to explore, supported by a feeling of *it’s not all beyond me in terms of complexity*. Being in control also mimics the experience with physical phenomena in the real world.
(Question: 32)
- The majority of the participants felt that the ability to test ‘what-if’ situations was a major factor in the developing a deeper understanding of relationships.
(Questions: 1, 13 and 28)

- There was some evidence that using the simulation tool added to the cognitive effort. Some students were also worried by the freedom to explore and the consequent complexity it added to their task.

(Questions: 22, 33 and 45)

CHAPTER 6

Synthesis and Further Research

6.0 Introduction

The overall outcome of the study is that it adds to the knowledge base of the application of simulations in educational settings. The study had three basic aims:

- to investigate simulations design issues in terms of contemporary theoretical principles which provide effective and realistic replicas of real world processes;
- to design and build a simulation tool based on these principles which addresses the issue of algal bloom growth, and;
- to implement and test the implications for students using the tool in terms of their construction of knowledge, understanding of relationships and overall learning outcomes.

6.1 Contemporary Principles

An essential question facing all developers is how to design computer-based learning environments that engage, motivate and enrich the learning experience using the power of the technology and maximising the learning outcomes. A number of the key issues are mooted in the introductory chapter and are expanded upon in the literature survey chapter.

There is a great deal of research supporting the proposition that multimedia-based learning environments such as *Exploring the Nardoo* “provide significant affordance to enrich student learning” (Bagui. 1998) and that one of the essential reasons for this is the ability of these environments to provide multiple perspectives leading ultimately to a deeper understanding of relationships.

Harper & Hedberg (1997) provide a listing of key issues that they suggest must be embraced by designers of such interactive multimedia learning environments.

They include:

- Information and Visual Design
- Access
- Interactivity and Control
- Motivation
- Problem based learning

The term simulation was in the past most often used to describe a model, usually stand alone and mathematically driven, that illustrated some aspect of a system, event or phenomenon, often in a training environment. In the more recent literature, simulations are now being described as encompassing a much broader context. Simulations have been variously defined as:

- a system that simulates or models reality;
- mathematical models that depict natural events and processes
- a substitute training environments for real world events;
- the dynamic execution or manipulation of a model of a real world process;
- exploratory tools that support real world activities;
- environments in which designers seek to provide realistic representations of real world experiences and,
- cognitive tools that support learners in their development and testing of mental models in a safe, risk free environment.

The various taxonomies proposed in the literature to date were summarised and a revised taxonomy which synthesises the characteristics and behaviours attributed to these various taxonomies was presented in Figure 2.2 along with a proposed new category *Contextualised Simulations*. The unique nature of the multi-representational algal bloom simulation tool developed and reported on in this study and its incorporation within the broader scale multi-representational simulated landscape, *Exploring the Nardoo*, could only be situated within the broader context of simulations by positioning it within this new category.

This study supports in general terms the importance of incorporating a number of *recognised design standards* gleaned and distilled from the literature over the past twenty years. These include;

- Provision of motivational environments;
- Promotion of development of higher order cognitive skills;
- Providing a high level of interactivity;
- Provide freedom to choose own pathway through informed choice;
- Design for educational outcomes and not the hardware and ;
- Build around the accomplishment of a goal rather than individual actions.

The design of the simulation tool which was the focus of this study, draws on research and literature which suggests that a number of characteristics which when incorporated in learning environments, have the potential to contribute to improved learning outcomes. They include:

- problem based investigation that is authentic and presented in an engaging manner;
- a high level of fidelity;
- facilitation of student exploration which allows them to assess their existing understanding and re-evaluate their mental models to accommodate new understanding through manipulation, decision making and feedback that reflects directly their actions;
- active participation by the learner;
- provision of a range of realistic consequences based on the users actions;
- model behaviour which reflects the users on-going interaction and;
- provision of tools that promote the development of higher order cognitive skills and their transference to novel situations.

6.2 The Simulation Tool

The interactive simulation tool allowed the students to explore, construct and test their understanding of the process of algal bloom growth. It was designed and built on the ideas and guidelines enunciated in the literature, and it was integrated within the whole

catchment management simulation package *Exploring the Nardoo*. Assessment of its performance was based on both its in-built characteristics and its operation as an integral part of the package.

Apart from the incorporation of the standard design features and characteristics mentioned above, there are two specific design features common to both *Exploring the Nardoo* and in particular the simulation tool: high level of fidelity and multiple representation of information, which were incorporated with the purpose of improving the learning outcomes for students using this package. While the data collected in this study confirms that the Blue-Green Algal bloom simulation tool contributed to improved learning outcomes for the students who used it, there is no direct evidence to confirm or dispute the contributions of these specific characteristics. Further research needs to be conducted to draw out more clearly their individual contributions.

The analysis of the data collected from the Cause and Effect Schedule (CES) provided strong support to the argument that the use of simulation models supports users in the development of a deeper understanding of relationships through the hands on manipulation of variables. The role played by model building was reported in detail in the literature review. The facility to *see relationships unfold* and *seeing processes in action* was important in their understanding. It must not be assumed however that allowing students to build models will invariably lead to improved learning and understanding. Although, providing students with the facility to map relationships and then build models to test them must add to the learning experience. It is argued that model building in isolation of a meaningful context and support framework, such as that provided by *Exploring the Nardoo* and the embedded algal bloom simulation tool will have limited value.

Evidence supporting the success of the simulation tool is two fold. The package as a complete learning environment and its performance both from the technical design and pedagogical perspectives has been peer reviewed on numerous occasions through peer reviewed journals and international presentations. It has also won several international awards for its educational excellence.

The data collected from the User Perceived Value Schedule (UPS) indicated that the students had the perception that they learned more using this package than if they had used

a more traditional method. It also indicated that many of the students believed that the highly visual nature of the package was a significant factor in their learning and that placing the learning in a familiar context helped them understand a complex process.

In terms of the simulation design, analysis of the UPS data provided ample support for the argument that, in terms of standard design parameters the simulation design was effective. Students reported that they were happy with the level of control, the ease of use and the overall functionality of the simulation tool. Of particular interest is the general perception among students who used the simulation tool that the ability to flip between representational modes for data output was an important factor in their learning and understanding and that having the ability to change variable and test the effect was a key factor in their development of a deeper understanding of the underlying processes and relationships. This study supported the assertion that, the design of the delivery tool is as important to the overall learning outcome for students as the way in which it is used in a classroom.

In summary, the overall findings suggest that, simulations which are designed in terms of contemporary theoretical principles with regard to functionality and pedagogical strategies, and are embedded within rich, multimedia based learning environments have the potential to provide the user with a greatly enriched experience by facilitating the review of existing learner knowledge and enabling construction of new learner knowledge. Overall, this resulted in a deeper understanding of the process being simulated. This is particularly so if they are multi-representational and provide the ability for the users' actions to impinge dynamically on the process being modelled.

6.3 Implementation

In terms of the research question and the related hypotheses presented in chapter 4, the results of the analysis of the data collected during the experimental study along with the findings from these results reported in chapter 5 of this thesis, demonstrate improved learning outcomes and development of understanding of relationships and provide corroboration of the effectiveness of the simulation tool.

The data collected from the Knowledge Acquisition Schedule (KAS) indicated that use of the package *Exploring the Nardoo* resulted in significantly improved acquisition of factual knowledge for both the control and experimental groups. This was not unexpected as the overall design of the software was such that all students had access to extensive multi-format information on all aspects of algal blooms and the investigation was designed so as to be *independent* of the algal bloom simulation tool.

The fact that the experimental groups KAS mean scores showed a significantly greater increase than those of the control group would suggest that using the tool also supported factual knowledge acquisition.

Analysis of the Cause and Effect Schedule (CES) data suggests that the simulation tool also facilitated a deeper understanding of the processes and the relationships between causal factors for the students who had access to the simulation tool. On examination of the data in terms of the degree of improvement between pre and post CES mean scores for the two groups, it is apparent that as in the case of the KAS mean scores, the students using the simulation tool not only improved their CES mean scores, but improved them by a significantly greater margin than those in the control group. This outcome adds support to the assertion that, when students have the opportunity to test and re-assess their mental models of complex systems, the processes and relationships at work, in meaningful learning environments and supported by appropriate tools, there is the potential for improved learning outcomes and the development of deeper understanding.

6.4 Further research.

In the more recent literature concerning pedagogical aspects of simulation design and the use of simulations in educational settings, an emerging theme is the consideration of the impact on learning outcomes when students are not only provided with real world based models and scenarios, but also with the facility to develop their own models. This may involve either the opportunity to construct models based on their current implicit understanding of the processes involved or to have access to the existing model on which the simulation is based so that they may modify it.

In both cases, it is suggested by a number of researchers, in particular, Aldrich et al., (1998) and Rose et al., (1998), that the value added to the experience for students is a strengthening of the powerful experimentation/testing 'what if' facility that well designed simulations bring to a learning experience. Modelling is a fundamental and integral part of learning regardless of the circumstances, or learners style, it is how the human brain makes sense of complex situations. We learn from these experiences by using internal modelling to test out and modify our thoughts and understanding of the world around us.

Hannafin & Land (1997) support this notion stating that learner generated predictions and model building support the formulation of intuitions or mental models. A logical extension of this is that using these techniques to re-evaluate and refine initial mental models must add to the power of the learning experience. The facility to manipulate an existing model or build one from first principles, affords an opportunity for students to improve how they learn by providing a way of asking themselves whether they understand their own way of thinking through a problem suggests Confrey & Doerr (1994).

There are a number of commercially available software packages available to support and accomplish this, particularly in building models from first principles. STELLA® and PowerSim™ are both examples of object driven interfaces allowing the development of dynamic models which facilitate the testing of the validity of parameters and relationships while at the same time communicating a feel for and understanding of the underlying logic of the system being modelled. The result is a powerful modelling tool that allows one to examine one's mental conceptualisation of the process.

The next phase of research should examine the learning outcomes for students who are provided with the facility to deconstruct and reconstruct the underlying model behind this simulation. The type and extent of support mechanisms that are required to accomplish this form of simulation will also push our boundaries of understanding of the practical world of educational simulations.

APPENDIX: 3.1

RESOURCES :

Filing Cabinet Documents on Blue Green Algae

Document #1

Blue-Green Algae

Blue Green Algae has become a significant problem in many bodies of water. The following material provides more detail about the algae and associated problems.

Identification

The telltale signs are:-

- sudden appearance or “bloom”, of green, yellow, or beige colouring in the water.
- surface scums coloured green, blue, beige or white.
- strong chemical or vegetation odours.
- refusal by livestock, especially cattle and horses to drink the water or signs of illness in stock.
- floating dead fish in the water

The only sure way to identify blue-green algae is to have a trained person examine a water sample under a microscope.

To facilitate this you must collect a fresh sample of the algal mass in water and transport it without delay in a sealed container to your local water management authority. They will test the sample and report back to you usually within 24 hours.

Document #2

What is a blue-green algal “bloom”?

“Bloom” is commonly used to describe a rapid increase in algal cell numbers to a point where they discolour water, form scums, produce odours and reduce water quality for human and livestock use.

- ***Linked picture available - use Media Bar on Viewer***

Often, blue-green algal blooms occur because the conditions for their rapid growth are created by human activities in the catchment of a farm dam, river or large public dam.

These conditions include above average to high levels of nutrients such as nitrogen and phosphorus in the water. The growth of the algae is most sensitive to the levels of phosphorus which need to be relatively high to produce a bloom.

As blue green algal cells must float to the surface to obtain enough light to grow, an essential condition is minimal to no water movement. Such conditions occur mostly behind weirs, in farm dams or in slow flowing rivers.

If these conditions change, a bloom may appear, disappear and reappear in the space of one day. Wind stirring and the inflow of water can play an important part in this process.

The illustrations below show types of blue-green algae under the microscope

• *Linked picture available - use Media Bar on Viewer*

As blue green algal cells must float to the surface to obtain enough light to grow, an essential condition is minimal to no water movement. Such conditions occur mostly behind weirs, in farm dams or in slow flowing rivers.

If these conditions change, a bloom may appear, disappear and reappear in the space of one day. Wind stirring and the inflow of water can play an important part in this process.

Document #3

The Dangers of blue-green algae

Aside from the aesthetic problems caused by their appearance, and the deterioration in water quality they produce, the worst feature of blue-green algae is their ability to produce poisons including neural toxins and liver toxins. These toxins, as well as the depletion in oxygen levels which may occur in waters where blooms are dying, can produce massive fish kills.

The recorded effects of these toxins on humans and animals coming into contact with the water include allergic reactions and skin and eye irritations. Gastroenteritis and liver damage may result if the water is taken into the body.

Each year, livestock deaths are reported due to the toxic effects of blue-green algae. Human deaths and illnesses have not been verified but evidence strongly suggests that the toxic effects are a hazard to human health.

Not all blue green algal blooms are toxic, and toxicity may occur for only part of the time or in only part of the bloom . The reasons for this are not fully understood as yet.

Blue green algal blooms often persist for several weeks, sometimes months, depending mainly on the weather or water flow. Cooler, windy, cloudy weather or increased flows usually reduce or stop a bloom fairly quickly.

What you can do ?

Immediate action

If you detect unpleasant odours or loss of water quality, observe surface scums or otherwise suspect that blue green algae have infested the water you used for drinking, cooking, kitchen uses, bathing and showering, swimming or livestock watering, you should stop using it until an algae bloom has been identified and confirmed by a trained person. Although chemical algicides are sometimes currently used to control blooms, researchers are working on other biological control methods. These include various bacteria which eat the toxins associated with algal blooms, small herbivorous crustaceans that graze on the algae, and viral substances which kill the algae.

Short-term action

Where the presence of blue green algae is suspected in dam or river water used for drinking or bathing, alternate water sources should be used. These might include water from a bore or rain water tank. For household use, carted water may be an effective short-term alternative. Bottled water may be appropriate for drinking purposes for short problem periods. Boiling water will not inactivate algal toxins.

Physical filtration of blue green algae (other than through activated carbon) or poisoning with copper based chemicals should not be carried out since these treatments break open the algal cells, releasing toxins into the water. Copper based treatments also introduce an additional poisonous element to the water.

Activated carbon is a processed form of charcoal. It absorbs organic chemicals including those causing unacceptable tastes and odours, and toxic effects. Filtering water through fine sediment filters first will remove particles, increasing the life of the carbon filter. Carbon filtration systems can be obtained from manufacturers of water treatment equipment. During a significant bloom, town water supplies may need to be filtered through activated carbon filters. This process is very expensive.

Short-term management options must concentrate on flow regimes, reducing stratification and temperature fluctuations through better management of dams and weirs. Reserving an amount of water in dams for flushing the river system in the event of a bloom may be a desirable short-term option.

Long-term action

Long-term strategies for prevention of blue green algal blooms are being developed by Government agencies.

An important element of these strategies involves improving catchment management to reduce the amount of phosphorus washed into farm dams, creeks and rivers, and to ensure an adequate and constant water flow.

Vegetation filters offer some protection for farm dams and rivers. Using products like superphosphate near streams and depressions that supply dams should be avoided. Reduced livestock access to the immediate dam catchment can also help.

Careful management of water withdrawal from the water body will prevent periods of critical low flow.

Sampling and testing

If you need to have your water examined for blue-green algae you will need to arrange to supply your local water management authority with a fresh sample of water for testing. The test takes about 24 hours and the results will show the type and abundance of algae. Physical filtration of blue green algae (other than through activated carbon) or poisoning with copper based chemicals should not be carried out since these treatments break open the algal cells, releasing toxins into the water. Copper based treatments also introduce an additional poisonous element to the water.

Activated carbon is a processed form of charcoal. It absorbs organic chemicals including those causing unacceptable tastes and odours, and toxic effects. Filtering water through fine sediment filters first will remove particles, increasing the life of the carbon filter.

Carbon filtration systems can be obtained from manufacturers of water treatment equipment. During a significant bloom, town water supplies may need to be filtered through activated carbon filters. This process is very expensive.

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Document #4

Impacts of Blue-Green Algae Outbreaks

Blooms of blue-green algae can have wide ranging social, economic and environmental impacts. Lost tourist trade and the potential for contamination of food products represent major threats to the economic viability of regions affected by blooms. Adverse publicity can raise undue fear in the community and our trading nations with consequent loss of business even though the water may be quite safe.

Eutrophication increases algal bloom frequency with consequent changes in phytoplankton biomass, littoral vegetation, zooplankton, fish and bottom fauna. Varying oxygen depletion and saturation by phytoplankton respiration and photosynthesis creates a stressful environment for organisms. This can result in a decrease of fish and other aquatic fauna. Such oxygen depletion can also affect water chemistry including pH, the liberation of hydrogen sulphide (rotten egg gas) and methane, and cause nutrients and metals to be released from the sediments.

As mentioned, the accumulation of scums along the banks of rivers and shores of lakes can result in animals ingesting a highly concentrated dose of cells, and possibly toxins, if they drink from the water's edge.

The cost of fencing off areas likely to be affected by blooms and either treating the water or obtaining alternative supplies for animals can be considerable. Similarly, the costs of algal blooms in town water supplies can be significant. A series of major blooms in the region a few years ago had a direct cost of \$1.26 million for alternative water supplies.

Studies have estimated that the cost of lost recreational benefits due to the blooms amounted to a further \$1.5 million. There are also substantial additional costs associated with routine and event monitoring programs, as well as research initiatives. The total annual expenditure (1992/93) by all primary research bodies and third parties on algal research has been estimated at \$10.6 million.

The cost of fencing off areas likely to be affected by blooms and either treating the water or obtaining alternative supplies for animals can be considerable. Similarly, the costs of algal blooms in town water supplies can be significant. A series of major blooms in the region a few years ago had a direct cost of \$1.26 million for alternative water supplies.

Document #5

Blue-Green Algae in Farm Dams

You probably have heard about the dangers of blue-green algae and wondered whether they are **present in your farm dams**.

Identification

The telltale signs are

- sudden appearance or “bloom” of green, yellow, or beige colouring in the water.
- surface scums coloured green, blue, beige or white.
- strong chemical or vegetation odours.
- refusal by livestock, especially cattle and horses to drink the water or signs of illness in stock.

The only sure way to identify blue-green algae is to have a trained person examine a water sample under a Microscope .

What are blue-green algae?

Blue green algae is a commonly used term for several types of algae that sometimes impart a blue-green tinge to water or form blue-green scums on the surface when present in large numbers.

They are extremely small organisms visible under a high powered microscope as single cells, or clumps of cells. They need sunlight to grow.

What is a blue-green algal “bloom”?

“Bloom” is commonly used to describe a rapid increase in algal numbers to a point where they discolour water, form scums, produce odours and reduce water quality for human and livestock use.

Often, blue-green algal blooms occur because the conditions for their rapid growth are created by human activities in the catchment of a farm dam, river or large public dam.

These conditions include high levels of phosphorus and low nitrogen in the water., calm water behind weirs, in farm dams or in slow flowing rivers, lack of fresh water inflows to rivers or dams murkiness, strong sunlight and high air and water temperatures.

Some blue green algae have tiny gas bubbles in their cells allowing them to float to the surface for sunlight or sink to the bottom to feed This explains why a bloom of blue-green algae can appear, disappear and reappear quickly even during a single day. Wind stirring also plays an important part in this process.

Document #6

Dangers of blue-green algae in farm dams

Aside from the aesthetic problems caused by their appearance, and their taints and odours, the worst feature of blue-green algae is their ability to produce poisons including neural toxins and liver toxins.

The recorded effects of these toxins on humans and animals coming into contact with the water include allergic reactions and skin and eye irritations. Gastroenteritis and liver damage may result if the water is taken into the body.

Each year in NSW, livestock deaths are reported due to the toxic effects of blue-green algae. Human deaths and illnesses have not been verified but evidence strongly suggests that the toxic effects are a hazard to human health.

Not all blue green algal blooms are toxic, and toxicity may occur for only part of the time or in only part of the bloom .

Blue green algal blooms often persist for several weeks, sometimes months, depending mainly on the weather or water flow. Cooler, windy, cloudy weather or increased flows usually reduce or stop a bloom fairly quickly.

What you can do if your dam is infested

Immediate action

If you detect unpleasant odours or taints, observe surface scums or otherwise suspect that blue green algae have infested the water you use for drinking, cooking, kitchen uses bathing and showering, swimming or livestock watering, you should stop using it until the algae have been identified by a trained person.

Short-term action

Where the presence of blue green algae is suspected in dam water used for drinking or bathing, alternate water sources should be used. These might include bore water or rain tank water. For household use, carted water may be an effective short-term alternative. Bottled water may appropriate for drinking purposes for short problem periods. Boiling water will not inactivate algal toxins.

Physical filtration of blue green algae (other than through activated carbon) or poisoning with copper chemicals should not be carried out since these treatments break open the algal cells, releasing toxins into the water. Copper treatments only introduce an additional poisonous element to the water.

Activated carbon is a processed form of charcoal. It absorbs organic chemicals including those causing algal tastes, odours and toxic effects. Filtering water through fine sediment filters first will remove particles, increasing the life of the carbon filter.

Carbon filtration systems can be obtained from manufacturers of water treatment equipment. The public Works Department provides advice on designing simple carbon filters for emergency use.

Long-term action

Long-term strategies for prevention of blue green algal blooms are being developed by Government agencies.

An important element of these strategies involves improving catchment management to reduce the amount of phosphorus washed into farm dams, creeks and rivers.

Vegetation filters offer some protection for farm dams. You should avoid using products like near creeks and depressions that supply your dams. Reduced livestock access to the immediate dam catchment can also help.

Sampling and testing

If you need to have your water examined for blue-green algae you should contact your local office of the Department of Water Resources. The Department will arrange for you to supply a fresh sample of water from your dam for testing. The test takes about 24 hours and the results will show the type and abundance of algae. A charge of about \$50 is made for the service. Toxicity testing costs around \$100.

They are extremely small organisms visible under a high powered microscope as single cells, or clumps of cells. They need sunlight to grow.

Document #7

Nutrients

Nutrients are substances essential for life. Nutrients become harmful when they produce unwanted (from a human point of view) changes in our waterways. Problems arise in our waterways when nutrients stimulate excessive plant growth, causing environmental changes and in some cases producing toxic side effects.

Although most plants need 30 or 40 nutrients for growth, the two most important plant nutrients are phosphorus (P), and nitrogen (N). Nitrogen and phosphorus are subject to most attention because they contribute most to undesirable changes in water bodies. Phosphorus is usually (not always) the limiting nutrient (i.e. you can have huge quantities of other nutrients but the development of nutrient nuisance is limited by the quantity of phosphorus). A simple summary of nutrient sources is given below.

Each pristine catchment has nutrients in the water. This level is the background nutrient level for the catchment. Background nutrient levels vary. The most important factors influencing background levels are presence of phosphate rich bedrock or soils, ground cover, stream water chemistry, and the existing aquatic flora and fauna. Nutrient levels in water bodies in pristine catchment are variable, but generally forested or undisturbed catchments produce low levels of nutrients.

Background Sources	Agricultural	Urban	Industrial
Rainwater	Leaching of fertiliser	Urban stormwater drainage	Industrial waste
Leaching from catchment soils	Animal wastes	Sewage	Air Pollution
Bacteria			
Ocean input			

In eastern Australia nutrient generation rates for undisturbed catchments range from 0.01 - 0.3 Kg/ha/yr. In these catchments, long periods of low nutrient generation might be followed by short, sharp, localised episodes of nutrient abundance (due to vegetation loss caused by frost, drought, disease, wombat population explosions, fire and so on). But averaged out over entire catchments and over long periods we would expect nutrient exports from “unspoilt” catchments to be low.

Human activities alter nutrient generation rates.

Where cultural practices such as agriculture and industry lead to new nutrient generation rates, the new rates will be superimposed on natural nutrient loads. There are many ways in which human land uses alter nutrient generation rates. Cultural practices which increase nutrient movement into the landscape include clearing, cultivation, crop farming, intensive and extensive animal raising, wildfires and control burning, construction and other practices which contribute to accelerated erosion. Others such as sewage disposal and intensive and extensive animal raising add nutrients directly to the land surface.

When a catchment is being “developed” for lets say intensive vegetable growing, land use practices associated with clearing, cultivation and irrigation will increase runoff. Increased runoff delivers more sediment and surface organic material to streams due to higher rates of surface runoff, increased gully erosion and wind erosion. Then, as fertilisers are applied to crops, increased quantities of nutrient rich material become available for export. Should the same catchment become further “developed” for say, dairy farming, animal wastes and fertilisers would increase available nutrients, while construction, clearing, soil compaction and trampling would increase runoff rates, and so on.

The basic principles are the same, whatever the development - remove the vegetation, increase soil erosion and increase fertiliser and manure, and nutrient loads in catchment water bodies will increase. How much a waterbody can stand without going into “nutrient mode will depend on the complex interactions between pre-existing nutrient loads, climatic factors, water flora and fauna, and water chemistry.

Many of the management practices developed for on land nutrient management have attempted to mimic the features of the pristine landscape which produced “nutrient buffering effects”. Management practices include low overall stocking rates and low grazing pressures, maintenance of layered ground cover, sediment traps, soil conservation and regulation of surface disturbance, and retention of nutrient hungry wetlands. Many catchment groups are developing buffer zones which mimic the nutrient retaining effects of the pristine catchment. But how large do buffers need to be before they can effectively absorb the higher nutrient loads produced by a developing catchment? And where should the nutrient buffers be located?

Eutrophication problems in the Nardoo River appear to be the result of some or all of five main nutrient sources in the catchment:

- (1) The feedlot/abattoir complex
- (2) Pilliga Crossing Sewage Treatment Works
- (3) Rural areas
- (4) Pilliga Crossing urban area
- (5) Pilliga Crossing industrial area

Total loads of phosphorus and percentage contributions from various sources are difficult to quantify precisely. Sources where pollution occurs via storm runoff will be less able to be defined than those where it occurs as a point source effluent. Therefore, phosphorus emanating from the sewage treatment works and the abattoir are quite consistent. However in rural areas, runoff occurs only on relatively infrequent occasions, and it is difficult to determine the correct frequency of occurrence.

A similar situation exists for the urban and industrial areas.

Document #8

Options for Managing Nutrients from Urban Sources

The Pilliga Crossing urban area appears to generate relatively small nutrient loads, except during wet weather and high flows. There are numerous potential nutrient sources in this area, but they are difficult to identify. A major difficulty is that most discharges are ephemeral, depending mainly on rainfall. This creates difficulties for monitoring effluent volume and nutrient concentrations.

Options for reducing nutrient loads from urban sources include the following:

- *Improvement of street sweeping to remove grit, organic matter and general matter.
- *Elimination of overflows and leakage of sewage and sullage into storm drains.
- *Installation of traps or basins for sediment, organic matter and rubbish on storm channels, (these devices are known as gross pollutant traps).
- *Creation of silt fences composed of hay bails in drainage lines.
- *Construction of “polishing” ponds, wetlands or urban lakes where urban drainage enters creeks or rivers.
- *Rehabilitation of urban streams to a “natural” state.

While the above management options try to reduce nutrient loads entering the river from creeks and drainage lines, it's important to make every effort to reduce urban sources of nutrients altogether. Here are some simple steps individuals and communities can do to reduce their use of phosphorus products, and minimise runoff to waterways:

*When shopping for detergents, check to see if the product contains phosphorus. Studies have shown that laundry detergents containing enzymes and zeolites instead of phosphorus are among the best and lowest cost-performers in washing clothes. They found that phosphorus free detergents are among the cheapest for each wash. By selecting the right detergent, we can get a better, cheaper wash, and help reduce phosphorus levels in the river.

*Use only the recommended amount of detergent Clothes don't get any cleaner by using more than the recommended amount.

*Wash only when you have a full load. You will use less detergent, water and electricity.

*Washing your car on the lawn both fertilises and waters the lawn. The detergent and water soak into the ground instead of flowing into the stormwater system.

*Use food wastes to make compost or put them out in the garbage. Using a sink garbage disposal unit only dumps phosphorus-rich organic waste into the sewerage system.

*Clean up or bury animal droppings so they don't get washed into the river system or stormwater runoff.

*When fertilising your lawn or garden follow recommended application rates carefully. Don't overwater and lose phosphorus through runoff or leaching.

Document #9

Managing Nutrient Rich Effluent from Pilliga Crossing Sewage Treatment Plant: The Options

Current Treatment Process

Pilliga Crossing sewage treatment plant currently treats sewage in three phases, primary, secondary and tertiary.

The main steps in the Pilliga Crossing sewage treatment process are:

Primary Treatment

- 1.The sewage is screened to remove grit.
- 2.Sludge is allowed to settle in sedimentation tanks where grease and scum rise to the surface.
- 3.Sludge and scum are collected in a large, covered digestion tank.
- 4.The sludge and scum are decomposed by micro-organisms that turn the sludge and scum into gasses and an organic material called 'digested sludge'.
- 5.Digested sludge is normally disposed of in a sludge lagoon but can be used as a fertiliser.
- 6.Excess water from the settling sludge is returned to start the secondary phase.

Secondary Treatment

7. The effluent passes through a dosing tank which regulates the flow rate and is sprinkled from the rotating arms of one of the plants two trickling filters.

These arms look like a large 'Hills Hoist' clothes line.

8. These dosing tanks are approximately two metres deep and filled with gravel. Air is circulated from holes at the bottom and as the effluent trickles down, micro-organisms that grow naturally on the surface of the rocks and stones devour the organic materials in the effluent.

9. These micro-organisms form slimes which eventually fall away from the gravel and are collected in another sedimentation tank and finally returned to the digester in step 4.

The resulting output from this secondary phase has had approximately 90% of the wastes removed and is quite clear in appearance.

Tertiary Treatment

10. In the tertiary phase the effluent enters a large oxidant pond that contains aerators which complete the task of 'cleaning' the effluent.

11. The aerators in conjunction with the action of the sun help to break down the remaining organic content of the effluent.

12. A disinfecting agent such as chlorine is used to kill any remaining bacteria.

13. The colourless and odourless effluent is finally discharged into the river.

•• *Linked picture available - use Media Bar on Viewer*

Future Management Options

Although the sewage treatment works were significantly upgraded a few years ago, there is undoubtedly need for the current process to be supplemented by nutrient removal, which reduces the phosphorus and nitrogen concentration in the effluent. The following table outlines phosphorus concentrations in the final effluent from various sewage treatment processes.

Trials are underway of a semi-portable system for enhanced biological phosphorus removal at the sewage treatment works.

This system has the potential to halve the phosphorus concentration in effluent discharged from the current works (ie., from approximately 6-7 mg/L to 3 mg/L).

A range of chemicals can be used to remove nutrients from treated sewage effluent as an additional step in sewage treatment. Removal occurs by flocculation/coagulation of fine particles containing nutrients, followed by sedimentation as a sludge.

The process occurs by electrolytic effects induced by multiple charges on the cation (positive ion) of the added chemical. The chemicals that can be used (in approximate order of effectiveness and common usage) are ferric chloride, ferrous sulphate, aluminium sulphate (alum) or calcium sulphate (gypsum). The main drawback with chemical dosing is the expense of providing the large supply of chemicals required.

Chemical dosing is not without undesirable side-effects such as introduction of the metals iron or aluminium into the waste stream and alteration of pH values which might need to be corrected with further chemical dosing.

The existing effluent from the treatment works travels fairly directly to the Nardoo River through a shallow drainage line about 100 metres long. Since the land between the sewage treatment and the river is relatively flat there is scope for zigzagging the effluent through a shallow absorption channel.

This would be aimed at increasing the flow distance and time so that nutrients could be extracted by aquatic and terrestrial plants growing in the channel. Nutrient removal could be achieved by periodically mowing and harvesting the plants. The system would basically be an artificial marsh or wetland composed of a shallow, linear (but zigzagging) and continuous spoon drain.

Effluent control and treatment systems with zero final effluent discharge are now common and should be considered.

Zero discharge is achieved in various ways, including extensive evaporation lagoons and land disposal by irrigation and harvesting of the resulting vegetation. Watering of tree lots is an attractive use of effluent. Reuse on parks, race tracks, golf courses and playing fields should be considered. Reuse would require all health concerns to be addressed, including pathogens and heavy metals in surface waters and nitrates in ground-water.

The main impediments to achieving zero discharge are low evaporation rates and high ground moisture contents during the winter months when rainfall and humidity are highest. Evaporation or irrigation during these times might not be successful unless large evaporation ponds and irrigation areas are affordable. If release to the river is necessary during winter, it should be controlled so as to occur during higher flows at a known and acceptable dilution.

Document #10

Options for Managing Nutrient Rich Effluent from Pilliga Crossing Abattoir

One of the major environmental concerns with abattoirs is the production and disposal of effluent wastes, both solid and liquid. Wastes from abattoirs contain high concentrations of the nutrient phosphorus which if allowed to accumulate in soils, is a potential source of water pollution. When this phosphorus eventually leaches into the river, it encourages the growth of toxic blue-green algae.

Of all contributors studies have shown that, within the Nardoo catchment, the abattoir contributes the highest phosphorus loads on an annual basis. It contributes by far the highest loads during the low and medium stream flow periods. These flows typically occur during the summer - the high algal growth period.

There are many phosphorus sources on the abattoir site which currently need addressing. However, the two main problems are effluent disposal methods and runoff from the holding yards.

The abattoir currently disposes of its effluent by simply flood irrigating grassed paddocks. The problem with this approach is twofold. Firstly, phosphorus levels in the effluent are in excess of the grasses' requirements, causing a build up in the soils which then leaches into the river. Secondly, at times, the soil in these paddocks is incapable of accepting the volume of effluent discharged. During wet periods the soil's ability to accept the effluent is greatly reduced. When the effluent is discharged during these climatic conditions, it runs-off directly into the river.

Runoff from rainfall flows uncontrolled through the holding yards, collecting nutrients from the soil. This contaminated runoff then drains directly into the river.

Future Management Practices.

A comprehensive land and water management plan for the abattoir is required. This would provide a blueprint for managing the abattoir's water and land resources to prevent pollution of Nardoo River.

The plan would detail many possible actions including:

- *Investigate and define the area of land required to effectively dispose of the nutrients and water loads likely to be generated by the abattoir.
- *Phasing out the use of paddocks as animal holding areas. Conversion of their primary use to effluent disposal areas, and in the future, to nutrient harvesting.
- *Investigate and define vegetation types, their management and harvesting systems best suited to provide nutrient removal and water use on the site. Potential is seen for a combination of mechanically harvested crops and controlled animal grazing of perennial pastures as well as tree plots.
- *Investigate the terrain and soil types of the area as to their ability to support the proposed irrigation practices.
- *Rehabilitation of areas suffering soil compaction by deep ripping and establishing deep rooted perennial pasture species.
- *Upgrading the effluent irrigation system by renewing pumps and main pipes, as well as installing a small trial area of fixed line fine spray irrigators.
- *Investigate and implement the most effective means of irrigation. Ensure that the irrigation system is compatible with the proposed harvesting and management systems.
- *Investigate the construction and management of an artificial wetland area to take up nutrients as well as act as a sediment trap and runoff control structure for the effluent disposal area.
- *Construction of holding dams to detain a effluent output during those times of the year when effective soil and vegetation assimilation is not possible because of naturally saturated soils.
- *Establishment of a system of waterways to guide runoff through a grassed riparian buffer zone, maximising filtration and runoff rate, before entering the river.

- *Construct levee banks around remaining holding yards to divert runoff into the effluent disposal areas.
- *Separate clean roof water from the dirty holding yard runoff by piping roof water direct to the river.
- *Reducing water use at the abattoir which would lead to less final effluent.
- *Upgrading of effluent collection, transport and treatment infrastructure.
- *Increasing its capacity to collect and remove nutrient rich materials via improved screening methods in the factory.
- *Implement a systematic monitoring program to test water quality and quantity discharge.

During wet periods the soil's ability to accept the effluent is greatly reduced. When the effluent is discharged during these climatic conditions, it runs-off directly into the river.

Runoff from rainfall flows uncontrolled through the holding yards, collecting nutrients from the soil. This contaminated runoff then drains directly into the river.

Document #11

Environmental Contingency Allowances

An Environmental Contingency Allowance is the reservation of a portion of regulated supply which can be used to meet urgent water quality and environmental needs when they occur. The volume will vary from river to river and will depend on the type of likely needs, their probable frequency and likely coincidence within each season. Should ECA needs reduce during a season, the water may be available for consumptive use.

Practical flow management considerations may limit the problems which an ECA can address. Dilution and flushing for water quality control, increased flow velocities to reduce the growth rate of algal blooms, support of bird breeding in wetlands, supply to wetlands at times when regulation has severely restricted the provision of water to assure fish migration, spawning and recruitment would be examples of legitimate ECA use. Large scale artificial or regular flooding would not be a legitimate use.

ECAs for water quality flushing would have a major use for flushing nutrients from agricultural and urban inputs in dry periods (when natural dilution flows are low). Water quality needs of the aquatic ecosystem need to be considered as well as the needs of consumptive users and recreational users. It is important to maintain good habitat throughout the year. Even short periods of poor quality water may be enough to seriously affect some aquatic organisms. Flushing is generally a last resort management tool, and prevention of pollution is always the preferred approach. Flushing of blue-green algal blooms is also generally not desirable as it may only move the problem further down stream. However, flushing flows may be used to move a bloom away from a town water supply inlet or to flush algae into a wetland.

Water bird breeding for many species is stimulated by periodic flooding of wetlands. The success of a breeding event and the survival of the fledglings depends upon the slow recession of a flood or the occurrence of follow-up floods to maintain water under rookery

nests. River regulation and extractions can cause the loss of some flood events, a more rapid recession of floods, or the loss of follow-up events. Species which breed on flood plain wetlands include ibises, egrets, herons, spoonbills and a variety of water fowl. The use of ECAs to extend the period of flooding is one measure to ensure the success of breeding.

Spawning for certain native fish species is triggered by flood events. In the past, the variable flow in Australian rivers has permitted free passage of fish only during floods or small runoff events.

Flushing of blue-green algal blooms is also generally not desirable as it may only move the problem further down stream. However, flushing flows may be used to move a bloom away from a town water supply inlet or to flush algae into a wetland.

Document #12

Impacts of Landfill Waste Disposal on Our Water Resources

Land filling is by far the most common method for the disposal of both domestic and industrial solid-wastes used today. Some inorganic solid wastes cannot be disposed of in any other way. Other wastes however may be able to be recycled, treated or disposed of in other ways, although perhaps at greater cost. Land filling will remain the most widely used method for the disposal of solid waste for the foreseeable future.

Unfortunately, landfill depots often have an adverse impact on the environment. Inadequate planning, poor siting, poor design or operation, deficient maintenance, or failure to apply appropriate environmental control measures, have too often caused uncontrolled polluting of the surrounding environment. This environmental damage can have an impact, both economically and socially, not only on river users, but the local community as a whole.

Document #13

Leaching

The greatest potential problem from landfill disposal is usually the leaching of toxic waste material into the watertable and waterways. During their lifetime most landfills produce large volumes of leachate. Leachate is formed by a process similar to brewing tea. Rainwater or ground water mixes with decomposing garbage, some of which is dissolved resulting in a leachate which can then move from the landfill site.

Only non-hazardous waste should therefore be disposed of by landfill.

Disposal of waste by landfill should not result in leachate from the site containing an unacceptable level of toxic contamination.

This objective can be met by:

- limiting what may go into the landfill,
- adopting a suitable standard test procedure for determining the potential for leaching of toxic substances from the waste, fixation / immobilisation of chemicals prior to or as landfill occurs,

-adopting standard leachate criteria, which in association with other information on the chemical properties of the waste and information on the disposal site, enable evaluation of the acceptability of landfill disposal.

A suitable leaching test involves contacting a waste material with a specific liquid to determine which component in the waste will dissolve in the liquid. As a general guideline, a waste material is suitable for disposal in a well managed landfill site if the concentration of any contaminating toxic material in the test leachate is less than 100 times a relevant water quality standard.

Wastes which generate leachate and do not meet the concentration criteria are unsuitable for general landfill disposal without prior treatment.

They may not necessarily be hazardous. The leaching test and other criteria are adopted to assist in assessing the suitability of a waste for disposal in landfill.

See the Guide sheet titled "Substances to be Excluded from landfill"

Document #14

Water Pollution through Landfill

In selecting the site, planning and design of the landfill and its daily operations, the developer must ensure that neither surface water nor ground water are polluted

Ground water and surface water moving through a landfill will pick up both dissolved and suspended solid matter and microbial waste products. The waste water or leachate so generated can be very polluting and can make affected waters unusable for domestic, recreational or irrigation purposes. It is essential, therefore, that hydrological and geological characteristics of the site be considered so that the landfill can be designed to prevent both chemical and bacteriological pollution of waters. In any landfill operation provision must be made for collection and treatment of any leachate generated.

A landfill site should never be established on a flood-plain where flooding occurs or on the bank of any stream, billabong, oxbow or any other area rich or potentially rich in animal or plant life.

Surface water pollution may be minimized by two methods:

- interception of all surface water drainage entering the landfill site and re-routing of these water either around the landfill or through it in sealed drainage system

- collection and treatment of all waters that fall on or pass through the landfill.

Providing a drainage system that prevents contact between surface water and contained wastes is inherently more efficient than the collection and treatment method.

Waters reaching the landfill from other parts of the catchment, and rainfall striking the landfill surface, may also produce leachate if they come into contact with deposited wastes. Therefore, provision must also be made for drainage of those waters falling on the fill area itself.

Deposited wastes must not be allowed to cause interference with a ground water system that is used, or has potential for being used, as a source of water for any purpose. The need for protection of a ground water resource and the degree of protection required will depend on the hydro geology of the site, and in particular on:

- the relationship of the base of the fill to the watertable
- the permeability of surrounding and underlying material
- the existing or potential use of the ground water.

Protection of a ground water system may be maximized by the following methods:

- containment of wastes/leachate by placing an impermeable liner beneath and around the fill.
- synthetic liners can be used but a cheaper alternative is clay.
- containment of wastes/leachate by reducing the infiltration of water into the fill by provision of surface and sub-surface drainage
- collection of any leachate generated

No matter how effective the surface drainage and whether or not liners are employed, a landfill site creates a large reservoir for the water that falls on it. Consequently, provision must be made for collection and disposal of leachate produced by that water.

Water quality monitoring sites must be established around the landfill site so that the effectiveness of pollution control measures can be assessed.

See the document Substances Excluded from landfill Disposal to obtain for a guide to the correct disposal of substances.

Only non-hazardous waste should therefore be disposed of by landfill.

Disposal of waste by landfill should not result in leachate from the site containing an unacceptable level of toxic contamination.

This objective can be met by:

- limiting what may go into the landfill,
- adopting a suitable standard test procedure for determining the potential for leaching of toxic substances from the waste,
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A suitable leaching test involves contacting a waste material with a specific liquid to determine which component in the waste will dissolve in the liquid. As a general guideline, a waste material is suitable for disposal in a well managed landfill site if the concentration of any contaminating toxic material in the test leachate is less than 100 times a relevant water quality standard.

Wastes which generate leachate and do not meet the concentration criteria are unsuitable for general landfill disposal without prior treatment.

They may not necessarily be hazardous. The leaching test and other criteria are adopted to assist in assessing the suitability of a waste for disposal in landfill.

See the Guide sheet titled “Substances to be Excluded from landfill”

APPENDIX: 3.2

**RESOURCES :
Newspaper Clipping Text**

Article #1

Company Damages Pristine River

On a recent visit to the region, city children were fortunate to meet Mrs Alice Butler, a local identity well known for her interests in native flora and fauna. When she learned of their intention to hike along the Nardoo River and camp on the lower side of Catfish Creek, she told the children about her recent trip.

“When people started complaining about the changes in the river I decided to look for myself,” Mrs Butler said.

While recounting her trip to the children, Mrs Butler described the concern she felt when she came across the results of careless extraction practices of the sand and gravel industry within Black Ridge.

“As I made my way upstream I could hear the noise of machinery echoing through the valley. The river beside me grew muddier as the noise grew louder. Rounding a bend I was shocked by what I saw. The native trees along the edge of the river had been cleared and sections of the bank had collapsed. Large tracts of forest had been removed and those trees left standing were covered by a thick layer of dust. Native flowers had choked and died. The birds which used to fly overhead were not to be seen. It was as though all the wildlife had suddenly vanished.”

The students were upset by the changes Mrs Butler had described but were eager to see the area for themselves. Mrs Butler said it was a shame that so much damage had been caused in Black Ridge, as sand and gravel extractors elsewhere had protected the landscape.

“In the next valley a company has been far more careful in maintaining the banks of the river around its extraction site, Mrs Butler said. “The banks have been kept as natural as possible and it is very unlikely that large amounts of sediment will wash into the river. As a result changes to the river’s course will be minimal.” Mrs Butler applauded the efforts of this company’s management in attempting to lessen their impact on the river, and for choosing to extract the sand and gravel which is deposited during flooding. Mrs Butler assured the children her efforts to bring the sand and gravel extraction problem to the attention of the wider community had only just begun operations.

“Thank goodness not all people are determined to ignore the needs of the environment. In the next valley, the extraction of sand and gravel has had valley. The river beside me grew muddier as the noise grew louder. Rounding a bend I was shocked by what I saw. The native trees along the edge of the river had been cleared and sections of the bank had collapsed. Large tracts of forest had been removed and those trees left standing were covered by a thick layer of dust. Native flowers had choked and died. The birds which used to fly overhead were not to be seen. It was as though all the wildlife had suddenly vanished.”

The students were upset by the changes Mrs Butler had described but were eager to see the area for themselves. Mrs Butler’s knowledge of the area allowed her to comment on similar much less impact. The company concerned has been far more careful in looking after and maintaining the river banks around the site. They have kept the banks as natural as possible and minimised changes to the river’s course. This has also helped in reducing

the possibility of increased sediment levels in the river. To lessen their impact on the river, they have also preferred to extract material which has built up after flooding.

Mrs Butler assured the children her efforts to bring the sand and gravel extraction problem to the attention of the wider community had only just begun. The business is set to expand as the government adopts policies encouraging the development of inland areas.

When visiting his sand and gravel business in the Black Ridge Region, Mr Granite commented, "The support offered by the government to those who wish to establish new farms or industries is quite substantial, and this will lead to a higher demand for building materials. There are quite a few more years of sand extraction left in this part of the river alone. Rock Solid supplies are of the highest quality and I intend to make them an integral part of any construction in this area."

Article #2

Boom Times Predicted

CHAIRMAN of the Rock Solid sand and gravel extraction company, Mr Archie Granite, predicts a steady growth in profits for his company shareholders. The business is set to expand as the government adopts policies encouraging the development of inland areas. When visiting his sand and gravel business in the Black Ridge Region, Mr Granite commented, "The support offered by the government to those who wish to establish new farms or industries is quite substantial, and this will lead to a higher demand for building materials. There are quite a few more years of sand extraction left in this part of the river alone. Rock Solid supplies are of the highest quality and I intend to make them an integral part of any construction in this area."

Article #3

BUILDING costs will rise if restrictions are imposed on Rock Solid's extraction operation in Black Ridge, say local builders. Pilliga Crossing residents have complained to the Nardoo River Water Authority about the recent deterioration of their water supply. Many have demanded the imposition of restrictions on the extraction business in order to limit the volume of sediment entering the river.

Building contractors at Pilliga Crossing claim that restrictions will lead to increases in the cost of building supplies. Bill Hammer, who operates the Hammer & Shovel Construction Company, says that if he is not able to obtain good quality sand and gravel at its current price, then he will pass any new costs on to his customers.

Mr Hammer says that he is able to keep his costs down by transporting the sand and gravel by boat from the Rock Solid operation in the Black Ridge Region.

Article #4

Extraction Limits Will Cost Dearly

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“My business is just beginning to give me some return for the money that I have invested. If I am forced to bring this material from out of the area, my transport costs will increase. I will have to either lay off some of my labourers or increase my charges. The people here do not really want to pay more for their roads and houses. They want cheap supplies. Anyway, I cannot see what all this fuss is about,” Mr Hammer said.

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Article #5

Angry Response To Saline Release

A meeting held in Pilliga Crossing yesterday sought to establish a new system for the release of salt water into Nardoo River. The meeting follows angry responses to the discharge of large amounts of salt water from the Black Ridge Colliery. The 50 people who attended the meeting were mostly downstream water users who rely on the river for their domestic and commercial supplies.

Colliery managers, and representatives of the Nardoo River Water Authority and the Pilliga Shire Council, were told that farms in the region needed ongoing irrigation from Nardoo River if they were to remain viable.

Mr William Keller, representing the Tanunda & Murrumbidgee Region Vineyards Association, wanted a guarantee that property owners would be compensated for any loss of income if their irrigation water became highly saline.

Colliery general manager, Mr Kevin McGuire, explained that, “The company’s on-site storage facilities have reached their capacity. If the amount of water produced by the mine continues to increase, we will need to discharge the stored water.”

Mine managers were considering long term water management plans, Mr McGuire said. The meeting ended with the formation of a working party to establish a system for the release of salt water from the colliery into the river. The party would include downstream water users, representatives of Black Ridge Colliery, Pilliga Shire Council and the Nardoo River Water Authority.

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Colliery general manager, Mr Kevin McGuire, explained that, “The company’s on-site storage facilities have reached their capacity. If the amount of water produced by the mine continues to increase, we will have to do something about it.

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release of salt water from the colliery into the river. The party would include downstream water users, representatives of Black Ridge Colliery, Pilliga Shire Council and the Nardoo River Water Authority.

Article #6

Colliery Investigated

The Nardoo River Water Authority today announced it was investigating the recent surge of saline water into Nardoo River adjacent to the Black Ridge Colliery.

Members of the community claim that the mining company started releasing saline water when its ponds reached capacity several months ago. Engineers are preparing a report on the structure and function of the storage ponds used at the mine.

Miss Sandra Vickers, Environmental Officer of the Nardoo River Water

Authority, says that heavy fines will be imposed on the colliery if saline water is being discharged into the river without authorisation, or if their storage ponds are found to be defective.

Article #7

Clearing To Blame For Muddy River

The Nardoo River Water Authority has found that the increasing murkiness of Nardoo River is caused by large amounts of topsoil washing into the river. The erosion has been linked to the large scale removal of vegetation by the Black Ridge Colliery and the Mallore Logging Company.

Miss Sandra Vickers, Environmental Officer of the Water Authority, said that high levels of suspended solids were found in the river after rain fell in the Black Ridge and Merringurra regions. During periods of low rainfall the concentration of suspended solids fell, but was still high enough to keep the river murky.

“The main problem is that large numbers of trees and shrubs were removed from both work sites. The soil dried out and, with no roots to hold it down, got washed away or blown around. Without vegetation, rain washes over the ground at speeds higher than normal carrying the soil into the nearby river.”

Miss Vickers added that chemicals or nutrients normally kept in the soil by plants also end up in the river when vegetation is cleared.

The manager of Black Ridge Colliery, Mr Kevin McGuire, indicated that the mine management was aware of the Water Authority’s findings and that the company was developing a program to plant native trees and shrubs in exposed areas.

Miss Vickers said that publicity of the costs created by soil erosion would make other land users careful not to repeat the mistakes of Black Ridge Colliery and the Mallore Logging Company.

The Pilliga Shire Council is still assessing the original lease agreement signed by the Mallore Logging Company. The council has not yet said whether the company would be made accountable for the restabilisation of the area or if funding would be found from government sources.

Article #8

New Ponds Sought

Black Ridge Colliery today applied to have two more water storage ponds constructed. In a recent incident when a pond reached capacity, the company was forced to discharge

saline water into the river during an extended dry period. As a result the concentration of salt in the river increased substantially.

The manager, Mr Kevin McGuire, stated that the building of more storage ponds would solve the problem of overfilling, especially in wet weather.

Over recent years the Black Ridge Colliery has expanded operations in the Black Ridge Region of Nardoo River. As it has dug deeper for coal the company has increasingly needed to deal with the accumulation of saline waste water. Initially the water was channelled straight into the river but a more environmentally sensitive approach saw the use of ponds for the storage of water.

Article #9

Koalas will die say greenies

Logging operations came to a standstill today as fifteen conservationists chained themselves to large trees in a protest against plans to extend logging in the Merringurra Forest. One protester, dressed in a koala suit and clutching gum leaves, pleaded with timber cutters to turn off their chainsaws and "save our forests now".

Spokesperson for the Pilliga Ecowatch Group, the organiser of today's demonstration, Bob Wood, said no thought had been given to the native fauna which depended on the forest habitat.

"If the Mallore Logging Company clears this area, the dwindling koala population will be devastated," he said. "The koalas depend on special eucalypts which only grow in the proposed new logging area."

Employees of the Mallore Logging Company called police who, after hours of negotiation with the protesters, brought in bolt cutters and forcibly removed them from the site.

A statement released by the logging company called on the conservationists to keep a "balanced perspective", and highlighted the future economic benefits for the Pilliga Crossing community and the national economy.

Article #10

Letter to the Editor

Dear Editor,

The township of Tarkine was a devastated wasteland until our community introduced environmentally sound practices. The Mallore Logging Company was responsible for huge amounts of topsoil removal. This resulted from the de-stabilisation of the land after enormous areas of trees were removed without any concern for the environment.

One of the legacies of this environmental pillaging was an increase in the amount of nutrient runoff and dissolved solids entering the Nardoo River below our township. This in turn made our efforts to contain a blue green algal outbreak in Pilliga Dam very difficult.

At the moment we are having some success on this front and it would be most unwise to start any venture that may aggravate this problem. It seems obvious that any increased activity in the Merringurra Forest by the Mallore Logging Company will allow more sediment and nutrient runoff into the dam. This may push the algal growth beyond the limits of our control, and result in a significant risk to our children and tourists who presently enjoy the beauty of Pilliga Dam.

I would like to call upon your readers to join with me in a united front to put a stop to any extension of logging by the Mallore Logging Company.

Yours Sincerely,
Bob Wood
Pilliga Ecowatch Group

Article #11

Water charges to rise

Water charges would rise if there was a continual increase in the turbidity level of the Nardoo River.

The Pilliga Water Supply Engineer, Mr Arthur Steel, explained at last night's council meeting that the increased treatment costs incurred by council would ultimately be passed on to the householder.

"Currently council pumps directly from the river into its own storage tanks where the water is purified. Any increase in turbidity will have a significant effect on this process," Mr Steel said.

"The sediment has the potential to block Council's pumps and pipelines, and to significantly reduce water storage capacity. Capacity reductions of over 25% have already been reported," said Mr Steel.

The meeting was told that the water purification process would need to be upgraded so that sediment could be removed before it entered the water mains. This would require aluminium sulphate to be added, causing the sediment to coagulate and sink. The water would then be filtered to remove the remaining particles.

"If council is to overcome these problems an expensive maintenance program will have to be introduced," Mr Steel said.

Article #12

Weed Effort Fails

RESIDENTS gathered last month near Possum Creek to rid the river of its weeds. Boats of all shapes and sizes were used to remove the green carpet of weed that had covered a narrow section of the river.

After two days of work the area was cleared of all but a few bits of weed. An attack on another section is planned for later in the month.

However, local fisherman, Mr Sam Chang, yesterday questioned the effectiveness of the residents' efforts.

"It looked like it was going to work, but now there are new areas down the river where the weeds are growing. The weeds are already growing back in the area we cleared. I think we need some expert advice before we really make a mess," Mr Chang said.

Article #13

Weed Eradication Programme

Irrigation farmers must report any noxious weed found in the Nardoo River.

DO NOT REMOVE, INFORM THE AUTHORITIES

A single node can start an outbreak,
block irrigation channels and infest crops.

Pamphlets are available from the post office

On the authority of Government scientist Dr David Abernathy.

Article #14

Logging Linked to Weed Growth

GOVERNMENT scientist, Dr David Abernathy, today released some of his findings about the rampant growth of weed in the Nardoo River. His conclusions were drawn from samples of water and weeds taken from the river's worst affected areas.

He suggests that the Mallore Logging company has contributed to the weed's growth. In his correspondence, Dr Abernathy writes, ". . . that an excess level of nutrients in the river below the logging site has contributed to the prolific growth of plants in that area . . .".

Dr Abernathy was unable to specify which part of the logging camp was the main source of the nutrients. While having not inspected the site personally, he found that in the water samples he tested, phosphorus and nitrogen were present in higher than normal concentrations. His report states that unless these chemicals are prevented from entering the river, the growth of the weeds will continue.

Article #15

Farmer Doubts Beetle Solution

DOUBTS remain about a suggestion from government scientist, Dr David Abernathy, to use the flea beetle, *Agasides hygrophilia*, to control the Alligator weed in the Nardoo River. When released, Dr Abernathy believes, the beetles will simply eat all the weed.

However yesterday, a local farmer, Mr Butch Hayes said, "I'm just not sure about this beetle the scientists are talking about. Remember the cane toad up north? Saviour of the sugar industry, it was said. It certainly got rid of the cane beetle, but now it's spreading to other areas of the state.

"We have already introduced the plant, so we need to be very careful about introducing a South American beetle! I do not understand why we can't just spray the weeds. That should get rid of them. People are saying that spraying is too expensive, but there must be some way of keeping both the cost and the risk down. Someone should look into it."

While other methods of controlling the weed are available, at this stage the biological control method, using the South American beetle, is the choice favoured by the government.

Article #16

Sediment Fills Dam

Measurements of water and sediment depth indicate that Pilliga Dam is shallowing. Water Authority officers say that sediment settling on the dam floor is the cause. If this trend continues, water supply to Pilliga Crossing residents and other users will be jeopardised during low flow periods. As part of a monitoring program for Pilliga Dam, the Nardoo River Water Authority is recording the water depth at various points along the dam.

Deposits of sediment were thought to be part of the natural system and were considered

when planning for the construction of the dam began. However the unusual increase in the depth of the sediment is causing concern for the dam management engineers. Investigations are in progress and conclusive information on the source of the problem will be available soon. Water authorities hope an action plan will stop the sediment problem from worsening.

Article #17

Soapbox

by Evelyn Krickstein

“We have seen the water flood the valley above the dam, swamping pristine forest and endangering plant species and wildlife. We see the red gums suffering because seasonal water has stopped flowing to areas below the dam.”

These are the laments of Miss Jessica Hansen, spokeswoman for the Pilliga Environment Watchdog.

Prior to its construction, environmentalists voiced their concern for the effects Pilliga Dam would have on the river environment. Experts made decisions about the site and size of the dam with little public debate. It was indicated that a full environmental impact study had been carried out but the time allowed for the community to view and comment upon the study was limited.

Environmentalists believed the logging and mining operations within the upper reaches of the river had caused enough damage and the dam would only make things worse.

Today, native plants and trees above the dam are unable to cope with the rise and fall in the river, a situation which has created a lifeless ring around the water's edge.

The environment above the dam has changed from one of running water associated with rivers and streams to one of standing water similar to lakes and lagoons. This has changed the sedimentation, water temperature, water chemistry and quality of aquatic organisms.

The environment below the dam is suffering because of the sudden change in the river's natural pattern of flow. Where once the river was dry or in seasonal flood, there is now a continual flow of water with only the largest of floods passing the dam.

The environment has adapted over thousands of years but now has to contend with changes brought about by the dam in only a few years. This has led to changes in the diversity and population of species that exist in and around the river.

The fears of fisherman have also been confirmed. Fish cannot climb the dam wall to spawn in their traditional breeding areas. Fish such as the golden perch will not spawn in the low temperature of the water released from the dam during summer.

“We are determined to continue monitoring the effects that Pilliga Dam is having on the environment and to do our part in informing the wider community about what we find,” says Ms Hansen. It may, however, be too late.

Article #18

Club fined for spill

Pilliga Crossing's residing magistrate, Justice Healey, yesterday found the Pilliga Aquatic Club guilty of causing environmental damage. The damage occurred when two 200 litre storage drums containing waste oils and solvents were deliberately dumped.

The environmental officer for the Nardoo River Water Authority, Anita Temmel, stated that she traced the source of the pollution to the service area used by the Aquatic Club.

The club admitted their liability in this instance and have since dismissed the employee responsible. They were fined \$10 000 and also forced to pay a further \$8 000 towards the

clean up of the spill.

Article #19

Scientist Offers Erosion Solution

WORLD renowned scientist and adviser to the State Government, Dr David Abernathy, is currently undertaking an inspection tour of the Tanunda Region. His task is to solve the problems currently faced by the local community: soil erosion and the deteriorating quality of the town's water supply from the Nardoo River. He was accompanied during his tour by a local naturalist, Mrs Alice Butler. They visited properties adjoining the river where Dr Abernathy extensively recorded details of the problems he found.

Dr Abernathy's findings were submitted yesterday to the State Government. They have been reproduced by the government printers and published for the public to read. Dr Abernathy's report is summarised below:"

The methods being used by farmers today are having a broad range of effects on the regional environment of Tununda. The excessive clearing of native vegetation along the banks of the Nardoo River has weakened the landscape. Many areas are now vulnerable to erosion, especially from the water as it moves with great force down the river.

Unusual quantities of algae and plant growth occur in abundance. They often appear in rivers where property owners have cleared vegetation from along the river and allowed stock to graze to the water's edge. While I require more time to gather additional data, I can report so far that the large amount of nutrients finding their way into the river is directly connected to the small number of plants growing along the edge of the river.

The Cavendish property is a prime example. In limiting the effects caused by clearing along the river, I recommend that native vegetation be restored to these areas. The State Government may need to assist farmers in devising a planting programme. In other areas I have witnessed the successful restoration of the banks of the river. This has mainly been achieved through the construction of fences to restrict sheep and cattle from designated areas along the river's edge. These have reduced the erosion caused by the impact of farm stock.

However, to eliminate erosion in the longer term, a combined programme must be introduced across a wider area. It would involve restricting the access of farm stock to the river and regenerating plants species throughout the Tununda region. Where the river banks are badly eroded, as is the case near some farms in the Walloway region, the original structure of the banks of the river must be stabilised. Such work must occur before revegetation can begin. The Government Water Authority can advise on the most appropriate means of restoring this structural damage."

Mr Abernathy warned that the river was unlikely to ever return to its original condition. "Any changes that people might make to the flow of the water will have an impact up and down the river. A plan to change the structure of the river requires serious thought and extensive planning."

Article #20

Letter to the Editor

It is time we started thinking a little more broadly. Whilst I am glad to see some serious debate about the state of our river and its banks, the interest seems only to be about how the river's demise affects us, our safety or agricultural productivity.

We have a responsibility to protect the natural environment of which we are all a part, and that means protecting habitats for other species. Riverbank vegetation provides shade for

fish in the stream just as fallen branches and trees provide shelter within the streams. The vegetation provides protection for our native fauna to use while traversing the region. In extensively cleared areas I have witnessed possums desperately making a dash across open paddocks in their attempts to reach shelter.

The vegetation along the banks of Nardoo River plays an important role in filtering nutrients before they flow into the river. However there is a limit to these plant's capacity to perform this role. It is better if we make a deliberate attempt to minimise the amount of nutrients running from farms into the river, and not expect nature to deal with the problems we have caused.

I am forming a local nature group which I hope will guard against irresponsible development in the region. Our charter is to ensure that development and changes to the region will not threaten the future of the natural environment and our standard of living. Anyone who is interested is welcome to join.

Yours Sincerely,
Alice Butler.
7 Main Street
Tununda

Article #21

Native Plants Will Save River

THE Water Authority has announced that it wants farmers to plant native trees along the edge of Nardoo River. In an attempt to address the local community's growing awareness of the need to revegetate the banks, the Authority released information gathered from similar schemes in the Merringurra region.

Mr Ross O'Reilly, of the Water Authority, said that willow trees used to strengthen the banks in the Merringurra region had caused additional problems. The trees had spread extensively along the river and were so thick in areas that they were almost choking the river.

Experts advising the Authority have suggested that only native plants, indigenous to this region, be used in any revegetation programme. A list of these plant species is available from the Water Authority.

Recommended plant species were able to tolerate occasional flooding, were suited to the type of soil in the area and were hardy enough to cope with the conditions of the river environment.

Exotic species, like the willow, were particularly unsuited to this type of revegetation programme. If allowed to grow unchecked, the species would dominate the remaining native flora.

Article #22

“Keep Out Of River”

The principal of Pilliga High School, Mr Craig, is concerned about the water quality of Nardoo River. In a recent newsletter he said that it would be unwise for students to take part in any activity that brought them into contact with the water in the Tanunda or Walloway regions.

Students living in that region have come to school with reports of dead fish floating among the reeds near their favourite swimming holes.

Mr Craig reported that the illness of at least one student was possibly caused by

consumption of fish taken from the river or from contact with the polluted water. Mr Craig has reported the matter to the Nardoo River Water Authority and will inform the parent body of developments as they come to hand.

Article #23

Acid Burns School Boys At Local Tip

Two boys were treated for serious skin burns yesterday after fossicking at the Pilliga Rubbish Tip. Mrs Sue Walters, mother of one of the boys affected, was horrified when her son Bret returned home in great pain with what appeared to be skin burns.

“The boys were looking for wheels for a billy cart they were building, when they found two unmarked drums. Bret says he hit one of them with a large stick and it burst open, spraying both of them,” she said.

Doctor Higgins, who treated the boys, said their injuries were consistent with acid burns. The manager of the tip, George McKenzie, expressed concern that the boys had been illegally foss- icking on the tip.

He also stated that, “Strict controls are maintained for the dangerous chemicals but sometimes loads have been dumped at the tip face instead of in the large storage pits. In the past we had a problem with dumping behind the tip when contractors arrived after closing time.”

Pilliga Shire Council will impose heavy fines on polluters if they can be identified, a spokesperson said.

Article #24

Industry Suspected Of Dumping Acid

The source of the acid dumped at Pilliga Rubbish Tip remains a mystery, but police are interviewing managers of businesses in the nearby industrial estate for clues.

Two boys received acid burns yesterday when fossicking among the rubbish at the tip. Police believe industrial acid caused the boys’ burns, but as yet no charges have been laid. Tip manager, Mr George McKenzie, said “The accident highlights the need for local industry to take care with the disposal of waste chemicals. Some industries in the estate create byproducts such as heavy metals and use other chemicals such as acids in their manufacturing processes.”

One manufacturer said most industries employ a contractor to transport and dispose of those waste chemicals which are not treated on site or discharged into the sewerage system under licence. Brok Investments is managing the expansion of the industrial estate but was unavailable for comment.

Pilliga Shire Council has provided a list of the types of businesses operating in the industrial area: zinc plating, soap detergent manufacturing, panel beating, mechanical repairing, paper production, battery manufacturing, paint and ink formulation and leather tanning.

Article #25

Industry Killed Fish, Says Worker

A local Sewage Treatment Plant worker, who has asked that his name be withheld, blames local industry for the recent fish kill in Nardoo River.

Various industries are licensed to discharge specified volumes of waste into the sewage system but concentrations of pollutants in the waste cannot exceed licensed levels. Wastes are tested on a monthly basis to ensure compliance with licence conditions.

“Obviously there are plenty of opportunities for companies to breach licence conditions without detection,” he said. “I suspect this happens regularly. The question is whether this time the practice has gone too far, and resulted in a major fish kill.”

Article #26

Golf’s best green yet!

The president of the Pilliga Golf Club, Mr Leonard Best, officially launched the Pilliga Women’s Open Competition last night. He believes that this will be the best competition ever held.

Mr Best described the course as being in excellent condition and the best he has seen. He said “The greenkeepers have extensively fertilised and watered the course this year in the lead up to the summer tournament. This has only been possible because of the availability of recycled water from the nearby sewerage works.

The insect problem has been solved with pesticide spraying. It’s been costly, but it will be worthwhile if the tournament’s a success.” In the ten years the Open has run it has attracted big names in Golf, and this year will be no exception.

Article #27

Algae poisons water

Casualty Ward at Pilliga Hospital is treating an increasing number of people suffering from skin rashes, diarrhoea and cramps. These symptoms are consistent with algal bloom contact.

The Local Hospital’s Health Department has issued a warning about the use of water from Nardoo River in the Walloway and Tanunda regions.

“If you have skin contact through showering, swimming or water skiing you may get rashes, swollen lips, eye or ear irritation, a sore throat, or respiratory problems,” said Dr Coombes, a representative of the Hospital’s Health Department. “If you drink the water you may experience nausea, vomiting, abdominal pains, diarrhoea, liver problems or muscle weakness.” Dr Coombes also warns that the danger of sickness increases with greater exposure to the river water.

The Department warns locals not to eat mussels, snails or shell fish taken from the river in these regions. Polluted fish have a muddy or earthy taste. Fishermen are advised to clean their catches thoroughly. Dr Coombs also says that pets and farm stock should be stopped from drinking contaminated parts of the river as algal toxins are deadly.

Article #28

Economy Suffers as Bloom Worsens

The algal bloom is devastating the economy of Pilliga Crossing, said The Pilliga Chamber of Commerce today.

The impact was said to be due to a number of factors.

Firstly, declining recreational use of the river was reducing regional tourism.

Secondly, farmers were unable to spend money in the town because of the cost of watering their stock and crops, and declining farm output.

Towns in other regions were now forced to transport water in by truck or drill for bore water. Both measures were proving to be expensive.

Article #29

Farmers Want Dam

REPEATED flooding in the Walloway Region has destroyed the banks and bed of the Nardoo River. Farmer, Mr Ben Hannigan, said he had experienced five floods during the past two years, which had reduced his property along the river by several acres.

The floods have caused severe damage to farmers' crops. Many of the farming families who have had their incomes reduced, were experiencing hardship resulting from the loss of production.

"Unless we bring the flooding river under control, the region will not grow and become prosperous," Mr Hannigan said.

Together with other land users, Mr Hannigan has written a petition which he will send to local councils pressing them to construct a dam on Nardoo River.

The petition explains the advantages of a dam:

- The damage associated with seasonal flooding would be prevented, allowing farmers to use land that is now unusable because it is prone to floods.
- The dam would store enough water for farmers and town residents to use, even during extended periods of drought.
- Pilliga Crossing could rely on the dam for its main supply of water. The water could be treated, if necessary, before reaching household taps.
- The area above the dam would be useful for leisure activities like rowing or fishing.

Mr Hannigan will present the petition at the next meeting of the local council.

Article #30

Authority Advises On Chemical Sprays

The level of chemicals downstream from cotton and rice growing farms is now well above recommended levels for inland fresh water rivers. Concentrations of insecticides, herbicides and fertilisers are now too dangerous for animal consumption.

Environmental Officer of the Nardoo River Water Authority, Miss Sandra Vickers, expressed concern over the chemical contamination of Nardoo River at the Sustainable Farming conference held yesterday.

Miss Vickers said that alternative farming practices would solve the problem.

"Chemicals enter the river system through four main methods: through over-spray drift during land and aerial spraying; as run-off from chemical laden soils and crops during heavy rain; through the inefficient recycling of irrigated tailwater; and the poor handling and disposal of containers used to hold agricultural chemicals."

Miss Vickers said that some chemicals have a greater impact than others because they are more likely to remain in the environment.

In her detailed presentation, Miss Vickers provided some ideas in attempting to minimise the impact of chemical contaminants.

"Pesticides and herbicides should be applied at optimum times relative to the weed and insect growth cycles of a farm's crop," she said. "Farmers need to be careful to use minimal, yet still effective, amounts of chemicals in controlling pests. And close attention must be made to weather conditions at the time of spraying."

Miss Vickers added, that efficient monitoring of irrigation systems would avoid the over watering of crops and, as a consequence, reduce the amount of run-off coming from farms. She recommended that pesticides and herbicides be selected with their impact on the environment in mind, and that chemicals with a specific use be considered over ones having multipurpose applications. She also suggested that farmers use pest resistant

varieties of plants to combat insects.

Miss Vickers said that information about these issues was freely available from the Water Authority.

Article #31

New dam proposed

A serious water shortage has prompted the Nardoo River Water authority to consider initial proposals for another dam on the Nardoo River. The site being considered is above Kaluna Point in the Black Ridge area.

Pilliga Dam currently supplies water to both Tarkine and Pilliga Crossing townships as well as the industrial estate and the surrounding farmland.

Local farmers have complained to the Authority that the continuing drought and the resulting low water allocations, have highlight the need to increase the water storage capacity in the catchment. They also revealed that Pilliga Council is considering applying restrictions to town residents.

Environmental groups are concerned that flooding of the upper reaches of the Nardoo River will destroy wildlife habitats. They say the building of a new dam could be deferred through the introduction of water demand management. They refer to the Nardoo River Water Authority's own report which details possible options.

Article #32

River needs water

Town residents along the Red Gum River are concerned that excess water use upstream is restricting the water available to them. A meeting called today by regional Councils will develop strategies for distribution of water to downstream users.

The Nardoo River Water Authority, in support of the residents, confirmed the downstream needs of water for stock, irrigation, towns, and the environment.

Spokesperson for the Water Authority, Anita Temmel said, "Before there were towns and farms along Nardoo River, water flowed freely into Red Gum River. As development increased, less water flowed into the river. People along the Red Gum River are now suffering water shortages.

"The health of this river is also suffering. The recent outbreak of blue-green algae shows that good water quality depends not only on our ability to control pollution, but also on the amount of water flowing into the river. Let's all remember that there are people below the Nardoo River who need water just as much as we do."

Mr Bob Wood, spokesperson for the Pilliga Ecowatch Group also supported the idea. He said, "Rivers that are stressed need to have their basic flow of water safeguarded."

Mr Wood said that any extra water gained through conservation measures, such as water restrictions, must remain in the river system to maintain its health.

APPENDIX 3.3

RESOURCES : Video Scripts

Script #1

WEED GROWTH DISTRESSES RESIDENTS

Archival Film

Newsreader

Residents are concerned about the rapid increase of weed in the Nardoo River. Government scientist, Dr David Abernathy, toured the worst affected areas with river boat captain Hugh Smythe as his guide. Later he addressed a public gathering on the banks of the river.

Dr Abernathy was confident that measures could be taken to reduce the damage caused by the weed. He warned that the treatment would be difficult and expensive due to the variety of weed species.

Water samples taken at various points along the river will be tested in a government laboratory. The results are expected to pinpoint the likely source of the problem and will soon be printed in the local newspaper.

Script #2

CAUSE OF ALGAL GROWTH FOUND

Archival Film

Interviewer

Mr Sam Chang is a local fisherman. He has been keeping an eye on the growth of weeds and algae in Nardoo River. He has identified a possible contributor to the problem.

Sam Chang

I was fishing up the river and I noticed weeds in the still parts. The weeds are greener and very matted near the logging area. It seemed to me that something nearby is making the weeds go wild.

Up near the jetty there's a narrow channel. Waste water comes out of it and ends up in the river. I think, the waste water comes from the huts which are near the riverside. The water stinks, so my guess is that some of the huts are used as showers and toilets.

Interviewer

When asked about the quality of the fishing in the river, Mr Chang had this to say. . .

Sam Chang

I can't fish in the worst areas because the weeds make it too difficult to move my boat. I hope something is done soon before the river gets even more clogged.

Script #3

RIVER CHOKED BY WILD WILLOWS

Archival Film

Interviewer (read at desk)

They may look green and healthy, but willows are choking Possum Creek. Mrs Alice Butler is a local naturalist. I asked her where the willows came from and why they were spreading . . .

Alice Butler

A few were originally planted by the Mallore Logging Company to strengthen the banks after they cleared the natural vegetation. They worked in that respect, but now they are all along the creek line.

Interviewer

How did they spread so easily?

Alice Butler

Willow branches are brittle and break easily in strong winds or floods. The broken stems then take root, and now all those trees are sucking the creek dry.

Interviewer

What should have been done?

Alice Butler

It was obviously a mistake to plant them in the first place. Native species should have been used instead.

Script #4

FISH FOUND DEAD IN RIVER

TV newsreader

Newsreader

In a disturbing sign that something is wrong with Nardoo River, dead fish have been found along its banks in Tanunda.

Environmental officer of the Nardoo River Water Authority, Sandra Vickers, is testing for traces of toxins in the fish.

Sandra Vickers

I'm really alarmed by the number of dead eels and silver perch floating among the plants on the edge of the river. I've been carrying out laboratory tests and the fish all contain a foreign chemical. I'm going to do more tests to determine it's exact nature. I'm also testing the river near the fish kill and I'll move the investigation upstream until I find the source of the contamination.

Newsreader

The Water Authority has warned people not to eat fish caught in the Tanunda region and not to drink, swim or shower in the river water.

Script #5

CHEMICAL DUMPING TO BE FINED

TV newsreader

Newsreader

Pollution inspectors will enforce fines against the illegal dumping of chemicals after more than 800 fish were found dead along the Nardoo River near Pilliga Rubbish Tip yesterday.

Preliminary testing indicates the fish were killed by a chemical substance which entered the river during the recent heavy rain.

Water Authority spokeswoman, Sandra Vickers, said that the authority was looking at setting up regular patrols along the river.

Sandra Vickers

Many people aren't aware that chemical dumping effects both the community and the environment.

Chemicals kill a lot of fish and damage the river environment. People rely on that river for drinking, also irrigating, as well as swimming and watering stock.

It's likely the chemicals were illegally dumped. We are appealing to anyone who saw something unusual in the Pilliga tip area during the last 24 hours to come forward.

Newsreader

The river's environment will take some time to recover from the chemicals and locals are warned not to eat fish caught in the area during the past 24 hours.

Script #6

SEWAGE BLAMED FOR ALGAL BLOOM

TV news

Journalist

Chairperson of the Pilliga Aquatic Club, Betty Carlisle, has blamed the current outbreak of blue-green algae on the Nardoo Water Authority's poor management of the local sewage treatment plant.

Betty Carlisle

The smell is terrible. We've written to the Water Authority about the algae before, but nothing's been done. Ten of my club members are ill because they fell off their skis into the river.

Journalist

But spokesperson for the Nardoo Water Authority, Anita Temmel responded to this criticism . . .

Anita Temmel

The plant is operating as efficiently as possible. The amount of nutrients entering the river can only be reduced with extra treatment. This involves additional chemical and biological processes.

Journalist

According to Anita Temmel, if the community wishes the plant to be upgraded to this level of tertiary treatment, then the cost of site and equipment expansion, as well as extra operating costs, will have to be passed on to householders and industry.

Anita Temmel

Smells from sewage treatment plants are inevitable. It is more likely to be the algae they can smell.

Script #7

PEOPLE FEAR CHEMICALS, SAYS SURVEY

TV news

Journalist

A recent Federal Office of Health survey has found the community believes agricultural chemicals threaten human health and the environment.

Over 90% of the respondents expect to find dangerous chemicals on farms. And most want to know about the effects of chemicals on their health and on the environment.

Spokeswoman for the Pilliga Environment Watchdog, Miss Jessica Hansen, is not surprised by the survey results.

Jessica Hansen

The public have not been informed of the effects that agricultural chemicals have on humans. Very little attention has been given to these issues.

Chemicals have been applied successfully to crops for specific purposes and the side effects have been largely ignored.

Journalist

However, local cotton farmer, Bob Simpson, defends his use of agricultural chemicals.

Bob Simpson

As an industry, we've learnt some valuable lessons and it's now in our best interest to protect people's health and the environment. Farming practices have improved a lot over the past ten years.

Chemicals that won't linger in the environment are being developed all the time, and we now use less insecticides and pesticides in our farming. Products have clearer labels with instructions on how to handle them carefully.

Journalist

The opposing environmental and farming views were presented at the Sustainable Farming conference held in Pilliga Crossing today. Miss Hansen called for a study to be done into the long term effects of using agricultural chemicals.

She accused farmers of having lax health and safety standards when they handle chemicals and of being unaware of the effects caused to humans and natural habitats.

Bob Simpson

People fail to realise that chemicals are an important part of food and fibre production all over the world. Without them, most farms wouldn't be profitable.

We have to feed and clothe more than 4 billion people on this planet, and it simply can't be done using organic farming techniques.

So the use of chemicals guarantees a very successful agricultural export industry.

Journalist

Miss Hansen added that no-one knew exactly how long chemicals remain in the environment.

Bob Simpson

Our industry is doing its utmost to minimise the harm caused by chemicals. A lot is spent each year on research and development projects in this area.

The bottom line, is that developed countries need agricultural chemicals to maintain a high standard of living. We have a responsibility to use the chemicals safely because the world can't do without them.

RESOURCES :
Radio Scripts

Script #1

WEEDS COVER RIVER, KILLING FISH

Radio newsreader

Newsreader

Thickly matted, floating weeds are reported to be covering large areas of the upper Nardoo River. Mr Sam Hargraves, a former resident of the region, recently made a canoeing excursion into the area with his students.

He reports that in the stiller, more densely covered areas of the river, fish and eels could be found close to the surface gulping for air. Further up the river, they noticed a thinning of the weed and that the river was muddier.

Mr Hargraves said he was horrified by the changes that had occurred since his last trip into the area.

Script #2

BOATS DESTROY FISHERMAN'S PARADISE

Radio documentary

Journalist

Joe Costanza is a fisherman who has lived in Merringurra for almost 40 years. Our journalist had the privilege of going fishing with him at his favourite fishing hole at 4 am this morning.

Interviewer

What was the fishing like when you were in your twenties?

Joe Costanza

This used to be paradise and every evening after work I would row out on the river and fish till dusk. Sometimes I'd get lucky and catch a lot of fish.

Interviewer

And what do you think of it now?

Joe Costanza

It's sad you know. I find I'm constantly cursing the river. Those yahoos charge up and down the river in those big boats.

The waves they make are eating away at the banks. At those speeds there is no way they can appreciate the beauty of the river.

They are either ripping up the weeds where the fish feed or scaring them away. You know, the amount of rubbish in the river has increased lately. I don't know if it is these yahoos or people today just don't care. It is really a shame.

Interviewer

What do you think can be done about it?

Joe Costanza

I'm going to see if people will support me to get rid of the motor boats. The water authority should leave part of the river for people to use who are not going to destroy it.

Script #3

CHEMICAL DISPOSAL POLICY OUTLINED

Radio studio interview

Interviewer

It has been reported that contractors have been dumping drums of waste chemicals away from the storage pits at Pilliga Rubbish Tip.

Recently a boy received burns from contact with acid dumped at the tip.

This has spurred local groups into pressuring Pilliga Shire Council to review its chemical waste policy and general waste handling practices.

Councillor Neil Saxby is with us in the studio . . . Councillor Saxby, what is the Council doing to remedy the situation?

Neil Saxby

Well, yesterday we announced a new campaign to encourage the correct disposal of hazardous waste from local industry and households.

Interviewer

What about the recent illegal dumping of waste near the tip?

Neil Saxby

Large amounts of chemicals should be placed in pits at the tip and then removed for treatment.

Interviewer

The tip is quite close to the river . . . Isn't this a problem?

Neil Saxby

Yes it is, if liquid waste is poured onto the tip face, then leaching from the tip could become a serious problem. Heavy rain could easily wash the hazardous waste directly into the river.

Interviewer

Who's going to pay for the waste removal?

Neil Saxby

Look, it is a matter for local industry to accept responsibility for the waste they generate. They should realise that the cost of the disposal is part of the manufacturing process.

Interviewer

What can residents do?

Neil Saxby

There is a temptation for individuals to dispose of small quantities of dangerous waste at the tip face. But, if this becomes a common practice, the end result could be just as disastrous as industrial dumping.

The Council does have a proposal before them to dramatically increase the fines for illegal dumping.

Interviewer

Thanks for your time Councillor.

Script #4

CHEMICAL DUMPING RADIO CAMPAIGN

Radio advertisement

A: Hey!

B: What?

A: You can't put paint down the sink!

B: Why not?

A: 'Cause it's gonna end up polluting the river.

B: So!

A: What about the people downstream; they won't be able to use the water.

B: I thought it got treated at the sewage plant.

A: No. Our local plant is only able to do primary treatment. It can't deal with things like paint or sump oil or even weed killer.

B: What am I supposed to do with the paint then?

A: Well, you're supposed to put it in a container and take it to the tip.

B: Well my little bit isn't going to make that much difference.

A: Everybody's little bit adds up to a big problem. C'mon, I'll take you down to the tip and show you the special area for paints and chemicals.

B: Say, I've got a can of sump oil in the shed, I'll take as well.

A: That's meant to be recycled at the petrol station, so we can drop it off on the way.

Script #5

TIP POISONS NEARBY RIVER

Radio news

Newsreader

Contaminated water flowing beneath the Pilliga Rubbish Tip is now seeping into the Nardoo River. Pilliga Shire Council is conducting tests of the ground water beneath the tip.

Drilling, water sampling, chemical analysis and soil testing has confirmed that chemicals stored and disposed of at the tip are finding their way into the ground water.

Visiting scientist Craig Morwell, has been consulted on the matter and is not at all surprised.

Craig Morwell

The area that is now the municipal water disposal site was once a natural wetland. The water table lies extremely close to the surface, so it's little wonder the ground water has been contaminated. Siting the tip on a wetland was a poor decision, obviously made with little understanding of ground water processes.

Newsreader

The council says it's presently looking for solutions to this problem.

Script #6

TIP CHEMICALS KILLED FISH

Radio news

Newsreader

Recent fish kills have been linked to empty agricultural chemical containers left at the municipal tip. These containers are often not adequately washed, and insecticides used widely in the cotton industry may have been allowed to seep into the river.

Pollution inspector, Nathan Pritchard commented . . .

Nathan Pritchard

Empty containers accumulate in such large numbers throughout the season that it becomes difficult to properly dispose of all of them. If the containers aren't triple rinsed and well sealed, chemical residues remain that can disperse into the environment. Seepage from disposal sites can result in the contamination of ground water. A fish kill is without doubt the most obvious environmental damage caused by insecticides.

Script #6

SICKNESS LINKED TO ALGAL BLOOM

Radio phone interview

Interviewer

Several people have reported getting skin rashes, cramps and diarrhoea after swimming in the Nardoo River. These problems have been connected to contact with the river's algal bloom.

On the phone today we have Dr Stephen Michaels from the Merringurra Water Research Centre.

Dr Michaels welcome to the show. What can you tell us about the bloom.

Dr Stephen Michaels

Thank you. This type of bloom has been a problem for the past few years.

This year though it is the worst it's ever been.

Interviewer

What's caused the bloom to increase?

Dr Stephen Michaels

The algal bloom has grown because the level of nutrients in the river has increased. The water level has dropped and the algae is thriving in this warmer weather.

Interviewer

You mentioned nutrients, what are these and where do they come from?

Dr Stephen Michaels

The nutrient that is most responsible for the algal bloom is phosphorus. The nutrients come from runoff and from an increasing amount of treated sewage being put into the river. Intense farming along the river banks contributes to the problem.

Interviewer

What is your research centre doing to investigate?

Dr Stephen Michaels

The Water Research Centre is currently measuring up and down the river to determine the exact source of the nutrients.

Interviewer

Lets hope you find them soon. Thanks for joining us. It's twelve past the hour.

Script #7

GREEN GROUP WANTS RIVER FLUSHED

Radio News

Newsreader

Pilliga Ecowatch Group spokesperson, Bob Wood, has called on local water authorities to release more water from the Pilliga dam. The group hopes the water will flush Blue-green algae from the Tanunda and Walloway regions of Nardoo River.

He claims heavy rains have dealt with previous algal blooms because the Water Authority was able to release more water from the dam into the river.

Environmentalists believe toxins produced by the algae are a health hazard for humans and animals. They are warning people about the potential dangers of the bloom.

Bob Wood

Look, whatever you do don't swim, drink or wash in the water where algal blooms exist.

APPENDIX 3.5

RESOURCES : Blue-Green Algae Simulation Expected Values

Simulator Inputs: Maximum and minimum values

Physical

Depth: 0 to 1.5 metres

Light Level: 10 to 500 lux

Temperature: 12° to 25°C

Turbidity: 0 to 500 (NTU)

Flush: On/OFF (acts as a pulse)

River Flow: Low/Medium/High

Time: 1 to 30 weeks

Chemical

River Nitrate concentration: 10 to 2000 µg/l

River Phosphate concentration: 10 to 5000 µg/l

Simulator Expected Value range

Outputs:

Algal cell mass: 0 to 35,000 cells/ml

Oxygen % Available: 45% to 100%

Toxicity Rating: 0 to 10 (Relative scale)

Algal bloom levels

Cell mass > 30,000 cells/ml (DANGEROUS)

Cell mass > 25,000 cells/ml (SIGNIFICANT)

Cell mass > 15,000cells/ml (NUISANCE)

Cell mass < 10,000 cells/ml (MINOR)

Eutrophication will occur when the algal cell count exceeds 25,000 cells/ml

Preset simulator input values:

Light level: 400 lux

Temperature: 21°C

Turbidity: 0

Flush: OFF

River flow: Low

Time: 15 weeks

River Nitrate concentration: 2000 µg/L

River Phosphate concentration: 3000 µg/L

Expected Algal Cell count: >30,000cells/ml

RESOURCES :
Blue-Green Algae Simulation Help Notes

ABOUT THE BLUE - GREEN ALGAE SIMULATOR :
GENERAL INFORMATION

Inputs:

- Ambient Light
- River Water temperature
- River Flow level
- River Flush
- River Nitrate concentrations
- River Phosphate concentrations
- River Turbidity
- Time regulated for a simulation run of 30 weeks

Outputs:

- Algal cell count
- Total River Nitrogen
- Total River Phosphorus
- Total oxygen
- Toxicity

General Control Panel Functions and Operation:

Inputs

On opening the simulation, default settings for each input will be present. The settings represent a significant bloom. This will act as a reference point for your simulation.

Phosphorus and Nitrogen concentrations, Light, Temperature, River flow level ,Turbidity and River flushes.

Values for these variables can be entered by adjusting the sliders. The relationships between these factors can be observed either in graphical or animated form.

Display

River Conditions

Leaving the simulator screen will cause the slider inputs to be reset to default values.

As the various inputs are set, the simulated graph and animation updates immediately to reflect algal bloom development over a period of 30 weeks.

Moving the time slider (below the graph), causes the output data windows to update for the selected time.

Using the 'Run' button will automate the time slider to move through the 30 week period until the 'Stop' button is depressed or it reaches the end. This can be used in both graph and animation views.

By studying the curves on the graph, significant points in the bloom's development can be identified eg. the point at which the algal cell count is at its maximum, or the oxygen level is at its minimum etc.

Using the Algal Bloom Simulator with River Data

If you want to simulate algal bloom in the river region that you are investigating then:

- take measurements in the river of nitrogen, phosphorus, temperature, oxygen, turbidity, algal cell count and river flow rate.
- go to the Algal Bloom Simulator in the Water Research Centre and choose the graph mode.
- use your river measurements of river flow and temperature as inputs to the simulator and use the preset values for nitrogen, phosphorus, oxygen, light and turbidity as your starting point.

To find a close match to the river conditions you measured:

- move the time slider to a point on the graph that is close to the algal cell count that you have measured in the river
- adjust the input sliders until you find settings that best represent your measured data. There may be many such settings, depending on the values you choose.

You now have an estimate of how many weeks since the algal bloom started, what the conditions were like when it started (input values of sliders) and a possible 30 week scenario of the development of the algal bloom

Good luck with your predicting.

RESOURCES:

Talking Head Scripts

Execution of talking heads:

Opening sequence

- *Introduction script to the WRC with the expert on simulations talking in general about simulations, their value, and the ones included in this package. Tells you to select the simulator.
- *Up comes the generic screen for simulation with talking head in simulator view window describing the general features of the operation of the interface. At this stage data panels are covered. Tells you to select a simulation.
- *The appropriate simulator interface opens. In the case of Personal water management, the improve your water use option is not selectable. It appears only after first run.

Others:

- *When ever talking heads appear, simulation goes into autopause, and user must restart the simulation by pressing the depressed pause button. The exceptions to this occur with the talking heads which give outcome statements.
- *Pause button is a toggle: down for pause and up for run.
- *Note: pause button needs to be added to all simulation interfaces.
- *In personal water use simulation, the extra information heads will appear on screen after the simulation has run and the outcome Talking Head has run. User may choose to use them or re-run the simulation with changes in place.
- *Numeric output for Personal Water Use simulation needs second set of figures, the after adjustments.
- *To clear any figures from a simulation, press reset or the default at startup is zero.
- *Dam numeric output boxes show figures as simulation runs and then places a cumulative figure for the run at completion.
- *Copy functions to PDA:
 - simulation view window needs to be shrunk when copied to PDA
 - select simulation view and drag across before copy function initiated
 - regardless of view and drag option, numeric data will always be included in copy action.
 - animated screen will not be selectable for copy

Introduction Scripts:

1) Click on Expert at Simulator:

“ Hi I’m and I have built some simulations which will help you better understand some of the problems encountered in the catchment of the Nardoo.

Simulations can be very useful because they allow you to test your ideas about any problems that you might observe while exploring the Nardoo without doing any harm. They can sometimes also allow you to predict what might happen under certain circumstances. Currently there are three simulations you can use, a Personal Water Use Simulator, a Dam Simulator and an Algal Bloom Simulator. Simply click on the model and have fun.”

2) Generic Interface:

In conjunction with cameraman movie

“You can select a simulation at any time by clicking a button on the control bar. You can start each simulation by pressing Run and you can Pause by pressing the Pause button. If you get a message during the simulation run, you can continue by releasing the pause button. If at any time you want a ‘fresh start’ simply press reset.” Select how you wish to view the results, either in animated or graph form, by pressing the appropriate button on the control panel. Data shown on the simulator screen can be selected and copied into the notebook.

If you want more details about any of the controls on the simulator, refer to the glossary/reference book (in the water resources centre)”

Blue-Green Algal Bloom:

The simulation runs 15 week time interval in default mode.

The essential movie which will play after each run is that which either congratulates the user or makes suggestions as to the possibility of reducing the bloom of algae improving the quality of the water or minimising the risks associated with such blooms.

How to Use Script:

In conjunction with cameraman movie

<Script>

“You may use this simulator to explore the relationships between the condition of river water in terms of nutrient loads, rate of flow and other characteristics and the development of destructive and sometimes toxic blue-green algal blooms.

You may alter any or all of the river conditions on the data panel.

The values for nutrients, temperature and light which appear when you open this simulator are those which you might expect to find in the river in time zone 4 before an algal bloom has been triggered. The simulator is set to run over 15 weeks. Lowering this value significantly may result in no apparent bloom. You may study the effect of the release of water from the dam or spills by turning on the river flush.

If you want more details about any of the controls on this simulator, refer to the glossary/reference book.”

Overall Simulation Outcome Scripts:

1) If values used for nutrients, light, flow rate etc produce a minimal bloom then:

<Script> Warning Routine needed

“Current river conditions are good at the moment. The combination of nutrient levels and sufficient water flow have produced very little algal bloom.” This is an ideal situation for all our waterways. You may like to investigate the effects of increasing the nutrient levels in the river or decreasing the river flow on algal bloom.”

OR

2) If values for nutrients, light , flow rate etc produce a moderate bloom then:

<Script> Warning Routine needed

“A significant bloom of blue-green algae has been produced because of high nutrient levels, and a low flow rate. Explore the effects of altering the nutrient levels, river flow rates, and see if you can improve the conditions in the river.”

OR

3) If values for nutrients, light, flow rate etc produce a dangerous bloom then:

<Script> Warning Routine needed

“The river is in a state of eutrophication. The large and dangerous blue-green algal bloom will result in damage to the river ecosystem. You need to consider and take action to improve the river environment.”

Other Triggered scripts:

1) If value for algal cell concentration exceeds certain value then:

<Script> Warning routine in model

“The number of blue-green algae cells in the water is approaching a dangerous level which may produce a destructive bloom and may result in an increase in the toxicity of the water to organisms in and around the river.”

2) If the available oxygen level drops below a certain value then:

<Script> Warning Routine in model

“The oxygen level is critically low and it may result in the death of many organisms in the river. Investigate the reasons for this drop in oxygen level and then take actions to improve the situation.

3) If Toxicity rating exceeds 5 say then:

<Script> Warning Routine in model

“The algal bloom that has developed in the river under the present conditions has the potential to produce toxic conditions which may effect organisms in and around the river. Fish may die and water users who come in contact with the water may become ill.”

4) If the River flow condition is set at low then:

<Script> Warning Routine in model

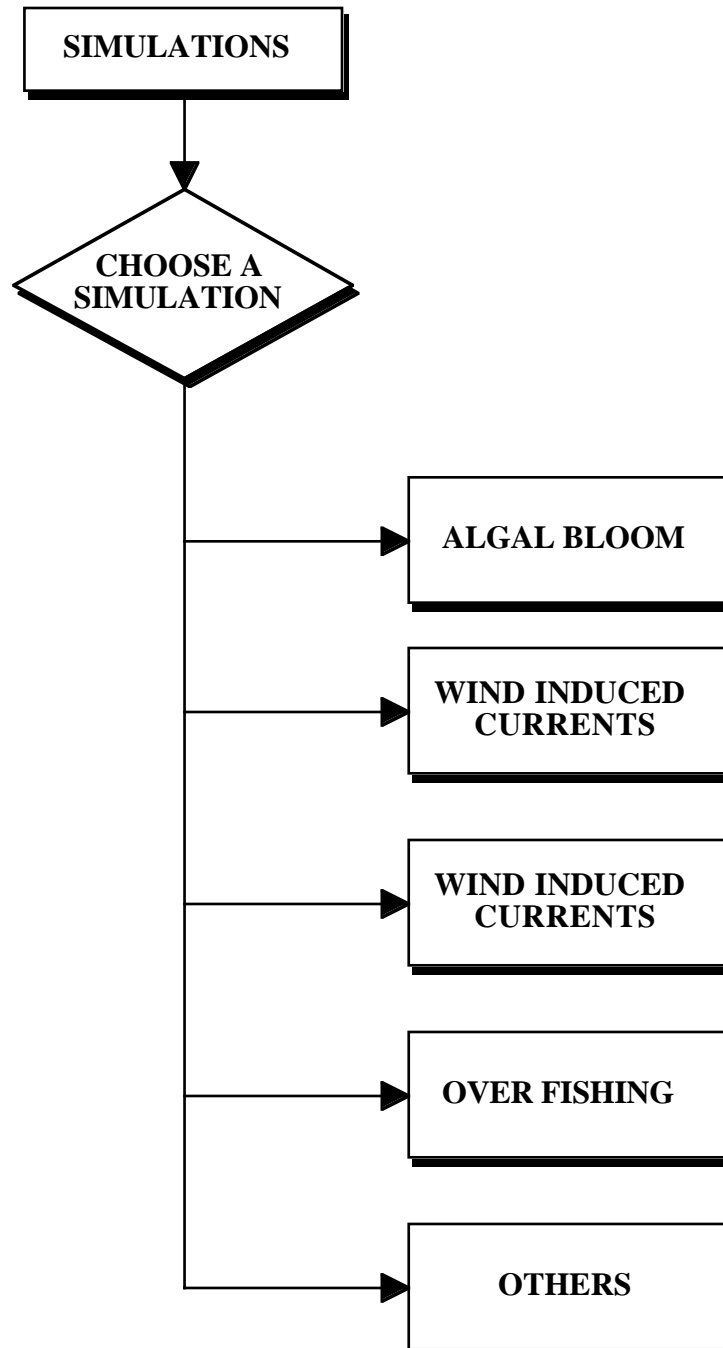
“The river may experience an algal bloom because of the low flow rate in the river.”

5) If the turbidity value exceeds 50% of the ‘normal’ value then:

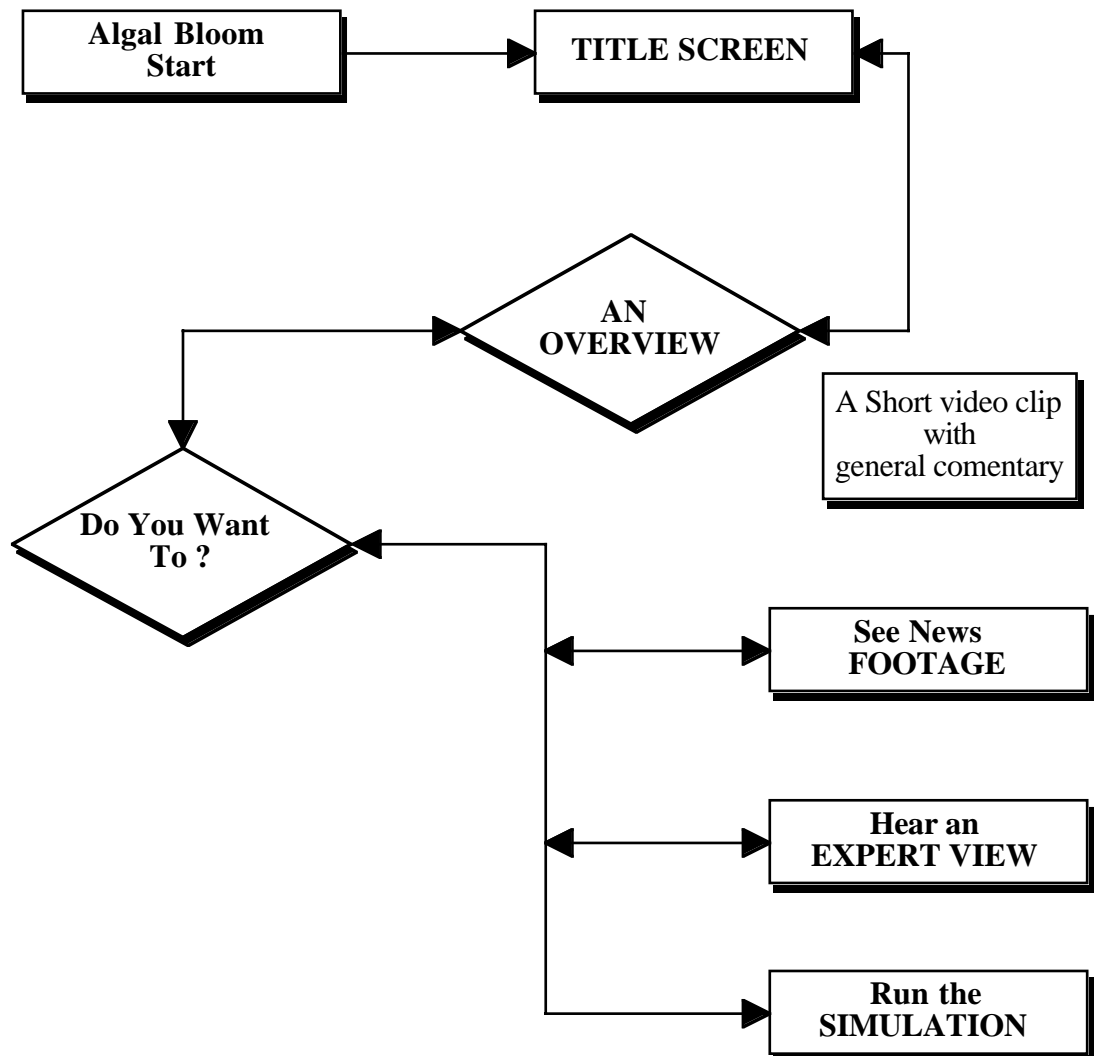
<Script> Warning Routine needed

“The turbidity of the river is increasing. This will lower the overall water quality and may result in an increase in the levels of nutrient in the water which may induce a significant algal bloom.”

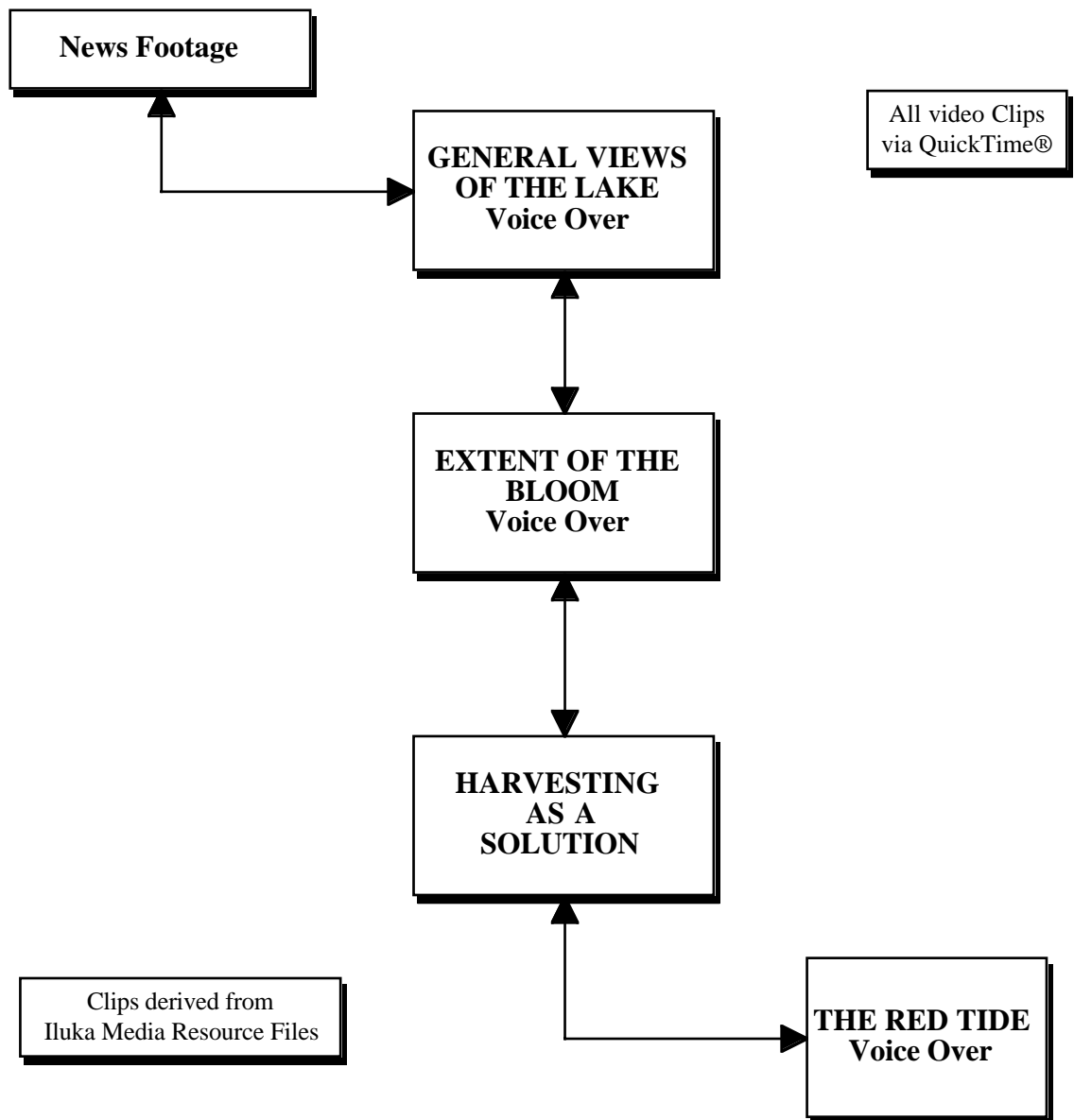
Flowcharts



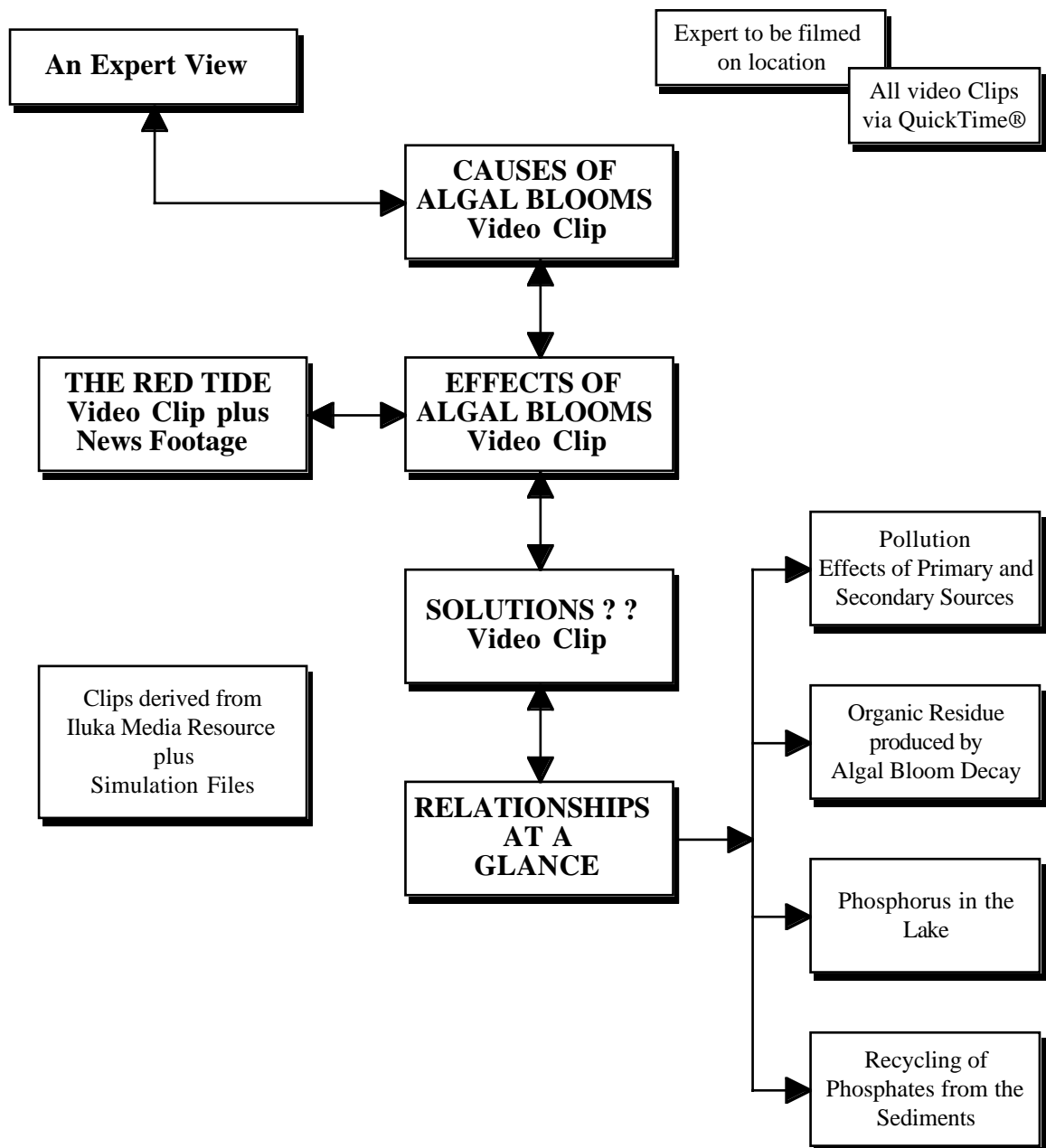
Flowchart (Simulation Structure) : Figure (1)



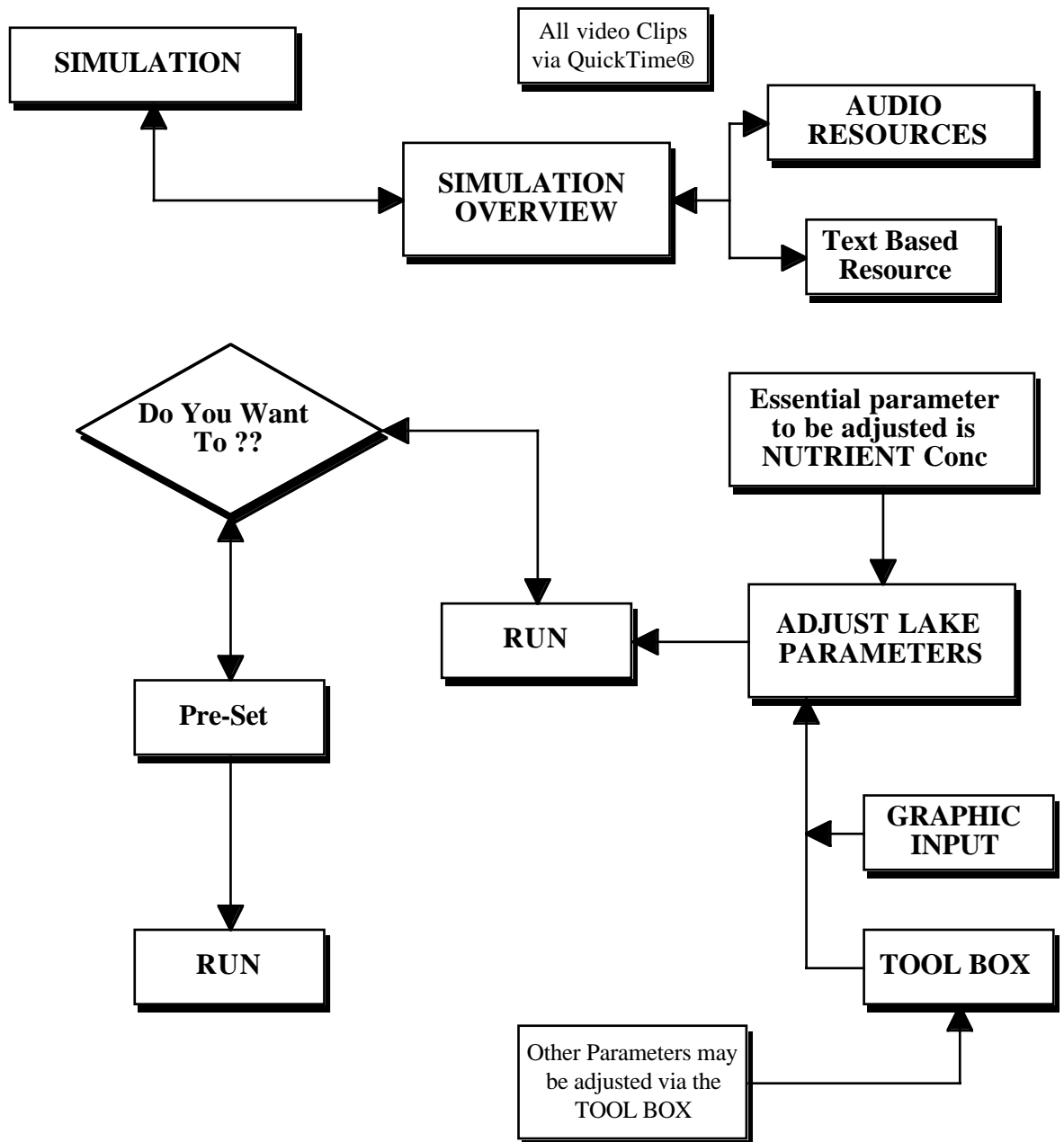
Flowchart (Simulation Structure) : Figure (2)



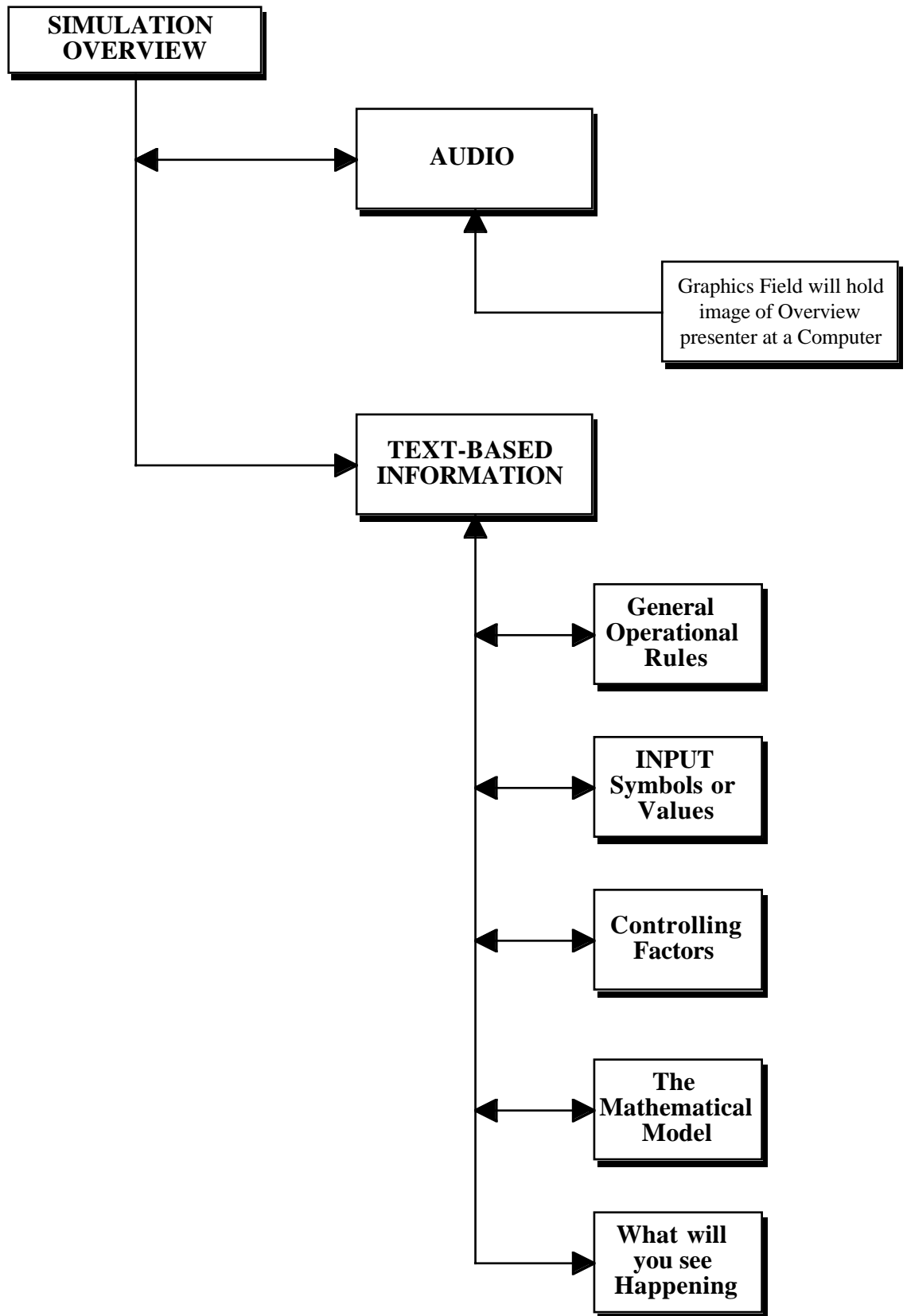
Flowchart (Simulation Structure) : Figure (3)



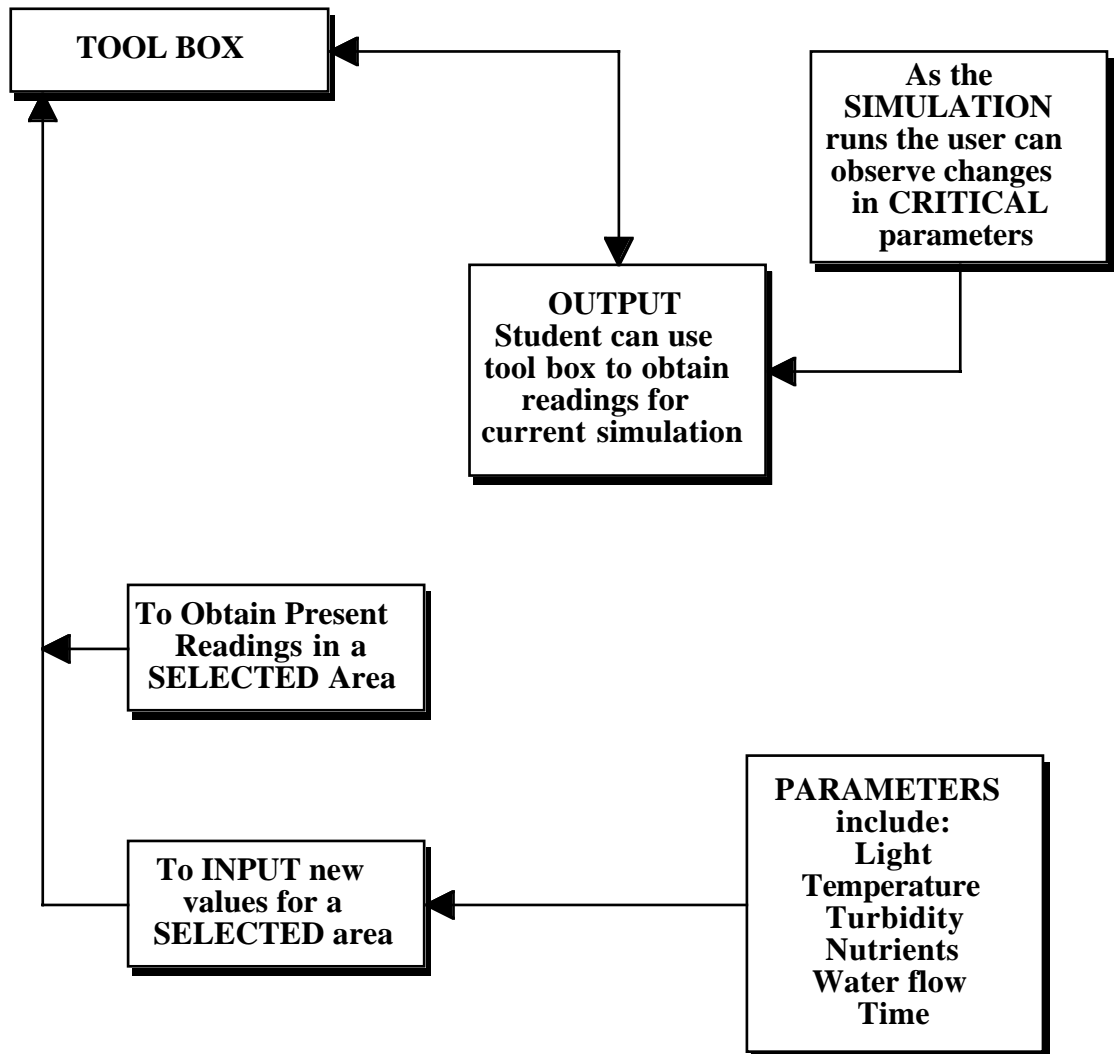
Flowchart (Simulation Structure) : Figure (4)



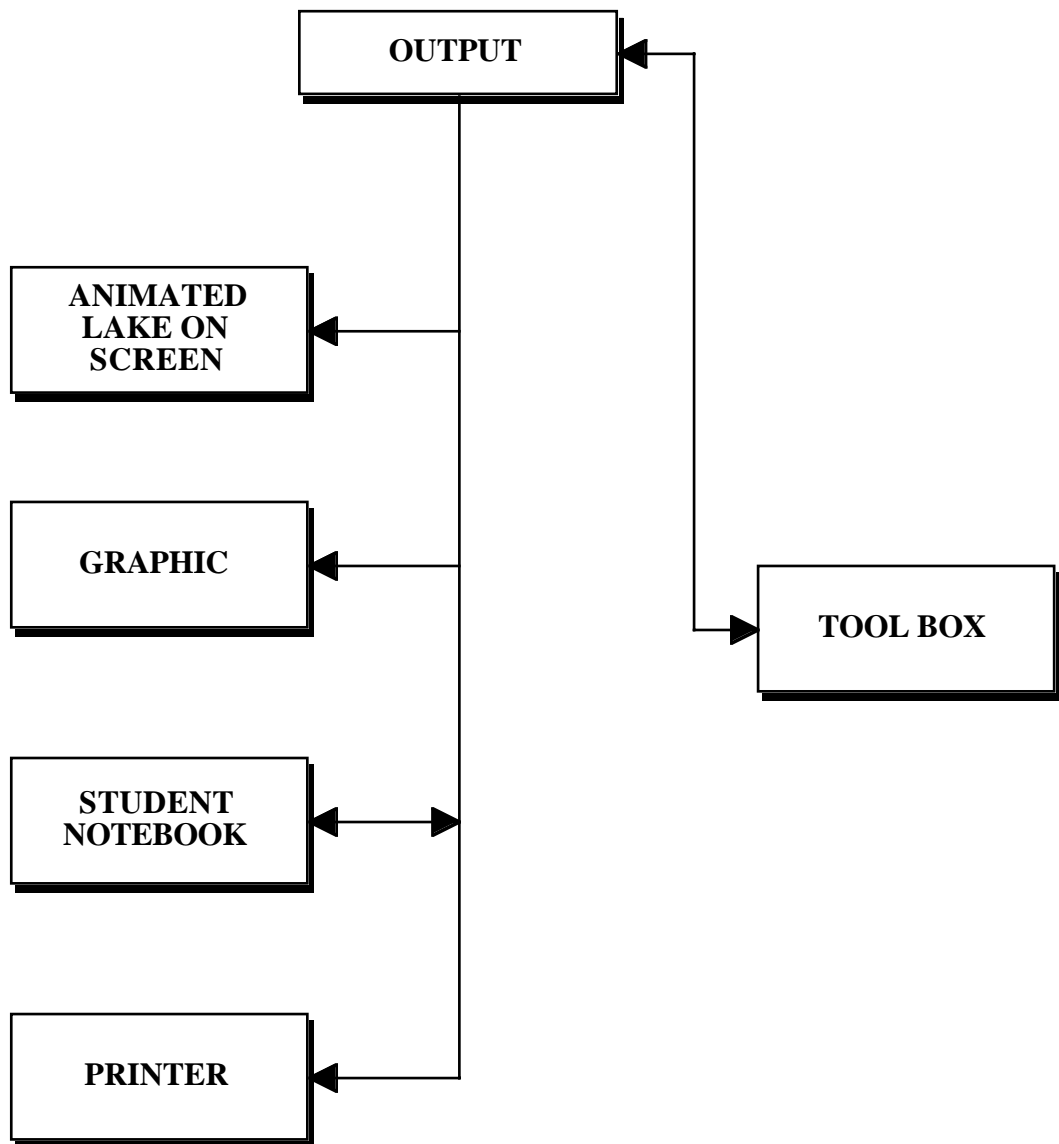
Flowchart (Simulation Structure) : Figure (5)



Flowchart (Simulation Structure) : Figure (6)

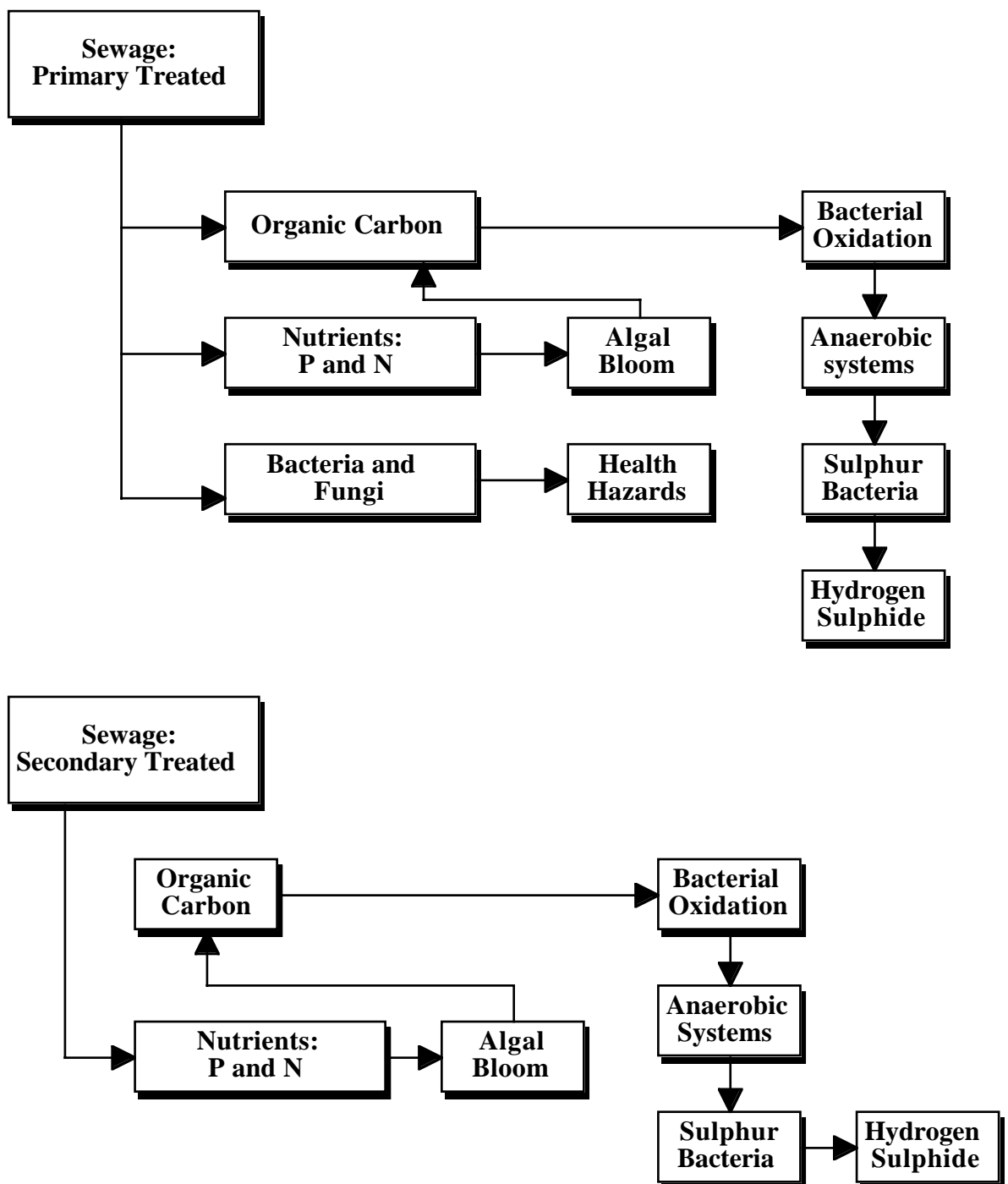


Flowchart (Simulation Structure) : Figure (7)



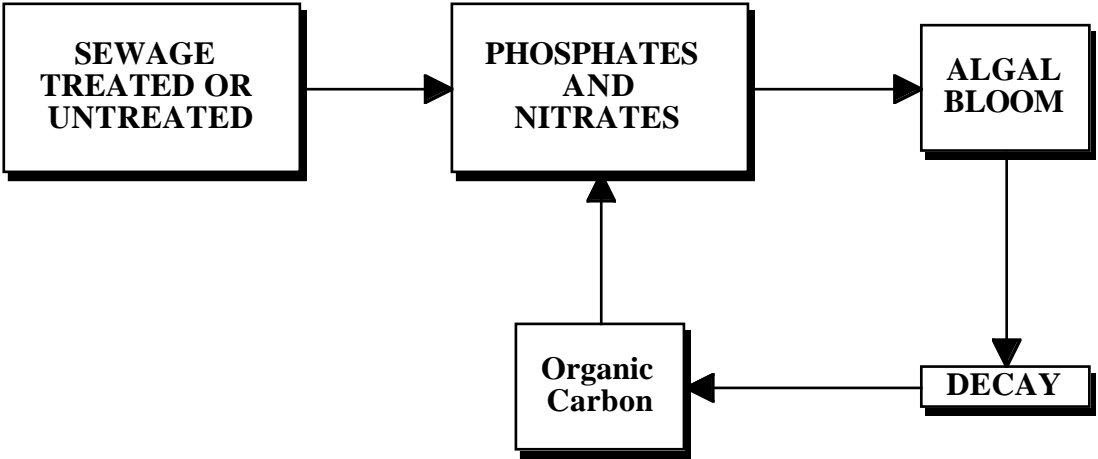
Flowchart (Simulation Structure) : Figure (8)

**RELATIONSHIPS IN EFFECTS OF
POLLUTION BY SEWAGE AFTER
PRIMARY OR SECONDARY
TREATMENT**
(After WWC Environmental Assessment)

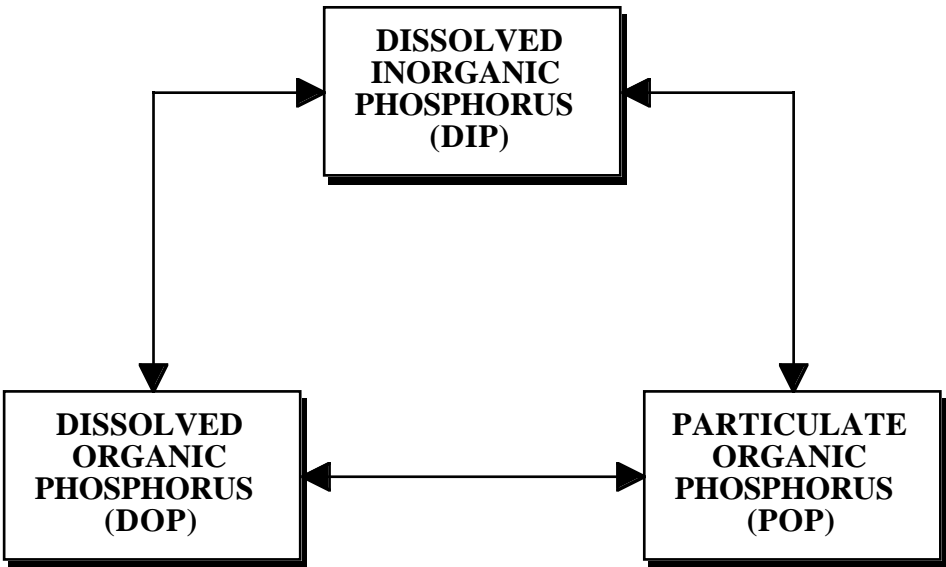


Flowchart (Simulation Structure) : Figure (9)

ORGANIC RESIDUES FROM ALGAL BLOOMS
(After WWC Environmental Assessment)

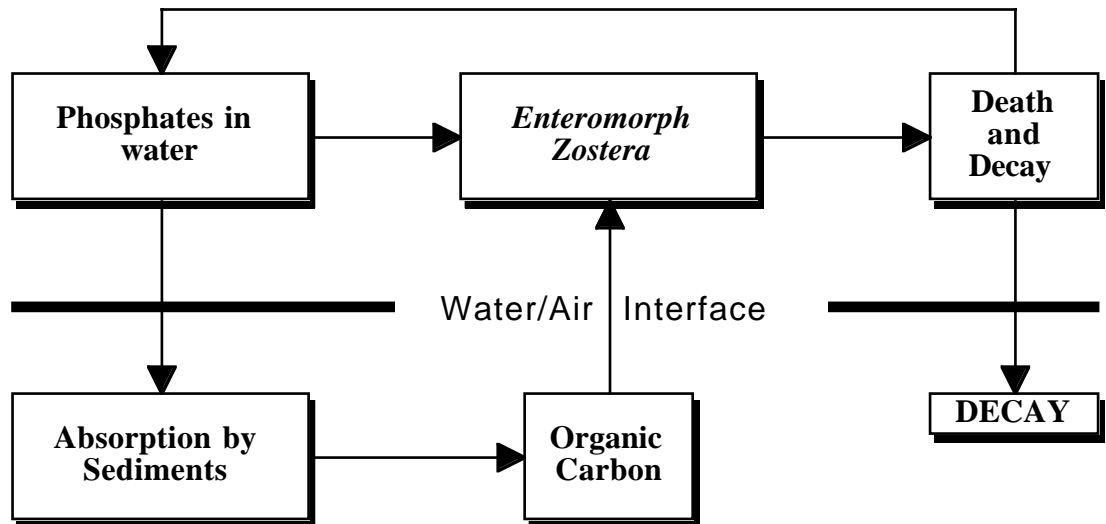


PHOSPHATES IN LAKES



Flowchart (Simulation Structure) : Figure (10)

**PLANT RECYCLING OF PHOSPHATES FROM
SEDIEMNTS
(After WWC Environmental Assessment)**



Flowchart (Simulation Structure) : Figure (11)

APPENDIX 3.9

Specific Help Hints

They are accessible in linear fashion through the WRC expert studying algal blooms by clicking on the person. The first is automatic and the others are successively revealed as more help is required.

- *There may be more than one contributor to the algal bloom problem.*

Character Script:

“You may be interested to know that last time I was in the area taking measurements, it was clear there was more than one major source of nutrients encouraging the bloom to grow.”

- *Find out which nutrients in the water seem to be associated with algal blooms.*

Character Script:

“My research has shown that algal blooms are closely associated with certain chemical nutrients that the activities of people and some industries produce. Make sure you take measurements in the river to find out what those chemicals are.”

- *Locate the possible sources of the nutrient problem by measuring the concentration of these nutrients along the river.*

Character Script:

“The chemicals that act as nutrients for the algal bloom can be found in many parts of the river. By measuring to find out where these chemicals are more concentrated, you should be able to locate some possible sources for the nutrients.”

- *Use the measurement tools to locate and record environmental data into your notes that you can experiment with in the Algal Bloom Simulator found in the Water Research Centre.*

Character Script:

“My colleague has developed an algal bloom simulation that you can experiment with. You may like to gather some measurements from the environment where the bloom is occurring and enter them into the simulator. It is very useful for seeing which conditions may cause the bloom to grow or die.”

- *Investigate the importance of river flow to algal bloom development.*

Character Script:

“When I was looking through the material on Algal Blooms in our filing cabinet I noticed that river flow rates are thought to have some effect on the algal bloom. You may like to use the algal bloom simulator to experiment with this idea.”

- *Algal blooms take varying periods of time to pass through different stages of development. This depends upon the mix of environmental conditions that exist. You may need to use the full extent of the simulator's time adjustment to see a complete pattern of algal bloom development.*

Character Script:

“The life cycle of algal blooms depends very much upon the existing environmental conditions over a period of time. Longer periods of time with a favourable mix of nutrients and environmental conditions can produce some interesting patterns. Keep this in mind if you decide to experiment with the algal bloom simulator.”

- *You may be able to find other material on algal blooms by making contact with your local water authority or investigating other sources of information in your library.*
- *There may be someone you know that has had some first hand experience with algal blooms with whom you could talk.*

Character Script:

“If you feel you’ve found all of the information available in our Water Research Centre and the Nardoo River area, you may be able to find other material on algal blooms by making contact with your local water authority or investigating other sources of information in your library. You may even know someone that has had some first hand experience with algal blooms with whom you could talk. Good luck.”

APPENDIX 3.10

Runtime Equations: Final Version of Iluka Engine

INIT Chlor'a' = 0

INIT Flush = 0

FlushPulse = IF(Flush=1)THEN(PULSE(1,2,1000))ELSE(0)

FlushFactor = FlushPulse

INIT Stream_Flow = 0

StreamMod = IF(Stream_Flow=0)THEN(0)ELSE

IF(Stream_Flow=1)THEN(.5)ELSE(1)

Loss_Factor_Chla = .22+(FlushFactor)+(StreamMod/20)

INIT TotalN = 0

Avail_LakeN = TotalN

INIT TotalP = 0

Avail_LakeP = TotalP

INIT StAlgaeConc = .0001

INIT Light_Level = 400

INIT Turbidity = 0

Pulse_fact = IF(FlushPulse=1)THEN(30)ELSE(0)

FlushT = IF(Pulse_fact=1)THEN(30)ELSE(0)

RFlowT = IF(StreamMod=.5)THEN(20)ELSE IF(StreamMod=1)THEN(28)ELSE(0)

Chlor'a'Tfactor = GRAPH(Chlor'a')

(0.00, 0.00), (0.007, 0.00), (0.014, 0.00), (0.021, 1.50), (0.028, 2.00), (0.035, 2.75),
(0.042, 4.25), (0.049, 6.75), (0.056, 14.8), (0.063, 33.8), (0.07, 49.8)

Total_Turbidity = Turbidity+FlushT+RFlowT+Chlor'a'Tfactor

Turbidity_Convertor = GRAPH(Total_Turbidity)

(0.00, 1.00), (4.17, 1.00), (8.33, 0.98), (12.5, 0.95), (16.7, 0.915), (20.8, 0.85), (25.0,
0.76), (29.2, 0.66), (33.3, 0.475), (37.5, 0.22), (41.7, 0.00), (45.8, 0.00), (50.0, 0.00)

Available_light = Light_Level*Turbidity_Convertor

Lux_Convertor = GRAPH(Available_light)

(10.0, 0.00), (50.8, 0.00), (91.7, 0.03), (132, 0.165), (173, 0.315), (214, 0.55), (255,
0.755), (296, 0.885), (337, 0.945), (378, 0.98), (418, 0.99), (459, 1.00), (500, 1.00)

INIT Water_Temperature = 21
 Temp_Convertor = GRAPH(Water_Temperature)
 (15.0, 0.075), (15.8, 0.37), (16.7, 0.68), (17.5, 0.89), (18.3, 0.965), (19.2, 0.98), (20.0, 0.99), (20.8, 1.00), (21.7, 1.00), (22.5, 1.00), (23.3, 1.00), (24.2, 1.00), (25.0, 1.00)

Growth = (((Avail_LakeN/720)+(Avail_LakeP/
 6.3)+StAlgaeConc)*Lux_Convertor)*Temp_Convertor)
 Rundown = Chlor'a'*Loss_Factor_Chla
 lossfactorN = .0806+(FlushFactor/.008)

INIT StNitrateConc = .2
 StFlowFn = IF(StreamMod=0)THEN(1) ELSE
 IF(StreamMod=.5)THEN(1.5)ELSE(1.8)
 StreamNconc = StNitrateConc*StFlowFn

EffectiveLakeN = GRAPH(StreamNconc)
 (0.00, 0.00), (0.0375, 0.054), (0.075, 0.108), (0.113, 0.144), (0.15, 0.174), (0.188, 0.201), (0.225, 0.224), (0.263, 0.237), (0.3, 0.257), (0.337, 0.267), (0.375, 0.282), (0.412, 0.292), (0.45, 0.3)

ReleaseNutrients = GRAPH(Total_Turbidity)
 (0.00, 0.00), (5.00, 0.00), (10.0, 0.005), (15.0, 0.01), (20.0, 0.02), (25.0, 0.035), (30.0, 0.075), (35.0, 0.145), (40.0, 0.26), (45.0, 0.555), (50.0, 1.00)

Washout_rate = IF(Stream_Flow=0)THEN(1)ELSE
 IF(Stream_Flow=1)THEN(.5)ELSE(.055)
 Inflow1 =
 (EffectiveLakeN+(ReleaseNutrients*0.01)+(Loss_Factor_Chla10))*Washout_rate
 Outflow1 = (Chlor'a'*60)*lossfactorN
 lossfactorP = .13+(FlushFactor/.008)
 INIT StPosphateConc = .03
 StreamPconc = StPosphateConc*StFlowFn

EffectiveLakeP = GRAPH(StreamPconc)
 (0.00, 0.00), (0.00667, 0.0076), (0.0133, 0.0156), (0.02, 0.0218), (0.0267, 0.0284), (0.0333, 0.0326), (0.04, 0.0348), (0.0467, 0.0372), (0.0533, 0.039), (0.06, 0.0396), (0.0667, 0.04), (0.0733, 0.04), (0.08, 0.04)
 Inflow2 = (EffectiveLakeP+(ReleaseNutrients*.1)+(Loss_Factor_Chla/100))*Washout_rate
 Outflow2 = (Chlor'a'*6.3)*lossfactorP
 Avail_Chlor'a' = Chlor'a'

OxygenUsage = GRAPH(IF(Avail_Chlor'a'<=.064)THEN(Avail_Chlor'a')ELSE(52))
 (0.00, 0.00), (0.00583, 0.00), (0.0117, 0.00), (0.0175, 1.00), (0.0233, 3.50), (0.0292,
 9.00), (0.035, 16.0), (0.0408, 23.5), (0.0467, 32.5), (0.0525, 39.0), (0.0583, 46.0),
 (0.0642, 52.0), (0.07, 55.5)

Avail_oxygen = DELAY(100-OxygenUsage,2.5)

Toxicity_Rating = GRAPH(DELAY(Avail_Chlor'a',5))
 (0.00, 0.00), (0.007, 0.3), (0.014, 0.45), (0.021, 0.8), (0.028, 2.00), (0.035, 3.25), (0.042,
 4.35), (0.049, 5.85), (0.056, 8.70), (0.063, 10.0), (0.07, 10.0)

Runtime Equations

Chlor'a'(t) = Chlor'a'(t - dt) + (Growth - Rundown) * dt

Flush(t) = Flush(t - dt)

Stream_Flow(t) = Stream_Flow(t - dt)

TotalN(t) = TotalN(t - dt) + (Inflow1 - Outflow1) * dt

TotalP(t) = TotalP(t - dt) + (Inflow2 - Outflow2) * dt

StAlgaeConc(t) = StAlgaeConc(t - dt)

Light_Level(t) = Light_Level(t - dt)

Turbidity(t) = Turbidity(t - dt)

Water_Temperature(t) = Water_Temperature(t - dt)

StNitrateConc(t) = StNitrateConc(t - dt)

StPhosphateConc(t) = StPhosphateConc(t - dt)

FlushPulse = IF(Flush=1)THEN(PULSE(1,2,1000))ELSE(0)

FlushFactor = FlushPulse

StreamMod = IF(Stream_Flow=0)THEN(0)ELSE

IF(Stream_Flow=1)THEN(.5)ELSE(1)

Loss_Factor_Chla = .22+(FlushFactor)+(StreamMod/20)

Avail_LakeN = TotalN

Avail_LakeP = TotalP

Pulse_fact = IF(FlushPulse=1)THEN(30)ELSE(0)

FlushT = IF(Pulse_fact=1)THEN(30)ELSE(0)

RFlowT = IF(StreamMod=.5)THEN(20)ELSE IF(StreamMod=1)THEN(28)ELSE(0)

Chlor'a'Tfactor = GRAPH(Chlor'a')

(0.00, 0.00), (0.007, 0.00), (0.014, 0.00), (0.021, 1.50), (0.028, 2.00), (0.035, 2.75),
 (0.042, 4.25), (0.049, 6.75), (0.056, 14.8), (0.063, 33.8), (0.07, 49.8)

Total_Turbidity = Turbidity+FlushT+RFlowT+Chlor'a'Tfactor

Turbidity_Convertor = GRAPH(Total_Turbidity)

(0.00, 1.00), (4.17, 1.00), (8.33, 0.98), (12.5, 0.95), (16.7, 0.915), (20.8, 0.85), (25.0,
 0.76), (29.2, 0.66), (33.3, 0.475), (37.5, 0.22), (41.7, 0.00), (45.8, 0.00), (50.0, 0.00)

Available_light = Light_Level*Turbidity_Convertor

Lux_Convertor = GRAPH(Available_light)

(10.0, 0.00), (50.8, 0.00), (91.7, 0.03), (132, 0.165), (173, 0.315), (214, 0.55), (255,
 0.755), (296, 0.885), (337, 0.945), (378, 0.98), (418, 0.99), (459, 1.00), (500, 1.00)

```

Temp_Convertor = GRAPH(Water_Temperature)
(15.0, 0.075), (15.8, 0.37), (16.7, 0.68), (17.5, 0.89), (18.3, 0.965), (19.2, 0.98), (20.0,
0.99), (20.8, 1.00), (21.7, 1.00), (22.5, 1.00), (23.3, 1.00), (24.2, 1.00), (25.0, 1.00)
Growth = (((Avail_LakeN/720)+(Avail_LakeP/
6.3)+StAlgaeConc)*Lux_Convertor)*Temp_Convertor)
Rundown = Chlor'a'*Loss_Factor_Chla
lossfactorN = .0806+(FlushFactor/.008)
StFlowFn = IF(StreamMod=0)THEN(1) ELSE
IF(StreamMod=.5)THEN(1.5)ELSE(1.8)
StreamNconc = StNitrateConc*StFlowFn
EffectiveLakeN = GRAPH(StreamNconc)
(0.00, 0.00), (0.0375, 0.054), (0.075, 0.108), (0.113, 0.144), (0.15, 0.174), (0.188,
0.201), (0.225, 0.224), (0.263, 0.237), (0.3, 0.257), (0.337, 0.267), (0.375, 0.282),
(0.412, 0.292), (0.45, 0.3)
ReleaseNutrients = GRAPH(Total_Turbidity)
(0.00, 0.00), (5.00, 0.00), (10.0, 0.005), (15.0, 0.01), (20.0, 0.02), (25.0, 0.035), (30.0,
0.075), (35.0, 0.145), (40.0, 0.26), (45.0, 0.555), (50.0, 1.00)
Washout_rate = IF(Stream_Flow=0)THEN(1)ELSE
IF(Stream_Flow=1)THEN(.5)ELSE(.055)
Inflow1 = (EffectiveLakeN+(ReleaseNutrients*0.01)+(Loss_Factor_Chla/
10))*Washout_rate
Outflow1 = (Chlor'a'*60)*lossfactorN
lossfactorP = .13+(FlushFactor/.008)
StreamPconc = StPosphateConc*StFlowFn
EffectiveLakeP = GRAPH(StreamPconc)
(0.00, 0.00), (0.00667, 0.0076), (0.0133, 0.0156), (0.02, 0.0218), (0.0267, 0.0284),
(0.0333, 0.0326), (0.04, 0.0348), (0.0467, 0.0372), (0.0533, 0.039), (0.06, 0.0396),
(0.0667, 0.04), (0.0733, 0.04), (0.08, 0.04)
Inflow2 = (EffectiveLakeP+(ReleaseNutrients*.1)+(Loss_Factor_Chla/
100))*Washout_rate
Outflow2 = (Chlor'a'*6.3)*lossfactorP
Avail_Chlor'a' = Chlor'a'
OxygenUsage = GRAPH(IF(Avail_Chlor'a'<=.064)THEN(Avail_Chlor'a')ELSE(52))
(0.00, 0.00), (0.00583, 0.00), (0.0117, 0.00), (0.0175, 1.00), (0.0233, 3.50), (0.0292,
9.00), (0.035, 16.0), (0.0408, 23.5), (0.0467, 32.5), (0.0525, 39.0), (0.0583, 46.0),
(0.0642, 52.0), (0.07, 55.5)
Avail_oxygen = DELAY(100-OxygenUsage,2.5)
Toxicity_Rating = GRAPH(DELAY(Avail_Chlor'a',5))
(0.00, 0.00), (0.007, 0.3), (0.014, 0.45), (0.021, 0.8), (0.028, 2.00), (0.035, 3.25), (0.042,
4.35), (0.049, 5.85), (0.056, 8.70), (0.063, 10.0), (0.07, 10.0)

```

General Interface Design Issues

Based on generic interface, 460x352 pixel's allowing room for PDA on RHS

Operation: Run, Stop and Rest buttons provided together with output display option.

Run /Stop provides control over period of simulation. Elapsed time displayed

Reset clears all data and output values

Time interval: set within model @ 1 week intervals with 0.15 increments.

Run time user definable. Total elapsed time could be displayed in window on interface and/or on axis of graphic read-out where appropriate.

Navigation: Icon corresponding to simulation. Click on display screen to select for copy and to 'go back'.

Display: select using button between animated and graph.

Aims:

- Provide a 'non-predictive' model of algal bloom
- Provide the user with a system which allows the manipulation of key river parameters (concentration of N and P, the temperature of the water, the input of water and the light levels) and the simulation of the growth of an algal bloom
- Provide to develop in the user an understanding of the factors involved in the development of an algal bloom.
- Provide support for the users investigation into river conditions and the associated problems.
- Provide feedback relating to prevention and management of an algal bloom.

Expected Outcomes:

- The user will be able observe the development of an algal bloom having manipulated the status of key factors (P and N conc, temp and light levels) in the river.

- The user will develop an understanding of the relationships between these key factors and the process of algal bloom.
- The user will have practice in decision making via a choice of actions.
- The user will be able to collect data from the simulation via the PDA for further investigation.

Operational Considerations:

Input:

Data points for each of the key factors will be embedded in the screen depiction of the catchment. The default values for each key factor will be zero, thus users must actually collect data from the screen or enter their own values for the simulation to run. These embedded 'default values' might produce a 'moderate' algal bloom spread. Data entry via 'River conditions' panel which will provide adjustments for each of the major parameters. The maximum and minimum values will be set as end points on the value adjusters.

Units are important and indicated on the panel

Output:

Three formats, numeric, graphic, animated

Numeric Option

An 'output panel exists in the lower RH corner of the simulator.

The values indicated here are max and min values for the key factors, N conc, P conc, Algal bloom and oxygen availability

Note that in this model, the measure of algal bloom is the concentration of chlorophyll 'a' in the water column rather than a biomass measure, hence the units $\mu\text{g/l}$. If biomass measures are needed then there are relationships which allow this to be equated to biomass. Such manipulation can be hidden within the structure.

Graphic option selected: A graph is developed, adjusted to the take advantage of the complete display area depending on the time span selected for the simulation.

Display Screen:

Default ‘ stylised catchment

Animate option selected will provide a zoom view of an area of the river.

During the simulation run, the algal bloom will be represented by a spread of colour from the edges of the river.

Graph option selected will provide a representation of the data in graph form over a dimmed image of the default screen thus facilitating the return to the default screen direct from the simulation.

Copy Data:

Clicking on the display screen will produce a highlight frame around the screen. It may then be copied via the copy button on the PDA. This will be functional for the animated screen, the graph based screen and the maximum-minimum panel in the lower RH corner.

Talking Head Feedback:

Located in top RHS of display screen

Will operate after simulation run regardless of the display mode chosen

Triggers—

If default values are used and a moderate algal bloom develops then talking head will appear:

“The current levels of nutrients in the river are sufficient to produce a significant bloom. Explore the effect that altering the river conditions has on the bloom. You might like to start by changing the levels of nutrients in the water.”

If values set produce minimal algal bloom then talking head will appear:

“The conditions in the river are excellent at the moment. This is the ideal situation for all waterways. Investigate and determine the factors which have most control over the development of algal bloom.”

If values produce maximum algal bloom then talking head will appear:

“The river is in a state of eutrophication and this will have a significant effect on all who depend on it. You need to consider the actions needed to minimise this bloom.”

Expected pattern of use:

Problem -

On selection of the simulator in the WRC, the generic simulator will open.

The display screen will contain a graphic of the entire catchment area

The control panel, including the ‘simulation choice’ buttons will be visible.

The area of the simulator in which data is entered and displayed will contain some blurred indistinct representation of input and output boxes and controls which will be covered with a semi transparent cover. When a simulation is selected by pressing the appropriate button, this cover slides out of the way to reveal the appropriate controls etc and the display screen displays the appropriate graphic.

On selection of the ‘algal bloom’ icon, the display screen will default to a stylised image of the whole catchment. All values will be set to zero.

User may then decide to alter variables or click on the area and **collect values** for each variable by **selecting it and clicking**. The value will then appear in the appropriate box in the ‘River Conditions’ panel.

In the simulation control panel, the user then **sets the number of weeks** over which the simulation is to run and presses the run button.

Screen animates or graph builds.

Weeks tick over and numerical values of output appear in the boxes in the lower region of the simulator panel.

The user may **run the simulation in either display mode**, or one may select either display mode after the simulation is complete and obtain the information pertaining the current simulator setting.

Depending on feedback about the results:

The user may be directed to explore methods of minimising water use or attempt to improve already 'good practice' and minimise cost.

Changing simulations:

Another simulation may be accessed at any time by selecting the appropriate button. When this is done, the cover will slide over the variables panel and the default 'catchment area' graphic will appear. It will then reopen to reveal the newly selected simulation.

Detailed Operational Considerations

Generic Simulator:

Appearance:

Simulator will have its input and output panels covered before a simulation is selected. Only the screen and control panel will be visible.

Introduction script #2 'generic interface' will play in conjunction with a cameraman movie on opening the simulator and then screen will zoom back to some form of cover panel with inscription "Nardoo Simulator ????" and a small version of the talking head window insert

On opening:

- input / output areas are uncovered
- each simulation has its own how to script (see below)

Algal Bloom:

How to use script:

Play in conjunction with a cameraman movie when simulator first accessed.

Click to stop How to use script:

Inputs required:

- Ambient Light
- River Water temperature
- River Flow level
- River Flush
- River Nitrate concentrations
- River Phosphate concentrations
- River Algal cell concentrations
- Time for simulation run

Outputs required:

- Maximum / minimum algae cell count
- Total River Nitrogen
- Total River Phosphorus
- Maximum / Minimum Nitrogen concentration
- Maximum / Minimum Available oxygen
- Toxicity rating
- Plus those tagged for display on general control panel

The responses listed below were to be 'Talking Head' feedback. Unfortunately as mentioned elsewhere they were not implemented in this version. These scripts would have greatly enriched the experience for simulator users. Their content is presented in Appendix 3.7

- Outcome Response: Minimal bloom (script #1)
- Outcome Response: Moderate Bloom(script #2)
- Outcome Response: Dangerous bloom(script #3)
- Triggered responses: Algal cell count becoming excessive(script #1)
- Triggered responses: Available oxygen at critical level(script #2)
- Triggered responses: Toxicity rating becoming dangerous(script #3)
- Triggered responses: River flow set at low(script #4)
- Triggered responses: Turbidity excessive(script #5)

General Control Panel Functions and Operation:**Inputs**

On opening simulation, default settings for each input will be present. If run is selected without any manipulation, a significant bloom will be produced. This will act as a reference point.

P and N concentrations

If as collected embedded data from the environment then these values will be inserted in the PDA and retrieved by the student and entered manually. Otherwise the user may simply enter any data within the pre-set, constrained ranges.

(see model)

Turbidity

Always a default value linked to both **river flow and flush** and/or can be manually adjusted to explore relationships

Light, Temperature, River flow level and flush(on/off)

Set manually

Display

River Conditions

Entered data remains current until simulation re-set when default data will reappear and screen will return to its original/pristine condition

Other

At the end of a simulation run, the maximum and minimum values indicated will be displayed

Copy Data

Animated screen

Select simulator screen - current data on River conditions and Max/Min values will be copied to PDA

Graph Screen

Select simulator screen - graph (as a pict file) plus current data on River conditions and Max/Min values will be copied to PDA

Other

In this simulation, the user may choose to pause at any time and then continue by releasing the pause button

Stop to end the simulation and it must be restarted by pressing run. All run data is deleted.

Reset clears the simulation of all data from the last run.

Simulator Screen

Refreshed with each simulation run. (pristine river)

Simulator Screen Actions:

Animated Screen

River starts in a pristine condition (all developments in place but river free of algae). By using the simulator and the environmental conditions the user can then simulate the outcome of measurements made in the environment or can enter data and simulate the expected outcome

Bloom

- colour intensity changes with algal cell count
- area covered changes with algal cell count

If Flush selected (note that this is a delayed action)

- bloom develops according to data in use and is then removed by flush
- river changes to a milk coffee colour in a streaky fashion
- apparent movement of water

Set Flow level

Low

- no water movement
- actions of bloom conditions activated

Moderate

- apparent water movement, colour swirls, objects moving down stream
- bloom development less apparent (more along edges and patchy)

High

- greater apparent movement, muddy areas of colour change and colour swirls move quickly down the river
- Bloom does not develop

Graph Screen

Graph on same axis

- Algal cell count
- Total P concentration
- Total N concentration
- Available oxygen
- Toxicity Rating

Talking Heads:

An **OUTCOME** script will run at the end of each run of the simulation within the simulator display screen (See Talking Head scripts Appendix 3.7)

TRIGGERED scripts will occur during a triggered pause (button displays depressed) in the simulation run. (See Talking Head Scripts)

Continuation of the run will be achieved by clicking the pause button off.

Output triggers are listed above

Model Base Parameters

Physical

Depth: 0 to 1.5 metres

Light Level: 10 to 500 lux

Temperature: 12° to 25°C

Turbidity: 0 to 500 (NTU)

Flush: On/OFF (acts as a pulse)

River Flow: Low/Medium/High

Time: 1 to 30 weeks

Chemical

River Nitrate concentration: 10 to 2000 µg/l

River Phosphate concentration: 10 to 5000 µg/l

Simulator Expected Value range

Outputs:

Algal cell mass: 0 to 35,000 cells/ml

Oxygen % Available: 45% to 100%

Toxicity Rating: 0 to 10 (Relative scale)

Algal bloom levels

Cell mass > 30,000 cells/ml (DANGEROUS)

Cell mass > 25,000 cells/ml (SIGNIFICANT)

Cell mass > 15,000cells/ml (NUISANCE)

Cell mass < 10,000 cells/ml (MINOR)

Eutrophication will occur when the algal cell count exceeds 25,000 cells/ml

Preset simulator input values:

Light level: 400 lux

Temperature: 21°C

Turbidity: 0

Flush: OFF

River flow: Low

Time: 15 weeks

River Nitrate concentration: 2000 µg/L

River Phosphate concentration: 3000 µg/L

Expected Algal Cell count: >30,000 cells/ml

Initialization Equations

INIT Algae = 0

INIT TotalN = .25

Avail_RiverN = TotalN

INIT Flush =

FlushPulse = IF(Flush=1)THEN(PULSE(1,2,1000))ELSE(0)

FlushFactor = FlushPulse

INIT River_Flow = 0

DOCUMENT: Riverflow will operate as a sliding scale. Nil (value input = 0), low (value input = 0 to 2), Medium (value input = 3 to 5), High (value input = 6 to 7) and Flood(value input 8 to 10)

RiverMod = IF(River_Flow=0)OR(River_Flow<=100)THEN(0) ELSE

IF(River_Flow=101)OR(River_Flow<=250)THEN(.25)ELSE

IF(River_Flow=251)OR(River_Flow<=500)THEN(.5)ELSE

IF(River_Flow=501)OR(River_Flow<=700)THEN(.85)ELSE(1)

INIT TotalP = .04

Avail_RiverP = TotalP

Loss_Factor_Chla=IF(Avail_RiverN<=0.01)THEN(.22+(FlushFactor)+(RiverMod/20)+1)

ELSE IF(Avail_RiverP<=0.01) THEN(.22+(FlushFactor)+(RiverMod/20)+.9)

ELSE(.22+(FlushFactor)+(RiverMod/20))

INIT RiverAlgaeConc = .0001

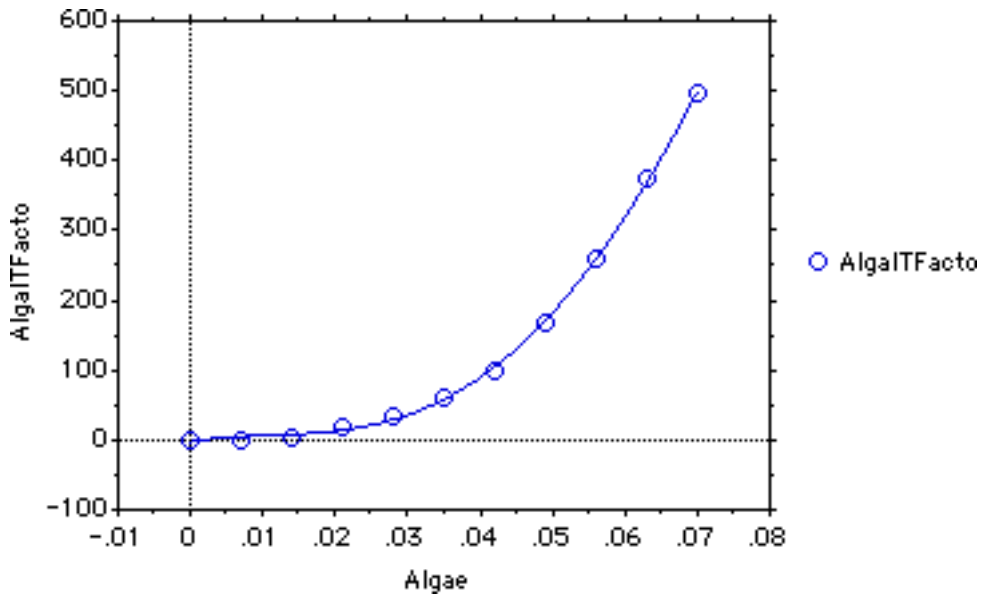
INIT Ambient_Light_Level = 400

INIT IndepTurbidity = 0

FlushT = IF(FlushPulse=1)THEN(350)ELSE(0)

RFlowT = IF(RiverMod=.5)THEN(298)ELSE IF(RiverMod=1)THEN(350)ELSE(0)

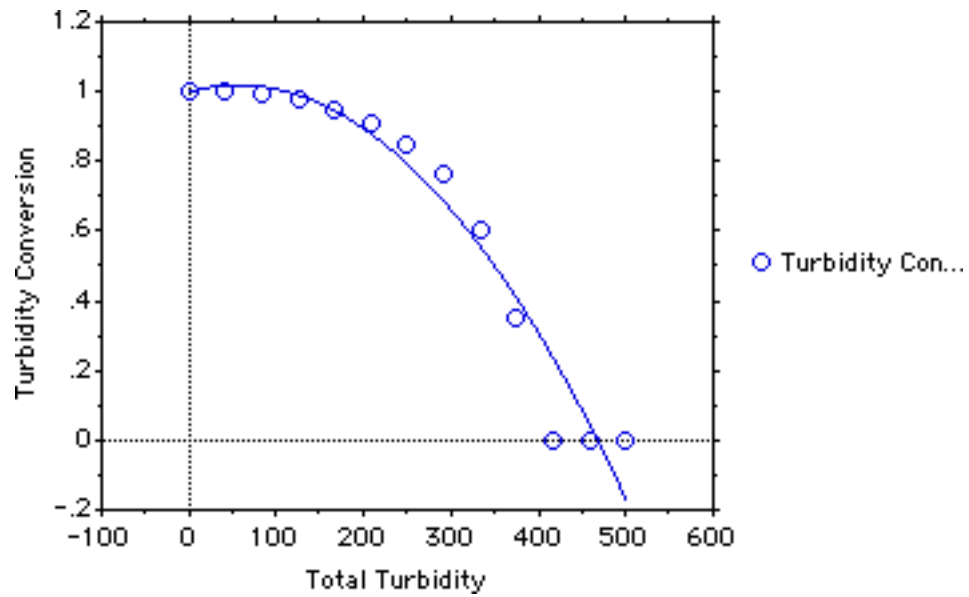
AlgaeTfactor = GRAPH(Algae)



EQUATION: $y = .185 - 6.938x + 243.804x^2 + 142431.265x^3$

Total_Turbidity = IndepTurbidity+FlushT+RFlowT+AlgaeTfactor

Turbidity_Convertor = GRAPH(Total_Turbidity)

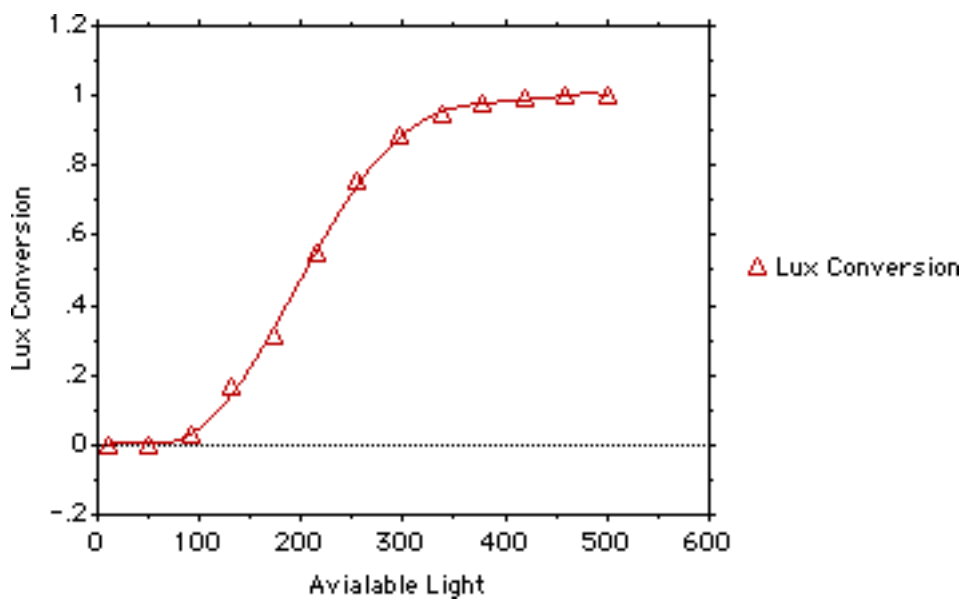


EQUATION: $y=1.036-0.003x-4.287E-4x^2$

TCLimit = IF(Turbidity_Convertor>=0)THEN(Turbidity_Convertor)ELSE(0)

Available_light = Ambient_Light_Level*TCLimit

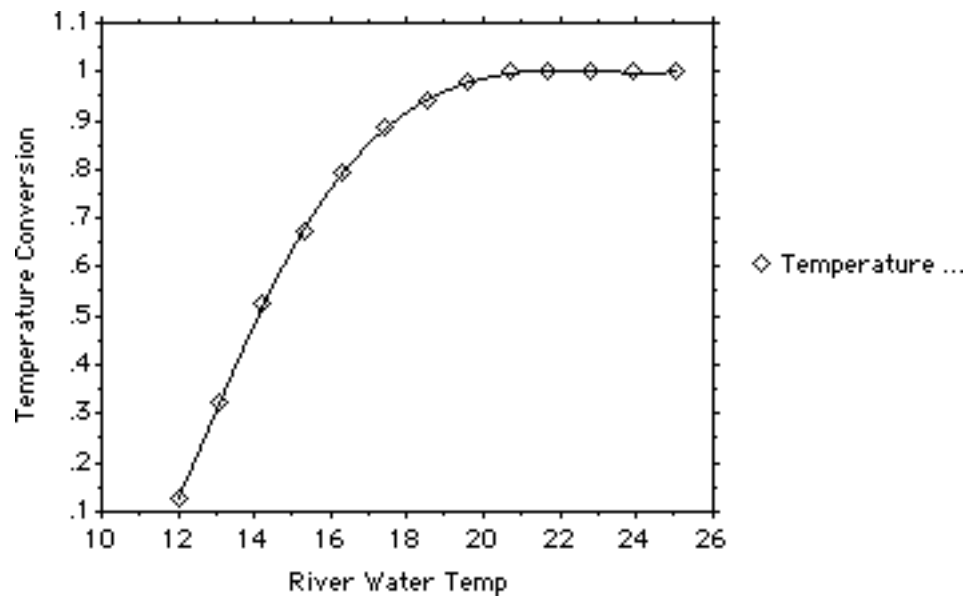
Lux_Convertor = GRAPH(Available_light)



EQUATION: $y = -0.026 + 0.003x - 8.843E-5x^2 + 9.230E-7x^3 - 3.553E-9x^4 + 5.898E-12x^5 - 3.598E-15x^6$

INIT RiverWater_Temperature = 21

Temp_Convertor = GRAPH(RiverWater_Temperature)



EQUATION: $y = -7.659 + 1.135x - 0.049x^2 + 0.001x^3$

$$\text{Growth} = (((\text{Avail_RiverN}/100) + (\text{Avail_RiverP} \cdot 6.3) + \text{RiverAlgaeConc}) * \text{Lux_Convertor}) * \text{Temp_Convertor})$$

$$\text{Rundown} = \text{Algae} * \text{Loss_Factor_Chla}$$

$$\text{Washout_rate} = \text{IF}(\text{River_Flow}=0) \text{OR} (\text{River_Flow} \leq 2) \text{ THEN } (0) \text{ ELSE}$$

$$\text{IF}(\text{River_Flow}=3) \text{OR} (\text{River_Flow} \leq 5) \text{ THEN } (.5) \text{ ELSE}$$

$$\text{IF}(\text{River_Flow}=6) \text{OR} (\text{River_Flow} \leq 8) \text{ THEN } (.75) \text{ ELSE } (1)$$

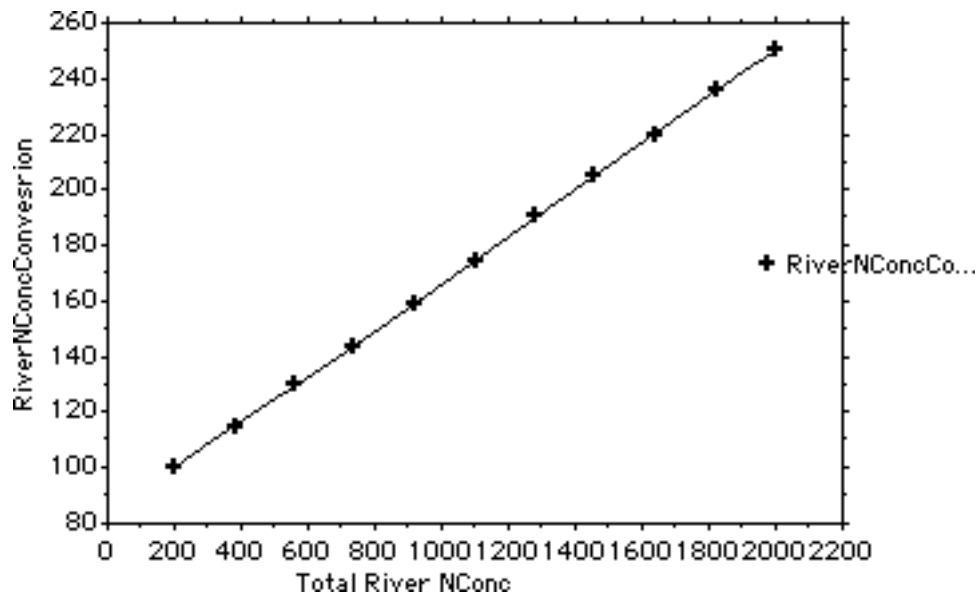
$$\text{lossfactorN} = .0806 + (\text{FlushFactor}/.008) + (\text{Washout_rate} * 6)$$

$$\text{INIT River_NitrateConc} = 2000$$

$$\text{RiverNconc} = 0$$

$$\text{Total_River_Nconc} = \text{River_NitrateConc} + \text{RiverNconc}$$

$$\text{RiverNconcConvert} = \text{GRAPH}(\text{Total_River_Nconc})$$



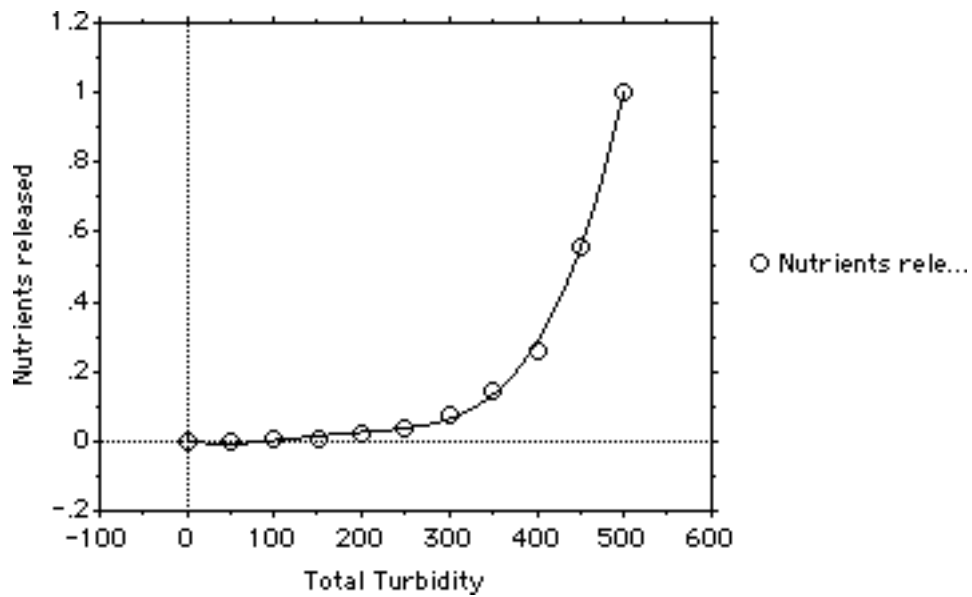
EQUATION: $y = 0.084x + 82.833$

RNtrateLimit = IF(RiverNconcConvert<=250)THEN(RiverNconcConvert)ELSE(250)

DOCUMENT: Limiting values placed to ensure model does not over-run

AbsModelNconc = RNtrateLimit/1000

ReleaseNutrients = GRAPH(Total_Turbidity)



EQUATION: $y=2.430E-4+1.977E-4x-7.168E-5x^2+1.408E-5x^3-6.351E-7x^4+1.082E-8x^5$

$\text{NutrientInflowN} = (\text{AbsModelNconc} + (\text{ReleaseNutrients} * 0.01) + (\text{Loss_Factor_Chla} / 10))$

$\text{NutrientOutflowN} = (\text{Algae} * 80) * \text{lossfactorN}$

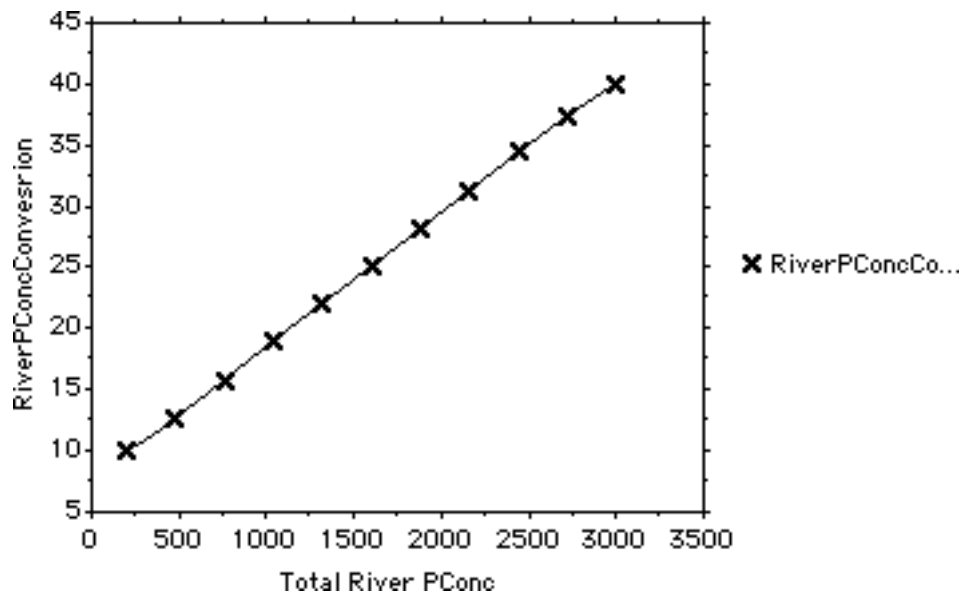
$\text{lossfactorP} = .13 + (\text{FlushFactor} / .008) + (\text{Washout_rate} * 8)$

$\text{INIT River_PosphateConc} = 3000$

$\text{RiverPconc} = 0$

$\text{Total_River_Pconc} = \text{River_PosphateConc} + \text{RiverPconc}$

$\text{RiverPconcConvert} = \text{GRAPH}(\text{Total_River_Pconc})$



EQUATION: $y = 0.011x + 7.695$

RPosphateLimit = IF(RiverPconcConvert<=40)THEN(RiverPconcConvert)ELSE(40)

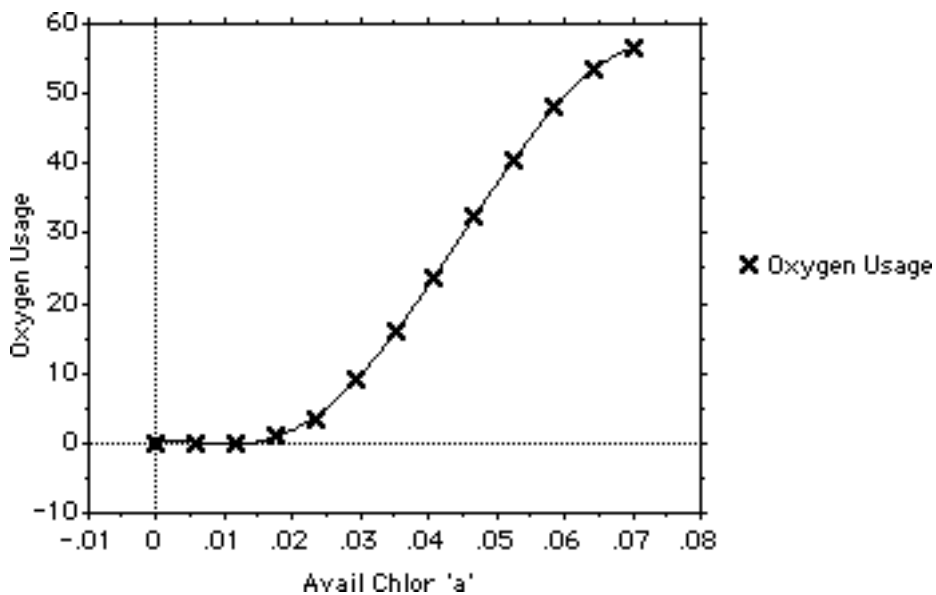
AbsModelPconc = RPosphateLimit/1000

NutrientInflowP = (AbsModelPconc+(ReleaseNutrients*0.001)+(Loss_Factor_Chla/100))

NutrientOutflowP = (Algae*6.3)*lossfactorP

Avail_Chlor'a' = Algae

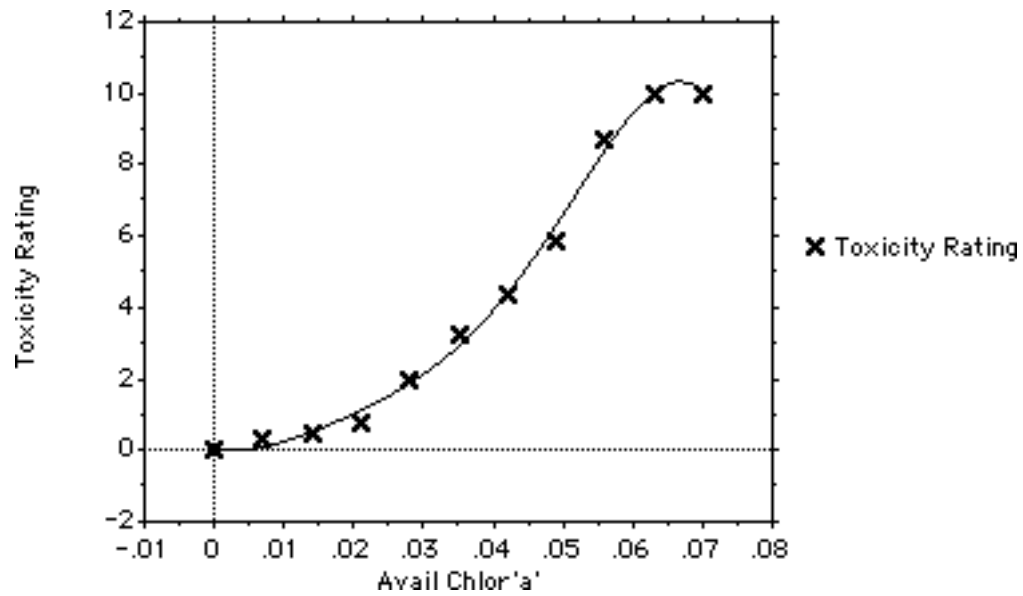
OxygenUsage = GRAPH(IF(Avail_Chlor'a'>=.064)THEN(52)ELSE
IF(Avail_Chlor'a'<=0)THEN(0)ELSE(Avail_Chlor'a'))



EQUATION: $y=0.332 - 179.556x + 3587.466x^2 + 654317.145x^3 - 7.227Ex^4$

Avail_oxygen = DELAY(100-OxygenUsage,2.5)

Toxicity_Rating = GRAPH(DELAY(Avail_Chlor'a',4))



EQUATION: $y = -0.291 + 42.197x + 1717.012x^2$

Warning#2 = SOUND(Algae-.05)

DOCUMENT: Warning of excessive bloom.

If algal concentration is greater than .05, then talking head will appear

Warning#1 = SOUND(Toxicity_Rating-7)

DOCUMENT: Warning of toxicity in bloom.

If toxicity rating is greater than 7, then talking head will appear

Warning#3 = SOUND(70-Avail_oxygen)

DOCUMENT: Warning of low oxygen content in water.

If available oxygen is less than 30%, then talking head will appear

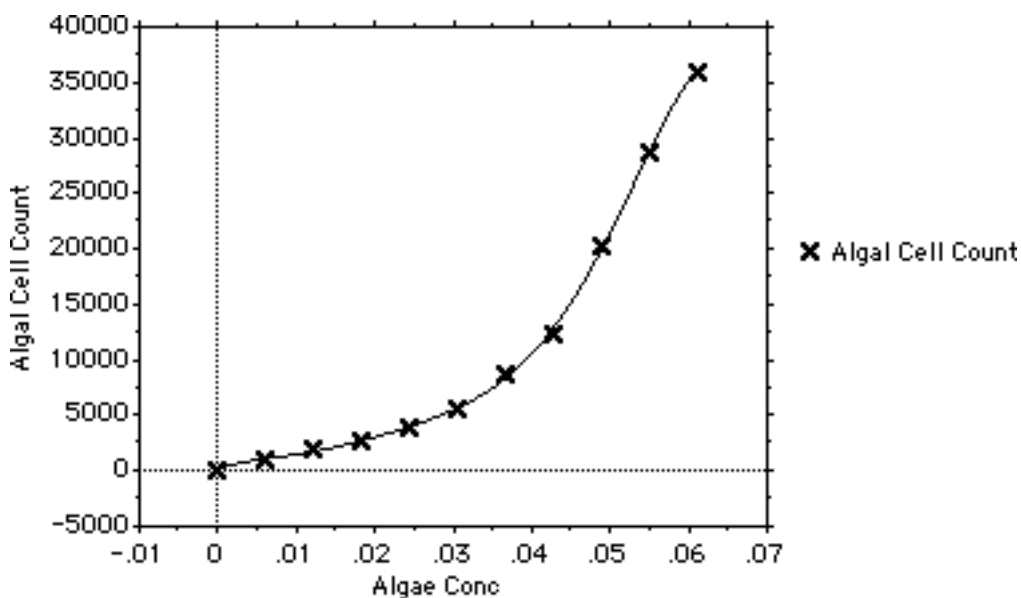
Warning#4 = Sound(Flush)

DOCUMENT: Warning sound to indicate Flush is about to occur

Talking head will appear when flush is selected to warn of a release of water from the dam

Warning_5 = SOUND(River_Flow<=1)

Algal_Cell_Count = GRAPH(Algae)



EQUATION: $y = -41.958 + 108452.658x - 7.83E6x^2 + 5.554E8x^3 - 5.291E9x^4$

RiverPconcConvert_2 = GRAPH(DELAY(Avail_RiverP,1))

EQUATION: $y = 0.017x + 6.507$

GraphP = IF(RiverPconcConvert_2<=0)THEN(0)ELSE(RiverPconcConvert_2)

RiverNconcConvert#2 = GRAPH(DELAY(Avail_RiverN,4))

EQUATION: $y = -5011.691x + 3007.96$

GraphN = IF(RiverNconcConvert#2<=0)THEN(0)ELSE(RiverNconcConvert#2)

APPENDIX: 3.15

Runtime Equations (Nardoo)

$$\text{Algae}(t) = \text{Algae}(t - dt) + (\text{Growth} - \text{Rundown}) * dt$$

$$\text{TotalN}(t) = \text{TotalN}(t - dt) + (\text{NutrientInflowN} - \text{NutrientOutflowN}) * dt$$

$$\text{Flush}(t) = \text{Flush}(t - dt)$$

$$\text{River_Flow}(t) = \text{River_Flow}(t - dt)$$

$$\text{TotalP}(t) = \text{TotalP}(t - dt) + (\text{NutrientInflowP} - \text{NutrientOutflowP}) * dt$$

$$\text{RiverAlgaeConc}(t) = \text{RiverAlgaeConc}(t - dt)$$

$$\text{Ambient_Light_Level}(t) = \text{Ambient_Light_Level}(t - dt)$$

$$\text{IndepTurbidity}(t) = \text{IndepTurbidity}(t - dt)$$

$$\text{RiverWater_Temperature}(t) = \text{RiverWater_Temperature}(t - dt)$$

$$\text{River_NitrateConc}(t) = \text{River_NitrateConc}(t - dt)$$

$$\text{River_PosphateConc}(t) = \text{River_PosphateConc}(t - dt)$$

$$\text{Avail_RiverN} = \text{TotalN}$$

$$\text{FlushPulse} = \text{IF}(\text{Flush}=1)\text{THEN}(\text{PULSE}(1,2,1000))\text{ELSE}(0)$$

$$\text{FlushFactor} = \text{FlushPulse}$$

$$\text{RiverMod} = \text{IF}(\text{River_Flow}=0)\text{OR}(\text{River_Flow}\leq 100)\text{THEN}(0) \text{ ELSE}$$

$$\text{IF}(\text{River_Flow}=101)\text{OR}(\text{River_Flow}\leq 250)\text{THEN}(.25) \text{ ELSE}$$

$$\text{IF}(\text{River_Flow}=251)\text{OR}(\text{River_Flow}\leq 500)\text{THEN}(.5) \text{ ELSE}$$

$$\text{IF}(\text{River_Flow}=501)\text{OR}(\text{River_Flow}\leq 700)\text{THEN}(.85)\text{ELSE}(1)$$

$$\text{Avail_RiverP} = \text{TotalP}$$

$$\begin{aligned} \text{Loss_Factor_Chla} = & \text{IF}(\text{Avail_RiverN}\leq 0.01)\text{THEN}(.22+(\text{FlushFactor})+(\text{RiverMod}/ \\ & 20)+.1) \text{ ELSE IF}(\text{Avail_RiverP}\leq 0.01) \text{ THEN}(.22+(\text{FlushFactor})+(\text{RiverMod}/20)+.9) \\ & \text{ELSE}(.22+(\text{FlushFactor})+(\text{RiverMod}/20)) \end{aligned}$$

$$\text{FlushT} = \text{IF}(\text{FlushPulse}=1)\text{THEN}(350)\text{ELSE}(0)$$

$$\text{RFlowT} = \text{IF}(\text{RiverMod}=.5)\text{THEN}(298)\text{ELSE IF}(\text{RiverMod}=1)\text{THEN}(350)\text{ELSE}(0)$$

AlgaeTfactor = GRAPH(Algae)

EQUATION $y = .185 - 6.938x + 243.804x^2 + 142431.265x^3$

Total_Turbidity = IndepTurbidity+FlushT+RFlowT+AlgaeTfactor

Turbidity_Convertor = GRAPH(Total_Turbidity)

EQUATION: $y = 1.036 - 0.003x - 4.287E-4x^2$

TCLimit = IF(Turbidity_Convertor>=0)THEN(Turbidity_Convertor)ELSE(0)

Available_light = Ambient_Light_Level*TCLimit

Lux_Convertor = GRAPH(Available_light)

EQUATION: $y = -0.026 + 0.003x - 8.843E-5x^2 + 9.230E-7x^3 - 3.553E-9x^4 + 5.898E-12x^5 - 3.598E-15x^6$

Temp_Convertor = GRAPH(RiverWater_Temperature)

EQUATION: $y = -7.659 + 1.135x - 0.049x^2 + 0.001x^3$

Growth = (((Avail_RiverN/100)+(Avail_RiverP/6.3)+RiverAlgaeConc)

*Lux_Convertor)*Temp_Convertor)

Rundown = Algae*Loss_Factor_Chla

Washout_rate = IF(River_Flow=0)OR(River_Flow<=2)THEN(0) ELSE

IF(River_Flow=3)OR(River_Flow<=5)THEN(.5) ELSE

IF(River_Flow=6)OR(River_Flow<=8)THEN(.75)ELSE(1)

lossfactorN = .0806+(FlushFactor/.008)+(Washout_rate*6)

Total_River_Nconc = River_NitrateConc+RiverNconc

RiverNconcConvert = GRAPH(Total_River_Nconc)

EQUATION: $y = 0.084x + 82.833$

RNitrateLimit = IF(RiverNconcConvert<=250)THEN(RiverNconcConvert)ELSE(250)

AbsModelNconc = RNitrateLimit/1000

ReleaseNutrients = GRAPH(Total_Turbidity)

EQUATION: $y = 2.430E-4 + 1.977E-4x - 7.168E-5x^2 + 1.408E-5x^3 - 6.351E-7x^4 + 1.082E-8x^5$

NutrientInflowN = (AbsModelNconc+(ReleaseNutrients*0.01)+(Loss_Factor_Chla/10))

NutrientOutflowN = (Algae*80)*lossfactorN

lossfactorP = .13+(FlushFactor/.008)+(Washout_rate*8)

Total_River_Pconc = River_PosphateConc+RiverPconc

RiverPconcConvert = GRAPH(Total_River_Pconc)

EQUATION: $y = 0.011x + 7.695$

RPosphateLimit = IF(RiverPconcConvert<=40)THEN(RiverPconcConvert)ELSE(40)

AbsModelPconc = RPosphateLimit/1000

NutrientInflowP = (AbsModelPconc+(ReleaseNutrients*0.001)+(Loss_Factor_Chla/100))

NutrientOutflowP = (Algae*6.3)*lossfactorP

Avail_Chlor'a' = Algae

OxygenUsage = GRAPH(IF(Avail_Chlor'a'>=.064)THEN(52)ELSE

IF(Avail_Chlor'a'<=0) THEN(0)ELSE(Avail_Chlor'a'))

EQUATION: $y = 0.332 - 179.556x + 3587.466x^2 + 654317.145x^3 - 7.227Ex^4$

Avail_oxygen = DELAY(100-OxygenUsage,2.5)

Toxicity_Rating = GRAPH(DELAY(Avail_Chlor'a',4))

EQUATION: $y = -0.291 + 42.197x + 1717.012x^2$

Algal_Cell_Count = GRAPH(Algae)

EQUATION: $y = -41.958 + 108452.658x - 7.83E6x^2 + 5.554E8x^3 - 5.291E9x^4$

RiverPconcConvert_2 = GRAPH(DELAY(Avail_RiverP,1))

EQUATION: $y = 0.017x + 6.507$

GraphP = IF(RiverPconcConvert_2<=0)THEN(0)ELSE(RiverPconcConvert_2)

RiverNconcConvert#2 = GRAPH(DELAY(Avail_RiverN,4))

EQUATION: $y = 5011.691x + 3007.96$

GraphN = IF(RiverNconcConvert#2<=0)THEN(0)ELSE(RiverNconcConvert#2)

Equation Programming Notes (Nardoo)

INIT Algae = 0

DOCUMENT: Algal growth maybe represented in terms of the concentration of Chlorophyll 'a' in mg/l or the number of algal cells in the water column. Suggested levels of Chloro'a' that represent eutrophication range from 40 to 60 µg/l. (Porcella et al) suggest that above 50 µg/l represents dangerous levels..advanced eutrophication, 35 µg/ to 50 µg/l (significant bloom) 25 µg/l to 35 µg/l acceptable average (if there is an acceptable level of eutrophication !), and below 25 µg/l) does not run the system into eutrophication

In this simulation, using stream input threshold values for N of 0.2mg/l or 200 µg/l and P of.03mg/l or 30 µg/l and assuming that the light and temperature levels are within the limits that support normal aquatic plant growth, the concentration level which represents a nuisance algal bloom in the river is >50 µg/l. (0.05mg/l) (0.005g/l)...this value can be altered by an inbuilt factor.

NOTE: The algal bloom model presented here flows the structure of the Minnesota model (Middlebrooks et al.'75). The relationships which have been adopted have generally been simplified as this model is not intended to be predictive, rather it is intended to relay the concepts and general cause/effect considerations.

NOTE: The time interval used is 1 week @ 0.1 week increments over a span of 15 weeks.This can be altered before coding. Integration is by Euler's method.

NOTE: The model treats the inclusion of volume as an unnecessary complication. A "flush" for the lake is built-in, such that the max possible flux will produce the desired and expected result in terms of N and P levels and the change in levels of Chlor'a'.

NOTE: the values for chl'a'/algal cell count in this model are developed in mg/l

NOTE: The timing and magnitude of the algal biomass is essentially sensitive to N and P levels, particularly P. Provided the river contains sufficient concentrations of these

nutrients then blooms will occur if the river is sufficiently stratified. This is the rationale for the method of incorporation of these variables within this model.

The curves produced for the threshold eutrophication point exhibit a reasonably close correlation to those produced for lakes of similar size in the literature.

INIT Flush = 0

DOCUMENT: A switch which produces a flush of 'clean water' from the dam. In this model the effect of the flush is delayed 2 time intervals to ensure that the user observes the effect on a developing algal bloom if the conditions are capable of producing a significant bloom.

FlushPulse

DOCUMENT: Pulse operates by sending a pulse of magnitude 1 into the model after two time intervals and repeats it every 1000 time units. This later figure means that the model will only undergo one flush when this switch is activated.

FlushFactor = FlushPulse

DOCUMENT: This is a pulse routine developed in the authoring medium

INIT River_Flow = 0

DOCUMENT: Riverflow will operate as a toggle switch with three positions, low (value input = 0), Medium (value input = 1) and High (value input = 2)

RiverMod = IF(River_Flow=0)THEN(0)ELSE IF(River_Flow=1)THEN(.5)ELSE(1)

Loss_Factor_Chla

DOCUMENT: This is an estimated value based on literature quoted values which take into account loss by death, wash-out and loss by predation etc. Most models suggest that this is a difficult factor to assess.

NOTE: Sensitive value. Should not be altered under normal investigations of the lake.

INIT TotalN = 20

DOCUMENT: Value developed in mg/l

Avail_RiverN = TotalN

DOCUMENT: *Assumed Nitrogen to Chloro'a' yield is set at 7.2mgN/l /mg Chloro'a'/l (from regression of particulate N on chlorophyll 'a' calculated in the Minnesota model. In model this value is expressed in mg/l and the uptake rate for N has been increased)

NOTE: this value could be changed in tandem with that for P to change the desired max output of chl'a'

INIT TotalP = 3

DOCUMENT: Value developed in mg/l

Avail_RiverP = TotalP

DOCUMENT: *Assumed Phosphorus to Chloro'a' yield is set at 0.63mg P/mg/l /mg Chloro'a'/l. From regression of particulate phosphorus on chlorophyll'a' calculated in the Minnesota model.

NOTE: this value could be changed in tandem with that for N to change the desired max output of chl'a'

INIT RiverAlgaeConc = .0001

DOCUMENT: The initial chloro'a' concentration or algal cell count in the water column is based on literature values. Illawarra data suggests that this value represents an 'average' for 'background' alga concentration.

NOTE: The value for this input can be the embedded lake values. It could also serve as the mechanism to setup initial scenarios of data for the 'pre-determined' catchment areas.

NOTE: value input as g/l

NOTE: One could also make a connection between this stock and the water volume of the lake if one desired to calculate the total algal biomass load for the entire photic zone.

INIT Ambient_Light_Level = 400

DOCUMENT: Light values are set at a minimum of 10 Lux up to 500 Lux.

* This may be altered in the model* (The actual value range being “normalised” via a unity convertor)

INIT IndepTurbidity = 0

DOCUMENT: The unit of measure is the FTU. The range selected is 0 to 50 (based on data from the Illawarra report). As the effect is “normalised” using a unity convertor, the actual scale is negotiable. This control is may not be user accessible in this model

Pulse_fact = IF(FlushPulse=1)THEN(30)ELSE(0)

FlushT = IF(Pulse_fact=1)THEN(30)ELSE(0)

RFlowT = IF(RiverMod=.5)THEN(31.8)ELSE IF(RiverMod=1)THEN(40)ELSE(0)

AlgaeTfactor = Third order polynomial

DOCUMENT: This factor builds in some increase in turbidity which would be expected to occur when the river is flushed, stirred up by high flow or heavily laden with algal bloom.

Turbidity_Convertor =Second order polynomial

DOCUMENT: The effect on available light levels is graphed as a function of FTU measurements (min to max) and effect (0 to 1)

TCLimit= IF(Turbidity Convertor>=0)THEN(Turbidity Convertor)ELSE(0)

DOCUMENT: If statement to prevent the return of a negative value from the equation for turbidity convertor

Available_light =

DOCUMENT: The actual light available for growth will be modified by the level of turbidity in the water. This will depend on the volume of sediment in the water, turbidity and the level of the algal bloom.

Lux_Convertor = Sixth order polynomial

DOCUMENT: Conversion of actual light levels in Lux to a unity scale facilitates a much simpler model structure. This may not improve the accuracy or predictability of the model but it is NOT the aim of this model to be an ‘absolute’ predictor of algal growth

INIT RiverWater_Temperature = 21

DOCUMENT: Provided the temperature is adequate algal growth will occur. From the data it may be suggested that the range in which some significant variation may occur is somewhere between 18° C and 25° C. The range is not critical to this model as the overall effect is “normalised” by running it through a unity convertor

Temp_Convertor = Third order polynomial

DOCUMENT: Graphical relationship is used to relate ‘absolute’ temperature and its effect on algal growth. The range used is quite small. Most models accept the notion that temperature per se is not a critical factor in the process of eutrophication.

Growth=

DOCUMENT: It is assumed that the change in the algal biomass (chloro’a’ level in mg/l) is obtained by the following relationship: = rate in (assumed to be zero) - rate out (wash out and loss by other means are combined in this model in the loss factor) + growth (determined from the yield rate of Chloro’a’ /mg/l / mg/l of available nitrogen plus the yield rate of chloro’a’ /mg/l / mg/l of available P all multiplied by the rate of formation factors imposed by light and temperature) - loss.

Rundown =

DOCUMENT: NOTE: Literature suggests that extinction rate for chlor’a’ is in the region of 19mg/l / mg/l chloro’a’

lossfactorN =

DOCUMENT: This is an estimated value based on literature quoted values which take into account loss by death, wash-out and loss by predation etc. Most models suggest that this is a difficult factor to assess. It is a sensitive value and should not be altered under normal investigations.

INIT River_NitrateConc = 200

DOCUMENT: Input values in mg/l. This figure is derived from the literature and is a conservative one.

NOTE: The value for this input could come from the embedded data in the lake or could be used to set up scenarios. Literature and research suggest that the general range of values for Nconc range from 0 µg/l to 300 µg/l. (Ellis & Kanamori '72-74: 0 µg/l to 200 µg/l), (Higgins '71: 0 µg/l to 90 µg/l and up to 690 µg/l), (Roy et al. '76: eutrophication 200 µg/l to 300 µg/l). Values input as mg/l

RNitrateLimit =

DOCUMENT: Limiting values placed to ensure model does not over-run

RiverNconc = 0

DOCUMENT: Input value of stream water concentration for N is in mg/l.

Max value expected in this model is 300mg/l

The model has been calibrated for Chloro'a' on 75% max value. Not active in this simulation.

ReleaseNutrients =Fifth order polynomial

Washout_rate = IF(River_Flow=0)THEN(1)ELSE IF (River_Flow=1) THEN(.5) ELSE (.055)

NutrientInflowN=

NutrientOutflowN =

DOCUMENT: This is an estimated value based on literature quoted values which take into account loss by death, wash-out and loss by predation etc. Most models suggest that this is a difficult factor to assess. Sensitive Value: should not be altered under normal investigations.

INIT River_PosphateConc = 30

DOCUMENT:

NOTE: input value in mg/l. This figure is derived from the literature and represents a conservative value (30 µg/l). See Initial Input document for N.

NOTE: Literature and research suggest the following ranges for this data: (Edmondson '69: 1 µg/l to 200 µg/l), (Higgins '71: 6 µg/l to 107 µg/l), (Ellis & Kanamori '72-74: 3 µg/l to 140 µg/l) In general, values of 30 µg/l or greater produce nuisance blooms while the eutrophication threshold is approximately 20 µg/l. Values input as mg/l

RPosphateLimit= IF(River_PosphateConc<=.04)THEN (River_PosphateConc) ELSE (.04)

DOCUMENT: Limiting values placed to ensure model does not over-run

RiverPconc = 0

DOCUMENT: Input value of stream water concentration for P is in mg/l.

Max value expected in this model is 200mg/l

The model has been calibrated for Chloro'a' on 75% max value.

NOTE: The literature suggests that nuisance blooms occur when Pconc > 30 µg/l

Not active in the final version of this simulation

NutrientInflowP=

NutrientOutflowP =

Avail_Chlor'a' = Algae

DOCUMENT: Developed in mg/l

OxygenUsage = Fourth order polynomial

DOCUMENT: Equation is a 2nd order polynomial

Input equals available chl_a and output is the % of oxygen used by algal growth/decay cycle.

Graph based on: 0.05g/l (50 µg/l) to 0.07g/l (70 µg/l) represents nuisance algal bloom with associated fish kill etc...at this level, oxygen usage is approx 50%, hence available oxygen, in terms of % saturation will be 50%...resulting in fish kill etc

Avail_oxygen = DELAY(100-OxygenUsage,2.5)

DOCUMENT: Expressed in terms of % saturation of available oxygen to aquatic life. Significant kill will occur with levels below 55%. The delay function ensures that the maximum oxygen loss occurs after the bloom when the algae is decaying. The delay is 2.5 time intervals.

Toxicity_Rating = Second order polynomial

DOCUMENT: The avail chlor'a' value to be input into the toxicity function is delayed by 4.5 time units.

Warning#2 = SOUND(Algae-.05)

DOCUMENT: Warning of excessive bloom.

If algal concentration is greater than .05, then talking head will appear

Warning#1 = SOUND(Toxicity_Rating-7)

DOCUMENT: Warning of toxicity in bloom.

If toxicity rating is greater than 7, then talking head will appear

Warning#3 = SOUND(70-Avail_oxygen)

DOCUMENT: Warning of low oxygen content in water.

If available oxygen is less than 30%, then talking head will appear

Warning#4 = Sound(Flush)

DOCUMENT: Warning sound to indicate Flush is about to occur

Talking head will appear when flush is selected to warn of a release of water from the dam

Warning_5 = SOUND(River_Flow<=1)

This can be altered before coding. Integration is by Euler's method.

NOTE: The model treats the inclusion of volume as an unnecessary complication. A "flush" for the lake is built-in, such that the max possible flux will produce the desired and expected result in terms of N and P levels and the change in levels of Chlor'a'.

NOTE: the values for chl'a'/algal cell count in this model are developed in mg/l

NOTE: The timing and magnitude of the algal biomass is essentially sensitive to N and P levels, particularly P. Provided the river contains sufficient concentrations of these nutrients then blooms will occur if the river is sufficiently stratified. This is the rationale for the method of incorporation of these variables within this model.

The curves produced for the threshold eutrophication point exhibit a reasonably close correlation to those produced for lakes of similar size in the literature.

RESOURCES :

Original Design Parameters Document

1.0 General

The basic design parameters to be met in the original brief are set out below. Essentially, these have not changed for the current version, however they have been extended and refined. The original parameters included:

- * This simulation package is to be built as a HyperCard® stack. The model engine is to be developed and run in a HyperCard® environment.
- * The format for the card design will be based on that stipulated in the basic design statements for the rest of the package. Some variations will operate for video displays and other media materials.
- * This simulation will represent one option available within the simulation ‘arm’ for this package.
- * This simulation will be a ‘stand alone’, ‘plug-in’ module.
- * The simulation will be based on a mathematical model which operates on the principle that, provided there is sufficient light, and the temperature is within the tolerance levels, the major controlling factor in the development of eutrophication in a lake is the availability of nutrients, namely phosphates and nitrates, both water born and within the sediment.

At the time of preparation of the original design brief, two models were under consideration as possible ‘engine shells’ for this simulation. Aquasim®, Bowker & Randerson (1989) provide a model which simulates an aquatic system with continuous throughput of water, a lake with fairly regular inflow/outflow, in which there operates a simple food chain comprising phytoplankton, zooplankton and fish. The model parameters may be varied by the user to simulate the response of the two forms of plankton to changes in light, temperature and nutrient concentrations in waters of different

trophic status. This model provided a starting point. Bowker & Randerson suggested that their model was the only one to date which had been designed to facilitate interactive learning via practical work at a computer. All previous models had been developed for the purpose of research. These authors also made reference to a model produced by Larsen, Mercier and Malueg (1975). Initial investigation suggested that this model might prove to be very useful as a benchmark for the behaviour of the model as it was based on a lake whose physical parameters were not unlike those of the lake used in this study as the source of raw data.

The final model described, implemented and tested in this study was loosely based on the model produced by Larsen et al., and the raw data used in obtaining the analysis of phosphorus and nitrate content of the waters of Lake Illawarra presented by Yassini (1985) in conjunction with the raw data used to determine, changes in oxygen content of the water, clarity of the water, nutrient content changes (both P and N), the relationship between nutrient concentration and currents, and the algal distributions presented in the Environmental Impact Statement (1988). The mathematical model was developed using STELLA® (Structural Thinking Learning Laboratory), a commercial software package designed to simplify the construction of relationships between impinging factors. A full description of the development of the model implemented in the 'Investigatin Lake Iluka' software is set out in section 5.

2.0 Input / Output:

It was proposed that the input of data for the operation of the simulation would be via either the 'tool box' within the system or via 'animated equivalents'.

The parameters over which input control (via the tool box) should be possible, would include:

- * temperature

- * light levels

- * Nutrient input from both the water and sediment

- * Time

- * Turbidity levels as they impinge on light penetration

- * Water input to the lake (via rain inflow and ocean exchange). Using the graphic input method, it may only be feasible to vary one parameter, nutrients, albeit via a number of sources including, homes, industries, agricultural pursuits etc.

2.1 Output of data:

Output should be provided in a clear and 'attractive' way in keeping with the general format of the 'Investigating Lake Iluka' package and take advantage of the display capabilities of the interface. Three methods of data presentation were considered:

- 1) an animated lake in which 'colour patches' equivalent to various levels of algal growth appear / disappear as the simulation runs.

- 2) graphic presentation of the data at any selected part of this lake. This will be facilitated using the tool box to 'sample' a selected area during the simulation to examine the effects of parameter manipulation.

- 3) a windoid displaying continuous changes in the key parameters as the simulation proceeds.

The animation output should be available on both the computer screen and 'snapshots' of the computer screen should be able to be cut and pasted into the 'notebook'. It should be noted also that it may also be desirable to have both the display of parameters

and the animated output visible on the screen simultaneously, the tool box as a windoid.

3.0 Visual displays / Audio output:

In the original design brief, it was suggested that visual output also be shown on an external video monitor simultaneously with the computer display. All video clips would be shown in windoids on the computer screen while on the video monitor, they would be shown full screen and would hold a 'static grab' frame from that clip until that section of the software was exited.

1) Stills. All should be compressed files and should be colour. Display of these on the computer screen should be within the 'graphics' field or a windoid but depending on whether information is supplied concurrent, it may fill the monitor screen. This should be the case if desktop size does not permit the display of full video. For example, 'talking to an expert' may involve the listening to the audio track with a static 'grab' frame of the expert displayed as a windoid on the computer screen.

2) Video sequences. All these sequences will be provided as QuickTime® 'pop-up' windoids. The position and size of these will depend on what other information is being displayed at the same time. During operation of this simulation, the computer screen should be in the 'card' format with textual information being confined to the 'text fields', the 'graphics field' should contain an image associated with the information being dealt with except when either video clips or full scale stills are accessed. When QuickTime® material is accessed, the computer should show the 'pop-up' version while the monitor, if in use should show the image full screen. It should revert to a 'black-card' format at the completion of the QuickTime® clip. When a full scale still is accessed, the same routine would apply.

3) Audio sequences. During 'audio only' play, the 'card' with which it is associated should be static on the computer screen.

In the case of video clips, a representative 'grab image' should be displayed.

* Student understanding of 'where they are' should be enhanced by the use of some

form of symbolic representation of the area in which they are or were working appears on each screen.

* Perhaps an extra option on the opening screen to provide a simple navigation flowchart of the entire system.

The overall planned structure and operational considerations for the original design brief are detailed in section 5. A series of flowcharts, Figures 1 to 11, used in the design brief are to be found in Appendix 3.8

4.0 Learning evaluation:

It is desirable that at any stage during the progress of the simulation operation the user should be able to determine what decisions have been made and what effect they have had on the outcomes to date. To this end there should be an option to display for any given moment:

- 1) the data input so far
- 2) the original settings for the area under study
- 3) the change in nutrient levels effected as each of the input parameters changed
- 4) the consequent changes in algae density in the area under study
- 5) It should also be possible to compare these values with some other area in the simulated lake via the 'tool box'.
- 6) It should be possible for the user to obtain a printout containing this information so that the value of group discussions and collaboration concerning the outcomes of parameter alterations can be fully utilized.
- 7) It may also be feasible in a consequent version to provide a 'skeletal' version of Stella II® so that the user may be able to directly manipulate the model itself, thus extending the ability to develop higher order cognitive skills such as critical thinking and problem solving.

5.0 The Original Design Brief - Some Operational Considerations

5.1 The General Interface format:

It is envisaged that eventually a number of simulations will be operational, all of which should be structured to follow the same basic format as the Iluka package. The exact nature of these is yet to be decided. Those listed in Appendix 3.8, Figure 1 are simply examples.

The simulation of algal blooms in lakes will be modelled on Lake Illawarra. The opening screen will be of a 'standard card' format based on the specifications set down in the design brief for 'Investigating Lake Iluka'. There will be a colour graphic in the 'graphic field' depicting a general aerial view of the lake. Labelled buttons could be employed to facilitate access to the branches within the system. These could be located according to general package design.

5.2 The Interface - Structural Components:

The first card will depict the 'Title Screen', Appendix 3.8, Figure 2 with a static colour picture of green 'algal mats', (from local TV news footage), within the 'graphics field' and the title of the simulation in the 'text field', with some general information as to navigation.

There could be 4 labelled pathway buttons which will be located according to general structural parameters.

* An overview this button could be highlighted on 'openCard. Selection of this button could provide two choices, a navigational map or, open a windoid on the computer screen in which would appear a video clip. Note that this video clip should appear 'full screen' on the video monitor. This option could also have a sub-option 'Help' which would provide more detail on operational aspects of the simulation.

* See News Footage The news footage option, Appendix 3.8, Figure 3, will provide three choices via labelled buttons, the 'General Views' button being highlighted on 'openCard'. The footage for this clip needs to be obtained either from library stock (local TV) or by commission. It should simply show some passes over the lake and the general area including shots which show, housing development, industrial and, agricultural areas.

This clip could be presented in a windoid on the computer screen and as a full screen image on the video monitor. The 'graphics field' on the card for this screen may contain a colour 'grab' frame from the video clip. The 'text field' may contain some basic dimensional data about the lake.

The 'extent of the bloom' option could have its source in the local TV news footage. When this option is chosen a 'pop-up' button might appear which could allow access to the 'red tide' video clip/ information screen. The same screen actions will apply as for 'General view'. It may be useful to have the 'red tide' option back linked to 'General view' button for quick return. In any case, the 'red tide' option will be linked to the 'Expert View' option.

'Harvesting' the bloom could also be supported by the local TV news footage already available, although some additional material may be needed.

* An Expert View..... The expert view option, Appendix 3.8, Figure 4 will provide three video clip interviews (supported by QuickTime®, as are all the video clips) which will need to the shot 'on location'. The scripts for these may be derived from the resource materials available elsewhere in the Iluka package.

The user will have three options, the button for 'Causes of Algal Bloom' being highlighted on 'openCard'. Two other choices could be, the 'Effects of the Bloom' and 'Possible Solutions'.

Each interview should be displayed on the computer screen in colour within a windoid, perhaps superimposed on the 'graphics field' which will display a colour 'grab'

frame from the news footage. The video monitor should display a full screen version and then display a static 'grab' from the video sequence when the interview is finished. The text field on this card will display text based information for the students. Should this exceed the field, a scrolling or next card facility should be available. Reference to the 'red tide' phenomenon will be made in both the interview and the screen based text material. Both the 'Causes' and 'Effect' options will therefore need to be linked to the 'red tide' option sequence.

The fourth option on the 'experts view' screen could lead to a series of flow - chart representations of some of the important interrelationships that exist within the ecological structure. Those presented in Appendix 3.82, Figures 9, 10 and 11, are some suggestions. It may be desirable to have others.

* Run Simulation.... The essential structural layout of the simulation is shown in Appendix 3.8, Figure 5. Upon selection of the simulation option, the screen displays an opening card with all the structural features of the cards previously outlined and with three option buttons, 'Simulation Overview', Appendix 3.8, Figure 6, (highlighted when the screen opens), a 'Run preset Simulation option' and an 'Input' or 'Adjust Lake parameters' option.

Selection of the 'overview' option provides a screen on the computer with a brief statement within the 'text field' as to the aim of the simulation, and a stylized colour lake graphic in the 'graphic field'. Two option buttons will be provided, one giving access to an audio description of the general operation, about starting the simulation, the input of data, and what to expect from the model. While this audio description is running, the computer screen will display a 'grab' frame of 'a biologist perhaps?' within a windoid superimposed on the 'text field'. The video monitor screen will display the same picture, full screen. It should then remain on screen until the simulation overview is exited.

Selection of the 'Preset' simulation will provide the user with visual clues as to what to expect from the system together with practice at accessing the different output facilities before actually using the simulation.

6.0 Input/Output Functions:

The 'Input' option gives the user access to the simulation proper. Selection of this button will result in the display on screen of an 'adjust the lake parameters option'. It is intended that two methods will be presented to the user for this process when this option is selected. The other, 'graphic symbols option' will provide the user with a series of symbols. These symbols would depict a nutrient contributing factor, for example, an urban development, a factory or the like, and each symbol would have a finite 'increase in concentration value ready to be linked into the mathematical model as the variable. It is intended that this option for access to the simulation is the simple one. It supports the notion presented in many of the research papers that, provided light and temperature are at acceptable levels, the real controlling factor in algal blooms is the nutrient level in the lake. The notion behind this use of representative symbols is that it presents in a similar way to such 'gaming software' as SimEarth and SimCity.

If students wish to have a more definitive control over the whole range of parameters they would be given the option of altering the parameters via the 'tool box'. Appendix 3.8, Figure 7. This would support and facilitate a more detailed exploration of the simulation and consequently, enrichment of the learning taking place by;

- * allowing the user to take readings using the 'tool box' at the site being studied and observe the changes as the simulation runs.
- * allowing these readings to be compared with readings of the same parameters taken at other locations and drawing inferences from such comparisons.
- * allowing the monitoring of all the parameters while the simulation is running with the aim of seeing how one relates to the other for example it may be instructive to see the changes in light levels as an algal bloom develops and at the same time monitor the return effect of this on the algal growth or other organisms in the same area.

Once parameters are set, the student would be given the option to;

- * make changes to their settings
- * run the simulation
- * select output options, or
- * quit or return to main menu.

The 'Output' options, Appendix 3.8, Figure 8 include:

- * an animated 'on going' simulated evolution/devolution of algal growth using some sort of coloured shading, related to either the physical extent and/or the quantity of the algal mass produced
- * graphic representation of the output
- * transfer of materials to the students 'clipboard' for later reference.
- * the printing out of data obtained when the ' tool box' method of variable adjustment is used.

Note that the output would essentially be displayed via the computer screen so that the system may be 'freestanding' with respect to classroom use. However it may be useful to provide video screen support for the outputs as an option. This would be particularly useful in terms of group discussions and the making of collaborative decisions.

APPENDIX: 4.0

EDUS 311 Science and Technology Ed (K-6) III**Assignment Requirements:**

The assignment falls into two parts:

Part A (10%)

Using the software package *Exploring the Nardoo*, investigate the problem set out below. Collect and use any resources, which you feel you, need to develop your response to the problem.

NOTE. You must collect all materials you need during the two 1 hour tutorial sessions, as the software is not available to you outside the lab.

Your response should be in the form of a 500-word report on the problem presented detailing what an algal bloom is, what causes it, how it can be dealt with, and what problems it causes the community.

Additional to this report, you must provide a list of all resources that you used in the preparation of your report. For example, in the case of the filing cabinet, give the titles of the documents you accessed and in the case of video clips, provide the title for the clip (found on the clipboard on the office wall. Titles of any newspaper articles, plants and/or animal information and audio clips accessed must also be supplied.

PART B (10%)

Exploring the Nardoo is primarily designed to be used in the curriculum of 8-12 students. Having used the software, into which main content strand(s) of the Science and Technology K-6 Syllabus might it fit? Outline an investigation that you could use with K-6 students that could make use of the Nardoo software. What special considerations might you have to consider in using it?

The Problem to be investigated

**Time Zone 4:1990's
Tanunda Region**

Blue-Green Algae

There have been a number of reports of illness among people using the Nardoo River for swimming. There have also been reports of dead stock floating in the river in the Walloway Region. The problem seems to be associated with a severe blue-green algal bloom.

Your task:

Explore the effected regions and gather information about the issues. Prepare a report detailing what an algal bloom is, what causes it, how it can be dealt with, and what problems it causes the community.

1. After selecting this investigation listen to the guide for advise as to how to go about researching this problem. Use the “GRAB” button to enter the investigation into your PDA. If you require further assistance click on your guide for more hints.

You may now either choose to go out into the environment:

2. Use the “GO” button to enter the area under investigation. Take 2 or 3 sets of **chemical** and **biological** measurements along the river with the measurement tools and enter the results into your notebook. (Compare these results with another set of measurements from a previous Time Zone in the same Region.)

3. Explore this area of the catchment - read, listen to and view the media reports. Collect any relevant material for your report in your notebook.

Also use the tools to check the stream quality as well as obtain measures of the physical and chemical parameters in the river in areas effected by algal bloom. These measurements may help you to more fully understand the relationships between all the factors involved in a blue-green algal bloom outbreak.

The following media provide you with a starting point for your investigation.

Television Reports

“Sewage blamed for algal bloom.”

Why did the Aquatic Club blame the treatment plant for the algal bloom?

How did the plant’s operators respond?

“New wetlands to absorb nutrients.”

Explain what is ‘ironic’ about the move to construct artificial wetlands in the area.

What are the other ‘options’ outlined by Dr Michaels?

“Workers’ brawl no Sunday picnic.”

Briefly outline the reaction of the local workers to the bloom.

Do you think the local government response is reasonable? Why?

Radio Reports

“Sickness linked to algal bloom.”

What symptoms have people been showing after swimming in the Nardoo River?

Detail the conditions that Dr Michaels outlines as promoting the growth of the algal bloom.

“Green group wants river flushed.”

Some groups believe the release of more water into the river will assist with the algal bloom? Explain this viewpoint.

“Dam too low to flush river.”

What has prompted the water authority to develop a water management plan?

Explain the role of the community in such a plan.

Newspaper Articles

“Golfs best green yet.”

Link the information revealed within this news story with other information on algal blooms (look in the filing cabinet). Write down any links you discover that may exist between the golf course and the algal bloom.

“Algae poisons water.”

What events led to the Pilliga Hospital issuing a public health warning?

Outline the things people should avoid doing, or be wary of, in order to avoid becoming ill.

“Economy suffers as bloom worsens.”

Describe the two effects resulting from the algal bloom that were having an impact on the region’s economy.

Does this article have a ‘hopeful’ or ‘gloomy’ tone to it? Explain.

NOTE : These media issues resources are also found in the WRC

4. Return to the WRC and check the Filing cabinet for articles on Blue Green Algae that may support your investigation. Collect any support material in your notebook.

5. If you have a version of Exploring the Nardoo which allows you access to the Blue-green Algal Bloom simulator, you may use it to help you discover the causes, effects and relationships between the factors involved in the development of such blooms.

Or stay in the WRC and access the materials stored in the Filing cabinet, or the video and audio clip boards.

6. Copy your notes and any media material you have collected in your PDA notebook into the “text tablet”. Use the editing tools and presentation guide to arrange and edit your work into a report and then **save it to disk as a TEXT** file with the file name AGB. (your personal ID code).

7. Take this disk home and spend some time on arranging your work for handing in a printed form as a 2 page report at the next lab session. Completion of this will earn your 10% of your total assessment. Working on the information at home will also help you consolidate in your mind the rich information you accessed during the session using the software.



THE UNIVERSITY OF WOLLONGONG

Faculty of Education

EXPLORING THE NARDOO
The Blue-Green Algal Bloom Problem
Knowledge Acquisition Schedule ©1998
Pre Test

Please tick box [D] in the blank row of question boxes if you used the SIMULATOR while researching the problem on algal bloom

- 1) Blue-green algal blooms are most likely to occur;
 - a) near sections of the river which have high banks.
 - b) in farm dams and behind weirs.
 - c) in areas of the river which are deep and with plenty of light.
 - d) in areas of the river where the water is moving quickly and there is plenty of light.

- 2) One of the effects of lower water temperature in rivers is that it;
 - a) increases the turbidity of the water.
 - b) prevents the formation of any algal bloom.
 - c) delays the development of an algal bloom.
 - d) causes an increase in the nutrient levels.

- 3) One of the most devastating aspects of many algal blooms is the release of toxins into the water. Not all blooms progress to this stage, but when they do, the level of toxins in the water usually peaks;
 - a) at the same time as the algal bloom is at its maximum.
 - b) about 10 weeks after the bloom is at its maximum.
 - c) after the bloom has died away through natural causes.
 - d) about 4 weeks after the bloom has reached its peak.

- 4) The two main chemical pollutants which seem to be directly related to algal bloom in rivers are;
 - a) Phosphorus and Oxygen.
 - b) Oxygen and Nitrogen.
 - c) Phosphorus and Nitrogen.
 - d) Oxygen and sulphates.

- 5) Humans can suffer a number of symptoms after swimming in water which has been contaminated by an algal bloom. These symptoms can include;
 - a) shortness of breath.
 - b) hair loss.
 - c) skin rashes.
 - d) skin discolouration.
- 6) The oxygen concentration in river water usually drops to a minimum during the algal bloom cycle;
 - a) just after the algae begins to grow.
 - b) when almost all the algae has died.
 - c) at around the same time that the algal growth reaches a maximum.
 - d) during the period when algal growth is escalating.
- 7) Some of the ways in which those responsible for catchment management could manage the nutrient problem in a river include;
 - a) using herbicides to kill the algae and reduced sewage input.
 - b) using dredging of the river bed to remove the roots of the algae.
 - c) reducing the input of nutrients and improving the water flow.
 - d) introducing some organism which destroys the algae.
- 8) The process by which nutrient levels lead to the development of excessive algal growth which in turn contributes to the lowering of the overall oxygen level in the water as the algae dies and decays is called;
 - a) Biodegradation.
 - b) Respiration.
 - c) Eutrophication.
 - d) Photosynthesis.
- 9) Significant algal cell growth can occur in rivers down to a maximum depth of approximately;
 - a) 1.4 metres.
 - b) 0.8 metres.
 - c) 0.6 metres.
 - d) 0.05 metres.
- 10) After a period of heavy rain, you would expect;
 - a) the levels of nutrients in river water to increase
 - b) the level of oxygen in river water to decrease.
 - c) the temperature of the water in a river to rise.
 - d) more fish than usual to die due to the influx of fresh water.
- 11) The nutrient which is most critical to the development of dangerous and nuisance bloom in a river is;
 - a) Oxygen.
 - b) Phosphorus.
 - c) Nitrogen.
 - d) Sulphates.

- 12) You could best describe the pattern of algal bloom in rivers as;
 - a) an abnormal phenomenon.
 - b) a cyclic phenomenon.
 - c) a once in a lifetime phenomenon.
 - d) a linear phenomenon.

- 13) During the development of a major nuisance bloom, generally the peak in the growth of the algae in rivers, given the right conditions, occurs within a period of;
 - a) 3 to 4 weeks from the start of the process.
 - b) 2 weeks from the start of the process.
 - c) 5 to 7 weeks from the start of the process.
 - d) 12 weeks after the start of the process.

- 14) Algal blooms often produce extensive fish kills because among other things they lower the oxygen saturation levels in the water. The critical level of oxygen saturation producing this effect is closest to;
 - a) 10%.
 - b) 40% to 50%.
 - c) 85%.
 - d) 90%.

- 15) If you suspect that there is an algal bloom in your farm dam, you should as a short term measure;
 - a) make sure that you only collect water from the dams deepest section.
 - b) boil all the water you collect before you use it.
 - c) run all the water you collect through a physical filtration process.
 - d) stop using water from the dam and use an alternative water source.

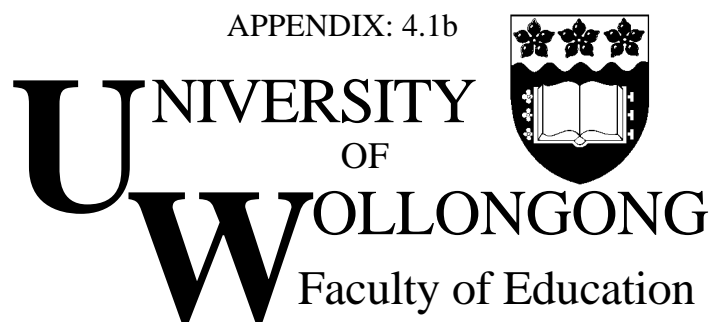
- 16) Important physical conditions that affect algal growth include;
 - a) the temperature of the water and the number of sunny days.
 - b) the flow rate of the water and the amount of sunlight.
 - c) the amount of sunlight and the size of the fish population.
 - d) the time of the year and the amount of oxygen in the water.

- 17) An increase in the concentration of nutrients in river water would be expected;
 - a) with an increase in farming around the catchment area
 - b) with a decrease in the average rainfall.
 - c) only after heavy flooding.
 - d) during the winter months.

- 18) Actually measuring the amount of algae that has grown in a river is virtually impossible and therefore it is difficult to get an actual measure of the significance of the bloom. To simplify the process, scientists use as a measure of the mass of an algal bloom;
- a) the concentration of oxygen in the river water.
 - b) the number of algal cells per litre of river water.
 - c) the level of change in colour of the river water.
 - d) the level of smell from the decaying algal mass.
- 19) The reported putrid smell noticed by residents around the river is probably the result of;
- a) sewage overflow into the river.
 - b) the development of black weed on the river banks.
 - c) excess nutrients in the water.
 - d) the decomposition of algal mats in the river.
- 20) Provided that there is enough light and other physical factors are within certain tolerances, the essential controlling factor of algal growth in a river is;
- a) the concentration of oxygen in the river water.
 - b) the surface area of the river.
 - c) the level of tourist activity on the river during summer.
 - d) the concentration of nutrients in the river water.
- 21) The optimum water temperature which results in maximal algal growth in rivers would seem to closest to;
- a) 12°C.
 - b) 25°C.
 - c) 17°C.
 - d) 30°C.
- 22) Increases in the amount of sewage, industrial waste, animal droppings, pesticides and storm water entering a river all cause;
- a) the smell of the river to get worse during hot weather.
 - b) the river to become grey in colour.
 - c) the silting up of the river.
 - d) the nutrient concentration to increase.
- 23) When the concentration of nitrogen in river water is between 1,000 and 2,000µg/l, the corresponding concentration of phosphorus needed to produce a nuisance level algal bloom would be closest to;
- a) 1,000 µg/l.
 - b) 2,000 µ g/l.
 - c) 4,000 µg/l.
 - d) 6,000 µ g/l.

**Finally please tick box [A] in question 24 boxes to agree with the following:
I understand that the data collected from this research will not have a bearing on my assignment mark, that the data will become anonymous when processed and agree with its use for research purposes.**

APPENDIX: 4.1b



EXPLORING THE NARDOO

The Blue-Green Algal Bloom Problem

Knowledge Acquisition Schedule ©1998

Post Test

Did you use the Algal Bloom simulator while researching the problem on algal bloom?

YES NO

☐ ☐

1) Blue-green algal blooms are most likely to occur;

- a) in areas of the river which are deep and sunny
- b) in farm dams and behind weirs
- c) in areas where the river is moving quickly
- d) near sections of the river which have high banks

A B C D

☐ ☐ ☐ ☐

2) If you suspect that there is an algal bloom in your farm dam, you should as a short term measure;

- a) make sure that you only collect water from the dams deepest section
- b) boil all the water you collect before you use it
- c) run all the water you collect through a physical filtration process
- d) stop using water from the dam and use an alternative water source

A B C D

☐ ☐ ☐ ☐

3) One of the most devastating aspects of many algal blooms is the release of toxins into the water. Not all blooms progress to this stage, but when they do, the level of toxins in the water usually peaks;

- a) at the same time as the algal bloom is at its maximum
- b) about 4 weeks after the bloom has reached its peak
- c) after the bloom has died away through natural causes
- d) about 10 weeks after the bloom is at its maximum

A B C D

☐ ☐ ☐ ☐

4) The two main chemical pollutants which seem to be directly related to algal bloom in rivers are;

- a) Phosphorus and Oxygen.
- b) Oxygen and Nitrogen.
- c) Phosphorus and Nitrogen.
- d) Oxygen and sulphates.

A B C D

☐ ☐ ☐ ☐

Appendices

- 5) Humans can suffer a number of symptoms after swimming in water which has been contaminated by an algal bloom. These symptoms can include;
- a) shortness of breath
b) hair loss
c) skin rashes
d) skin discolouration
- 6) The reported putrid smell noticed by residents around the river is probably the result of;
- a) the decomposition of algal mats in the river
b) the development of black weed on the river banks.
c) excess nutrients in the water.
d) sewage overflow into the river.
- 7) Some of the ways in which those responsible for catchment management could manage the nutrient problem in a river include;
- a) using herbicides to kill the algae and reduced sewage input.
b) using dredging of the river bed to remove the roots of the algae.
c) reducing the input of nutrients and improving the water flow.
d) introducing some organism which lives on the algae.
- 8) The process by which nutrient levels lead to the development of excessive algal growth which in turn contributes to the lowering of the overall oxygen level in the water as the algae dies and decays is called;
- a) Biodegradation.
b) Respiration.
c) Eutrophication.
d) Photosynthesis.
- 9) You would NOT expect to find significant algal cell growth at river depths below;
- a) 1.4 metres
b) 0.8 metres
c) 0.6 metres
d) 0.05 metres
- 11) After a period of heavy rain, you would expect;
- a) the levels of nutrients in river water to increase
b) the level of oxygen in river water to decrease.
c) the temperature of the water in a river to rise.
d) more fish than usual to die due to the influx of fresh water.

A B C D
☐ ☐ ☐ ☐

A B C D
☐ ☐ ☐ ☐

A B C D
☐ ☐ ☐ ☐

A B C D
☐ ☐ ☐ ☐

A B C D
☐ ☐ ☐ ☐

A B C D
☐ ☐ ☐ ☐

Appendices

- 12) The nutrient which is most critical to the development of dangerous and nuisance bloom in a river is;
- a) Oxygen.
 - b) Phosphorus.
 - c) Nitrogen.
 - d) Sulphates.

A B C D
☐ ☐ ☐ ☐

- 13) You could best describe the pattern of algal bloom in rivers as;
- a) an abnormal phenomenon.
 - b) a cyclic phenomenon.
 - c) a once in a lifetime process.
 - d) a linear process.

A B C D
☐ ☐ ☐ ☐

- 14) During the development of a major nuisance bloom, generally the peak in the growth of the algae in rivers, given the right conditions, occurs within a period of;
- a) 3 to 4 weeks from the start of the process.
 - b) 2 weeks from the start of the process.
 - c) 5 to 7 weeks from the start of the process.
 - d) 12 weeks after the start of the process.

A B C D
☐ ☐ ☐ ☐

- 15) Algal blooms often produce extensive fish kills because among other things they lower the oxygen saturation levels in the water. The critical level of oxygen saturation producing this effect is closest to;
- a) 10%.
 - b) 40% to 50%.
 - c) 85%.
 - d) 90%.

A B C D
☐ ☐ ☐ ☐

- 16) One of the effects of lower water temperature in rivers is that it;
- a) increases the turbidity of the water
 - b) prevents the formation of any algal bloom
 - c) delays the development of an algal bloom
 - d) causes an increase in the nutrient levels

A B C D
☐ ☐ ☐ ☐

- 17) Important physical conditions that affect algal growth include;
- a) the temperature of the water and the number of sunny days.
 - b) the flow rate of the water and the amount of sunlight.
 - c) the amount of sunlight and the size of the fish population.
 - d) the time of the year and the amount of oxygen in the water.

A B C D
☐ ☐ ☐ ☐

- 18) An increase in the concentration of nutrients in river water would be expected;
- a) with an increase in farming around the catchment area
b) with a decrease in the average rainfall.
c) only after heavy flooding.
d) during the winter months.
- A B C D
☐ ☐ ☐ ☐
- 19) Actually measuring the amount of algae that has grown in a river is virtually impossible and therefore it is difficult to get an actual measure of the significance of the bloom. To simplify the process, scientists use as a measure of the mass of an algal bloom;
- a) the concentration of oxygen in the river water.
b) the number of algal cells per litre of river water.
c) the level of change in colour of the river water.
d) the level of smell from the decaying algal mass.
- A B C D
☐ ☐ ☐ ☐
- 20) The oxygen concentration in river water usually drops to a minimum during the algal bloom cycle;
- a) just after the algae begins to grow.
b) when almost all the algae has died.
c) at around the same time that the algal growth reaches a maximum.
d) during the period when algal growth is escalating.
- A B C D
☐ ☐ ☐ ☐
- 21) Provided that there is enough light and other physical factors are within certain tolerances, the essential controlling factor of algal growth in a river is;
- a) the concentration of oxygen in the river water.
b) the surface area of the river.
c) the level of tourist activity on the river during summer.
d) the concentration of nutrients in the river water.
- A B C D
☐ ☐ ☐ ☐
- 22) The optimum water temperature which results in maximal algal growth in rivers would seem to closest to;
- a) 12°C
b) 25°C
c) 17°C
d) 30°C
- A B C D
☐ ☐ ☐ ☐
- 23) Increases in the amount of sewage, industrial waste, animal droppings, pesticides and storm water entering a river all cause;
- a) the smell of the river to get worse during hot weather.
b) the river to become grey in colour.
c) the silting up of the river.
d) the nutrient concentration to increase.
- A B C D
☐ ☐ ☐ ☐

Appendices

- 24) When the concentration of nitrogen in river water is between 1,000 and 2,000 $\mu\text{g/l}$, the corresponding concentration of phosphorus needed to produce a nuisance level algal bloom would be closest to;
- a) 1,000 $\mu\text{g/l}$
 - b) 2,000 $\mu\text{g/l}$
 - c) 4,000 $\mu\text{g/l}$
 - d) 6,000 $\mu\text{g/l}$

A	B	C	D
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

APPENDIX: 4.1c

User Name:.....

Gender (M) (F)

**THE UNIVERSITY OF WOLLONGONG****Faculty of Education**

**Exporing the Nardoo
Research Project
Answer Blank © 1998**

Instructions for Use

- Write your name in the space provided. The data collected from this form will become anonymous when statistically processed.
- For each question, using a pencil or biro, place a cross in either the box a, b, c or d which corresponds to the letter next to the statement which you think best answers the question.
- Ensure that you place a cross in only one box for each.

Question No.	A	B	C	D
1	A	B	C	D
2	A	B	C	D
3	A	B	C	D
4	A	B	C	D
5	A	B	C	D
6	A	B	C	D
7	A	B	C	D
8	A	B	C	D
9	A	B	C	D
10	A	B	C	D
11	A	B	C	D
12	A	B	C	D
13	A	B	C	D
14	A	B	C	D
15	A	B	C	D
16	A	B	C	D
17	A	B	C	D
18	A	B	C	D
19	A	B	C	D
20	A	B	C	D
21	A	B	C	D
22	A	B	C	D
23	A	B	C	D
24	A	B	C	D

**THE UNIVERSITY OF WOLLONGONG****Faculty of Education**

EXPLORING THE NARDOO

The Blue-Green Algal Bloom Problem

Process and Effect Schedule ©1998

Pre Test

Blue-green algal blooms are a natural part of river systems. The relationships between the various factors which cause such blooms and the extent of these blooms are complex. Understanding these complex relationships is essential if we are to be able to study and possibly solve the problems associated with algal blooms.

One way of linking and making use of the new knowledge that you gain in using this computer package is to recognise the **process and effect** relationships that exist in the Nardoo River environment.

Set out on the next page are some of the important effects observed in the river and a list of possible processes which contribute to producing them.

To assess how well you understood the information you accessed while finding a solution to the problem of blue-green algal blooms in the Nardoo River, please complete the schedule over the page by drawing arrows from the processes which produce the effects listed on the left.

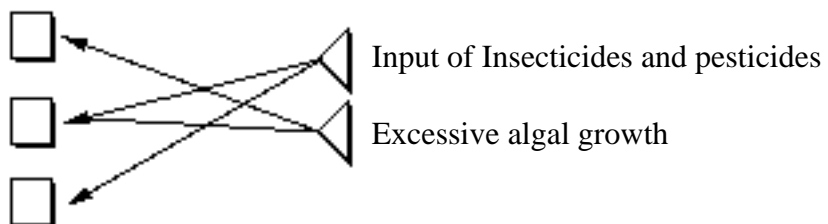
Note that a single process may contribute to more than one effect. Try to link a process to its MOST DIRECT effect using a pencil or biro.

EXAMPLE:

Turbidity

Fish Kills

Eutrophication



NOW Please turn the page and begin.

Name:.....

Gender: (M) (F)

Did you use the Algal Bloom simulator while researching the problem on algal bloom?

YES NO

☐ ☐

EFFECT

PROCESSES

Decrease in Oxygen levels
in the water

☐

Increase in nutrients

☐

Dangerous Algal bloom

☐

Increase in algal cell count

☐

Death of Fish

☐

Increase in Oxygen levels
in the water

☐

Increase in putrid smells

☐

Eutrophication

☐

Increase in turbidity

☐

Decrease in algal cell count

☐

Sickness in Animals

☐

◀ Sewage inflows

◀ Increase in industrial activity

◀ Stormwater drains

◀ Increased Phosphorous levels

◀ Human recreational activities

◀ Algal cell count > 30,000

◀ Algal scum develops on edge of the river

◀ Increase in stream flow

◀ Death of algal bloom

◀ Increase in Nitrogen levels

◀ Input of Insecticides and pesticides

◀ Continuous high water flow

◀ Significant spread of algal growth

◀ River flushing

◀ Increase in toxin levels in the water

◀ Use of fertilizers in the catchment areas

◀ Light levels of 100 to 200 lux

◀ Temperature < 20 degrees

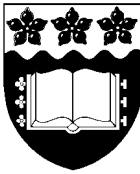
**THE UNIVERSITY OF WOLLONGONG****Faculty of Education****Exploring the Nardoo****USER PERCEIVED VALUE SCHEDULE ©1998**

Please fill in the blank data form at the back of this schedule and
RETURN IT WITH YOUR ASSIGNMENT

- 1) I learned the most about the growth of algae in the package by running the simulation.
- 2) I don't enjoy researching materials from textbooks.
- 3) I think this kind of computer based CD-ROM package makes learning easier.
- 4) I didn't need to use the help function very often to complete the problem.
- 5) While using the blue-green algae simulator I felt that I had control over its operation.
- 6) The controls on the simulator were easy to use.
- 7) The filing cabinet in the water research centre provided me with more information about the causes of algal growth in the river than any of the other available resources.
- 8) I preferred using the simulator to discover the causes and effects of algal blooms in rivers than any of the other resources available to me in the package.
- 9) I found using the simulator confused me rather than helping me.
- 10) I think that the facility to measure various features including levels of nutrients in the river was helpful in learning about the role of such factors in the development of algal blooms.
- 11) I found using the simulator was very simple and easy.
- 12) I learned more about algal growth by reading the references and using the media sections of this package than I did by using the simulator.
- 13) My understanding of the process of algal growth in rivers was improved by "seeing it happen before my eyes" in the simulator.
- 14) When using the blue-green algae simulator, I preferred to use it in the 'graph mode' rather than the animate mode'.
- 15) Learning by using computer software packages is easier than reading a textbook or listening to a teacher.
- 16) I was not able to gain useful information from the simulator until I had used the help section.
- 17) I prefer learning using visual media/representations such as, video clips, graphs, pictures etc.
- 18) I experimented with the different controls on the simulator before I tried to use it to research to problem.
- 19) I had access to the simulator but did not even try to use it because I am not good on computers.
- 20) I am good at maths but found the simulator too difficult to use.
- 21) Simulating the conditions that may produce blue-green algal blooms gave me a better understanding of the process of blue-green algal over-growth in rivers.
- 22) I found that I got lost while working my way through the package and often needed to access the help function.
- 23) I prefer using text based materials to collect information about a topic
- 24) I needed quite a deal of help from the teacher to get started on this package.
- 25) The teacher had difficulty in showing us how to use this package and in helping us with problems we had.

- 26) I could understand the process of blue-green algal blooms more easily by looking at the output from the numerical data windows in the simulator.
- 27) I feel that simulating the “real world” is a more interesting way to learn about things than simply reading about them or being told about them.
- 28) I think that the blue-green algae simulator helped me to understand the causes and effects of excessive algal growth in the Nardoo river.
- 29) I think that I have learned more about ecology in general from the package than I would have learned if I studied the work in the normal classroom or using textbooks.
- 30) I think using the blue-green algae simulator is essential to understanding algal blooms.
- 31) The function of each of the controls on the simulator was clear.
- 32) I think the best thing about the Exploring the Nardoo package in general is that it lets you explore and choose your own areas to research if you wish.
- 33) I found the layout in the package easy to follow and had no trouble finding my way around.
- 34) I don't think it necessary to use the simulator to fully understand the causes and effects of algal blooms.
- 35) Some of the problems could not be answered fully unless you used the simulator.
- 36) I think the package was too detailed and complex. I didn't know where to start or how to go about solving the problem.
- 37) A good feature of this package was that the graphics were clear and easily understood.
- 38) I found the layout in this package confusing because there were too many choices and pathways. I didn't know where to start.
- 39) I looked at all the video clips before I looked at anything else.
- 40) I browsed through the whole package so that I would not miss anything. Then I worked on researching the set problem.
- 41) The ability to swap between the different kinds of output from the simulator, graphic, animation and numerical, was useful and helped me better understand the process at work.
- 42) I think the graphs produced by the algal bloom simulator helped me most in understanding the process.
- 43) I feel that the blue-green algae simulator is an important part of the whole package.
- 44) I think most of the media materials were very useful and provided good support in solving the set problem.
- 45) I became frustrated and didn't get round to completing all the sections because I found it difficult to find the materials I needed to answer some of the parts of the set problem.
- 46) I became frustrated and didn't work through all the sections of this package because it did not interest me.
- 47) I don't think you can fully understand the processes involved in the development of blue-green algal blooms without using the simulator in this package.
- 48) I found the animated output, (depiction of algal growth as it occurred), from the simulator helped me to best understand the process.
- 49) I found the graphical output generated in the simulator helped me most in understanding the process.
- 50) I had no difficulty in obtaining enough information to solve the problem from the filing cabinet, video clips, radio reports and the newspaper articles.

FINALLY: Please tick the [SA] box if you are interested in participating in a short interview about how you found the overall package if you are those selected at random.
I will contact you through Brian or Garry if you are selected.



THE UNIVERSITY OF WOLLONGONG

Faculty of Education

Exploring the Nardoo
USER PERCEIVED VALUE SCHEDULE ©1998
DATA SHEET

NAME:-----

Gender: ☐ [M] ☐ [F]

I USED THE SIMULATOR IN THE PACKAGE

YES] [NO]

Please use this sheet to indicate your level of agreement or disagreement for each of the statements on the accompanying User Perceived Value Schedule.

The letters indicate your level of agreement or otherwise as follows:

SA = Strongly Agree
A = Agree
U = Undecided
D = Disagree
SD = Strongly Disagree

If you cannot respond to a statement for some reason, for example, you did not use the part of the package being referred to, tick the box NA

NA = Not Applicable

Q	SA	A	U	D	SD	NA
1						
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Thank you for your taking the time to complete the questionnaire and for your tolerance and understanding during the whole data collection process. Your input will provide a valuable source of information in the continuing design and development of educational software at the University of Wollongong.

PLEASE RETURN THIS FORM stapled to your ASSIGNMENT

APPENDIX: 4.4

Sample Interview Questions

The duration of each interview was approximately 15 minutes.

The record of interview consisted of notes,

The questions were constructed to provide a general impression from the students perspective of both the package as a whole and in the case of the experimental group, the simulator tool. Not all questions were asked of each interviewee.

Questioning was open, in that the interviewer followed the direction set by the interviewee's responses

Did you enjoy using the package *Exploring the Nardoo*?

Did it help you in finding a solution to the task set? Explain.

What do you think was the best aspect of the whole *Exploring the Nardoo* package?

What do you think the advantages/disadvantages were in using this package to complete the task?

What was the most useful tool in the package? Can you tell me why?

Was the simulator tool useful to you in completing the task? (Experimental only)

Can you elaborate on this?

Did you find it necessary to use the simulator in working through the problem? (Experimental only)

What was the best aspect of the simulator tool? Explain

Did you find this package easy to use? Explain.

Did you find working with a partner useful? Explain.

APPENDIX: 5.1

Pilot Study: Control Group Dataset

Subject	Gender	Pre-Treat KAS	Post-Treat KAS	Pre-Treat CES	Post-Treat CES
1	F	11	16	6	7
2	M	18	13	9	10
3	M	15	16	16	9
4	M	12	18	6	9
5	F	14	15	9	10
6	F	15	14	3	7
7	F	15	16	10	7
8	M	16	17	7	9
9	F	9	13	7	12
10	M	14	14	5	6
11	M	17	13	9	8
12	M	14	15	10	13
13	F	13	14	10	11
14	F	15	14	8	10
15	F	18	14	8	11
16	F	14	15	11	7
17	M	11	13	1	4
18	M	17	17	8	8
19	M	11	15	8	13
20	M	18	19	14	13
n=20	M= 55% F = 45%	14.2 SD=2.6	14.8 SD=1.7	8.3 SD=3.4	9.0 SD=2.5

APPENDIX: 5.2

Pilot Study: Experimental Group Dataset

Subject	Gender	Pre-Treat KAS	Post-Treat KAS	Pre-Treat CES	Post-Treat CES
1	M	19	19	16	25
2	F	14	16	9	18
3	F	13	18	9	19
4	F	7	16	8	15
5	F	16	14	10	10
6	F	12	19	6	13
7	F	8	14	4	9
8	F	7	14	3	11
9	F	14	16	16	19
10	M	12	16	6	10
11	M	13	17	5	10
12	F	12	20	8	12
13	F	14	19	17	15
14	F	12	20	5	12
15	F	16	15	10	19
16	F	15	19	8	13
17	F	10	10	3	4
18	F	9	18	5	19
19	M	12	17	9	17
20	M	5	17	9	10
n=20	M= 25% F = 75%	12.0 SD=3.5	16.7 SD=2.5	8.3 SD=4.1	14.0 SD=4.9

APPENDIX: 5.3

Pilot Study: Paired ‘t’ Test Results

Experimental vs Control Pre/Post KAS scores
Experimental vs Control Pre/Post CES scores

Paired t-Test X₁ : Exp_Pre_KAS Y₁ : Con_Pre-KAS

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	-2.35	-2.18	.0418

Paired t-Test X₂ : Exp_Post_KAS Y₂ : Con_Post_KAS

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	1.65	2.54	.02

Paired t-Test X₃ : Con_Pre_CES Y₃ : Exp_Pre_CES

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	-.05	-.05	.9629

Paired t-Test X₄ : Con_Post_CES Y₄ : EXp_Post_CES

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	-4.8	-4.44	.0003

APPENDIX: 5.3a

Pilot Study: KAS/CES Differences vs Treatment
Paired 't' Test Results

Paired t-Test X₁: Exp_KAS_Diff Y₁: Con_KAS_Diff

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	4	4.1	.0007

Paired t-Test X₂: Exp_CES_Diff Y₂: Con_CES_Diff

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
19	4.8	4.1	.0006

APPENDIX: 5.4

Main Study: Control Group Dataset

Subject	Gender	Pre-Treat KAS	Post-Treat KAS	Pre-Treat CES	Post-Treat CES
1	F	10	16	9	11
2	F	9	15	3	11
3	F	10	15	7	10
4	F	11	16	7	10
5	F	11	16	6	7
6	M	18	13	9	10
7	F	12	15	6	12
8	F	15	17	6	8
9	M	10	8	10	13
10	F	14	15	7	10
11	F	14	14	5	9
12	M	12	15	6	12
13	M	17	17	10	9
14	F	9	12	5	13
15	F	3	9	7	7
16	F	10	17	7	15
17	F	15	16	10	7
18	F	7	14	2	6
19	F	9	19	5	9
20	F	15	15	3	9
21	M	11	17	7	9
22	F	12	17	7	11
23	F	18	16	7	10
24	M	12	12	6	7
25	F	10	17	5	7
26	F	10	16	7	10
27	F	4	10	5	7
28	F	9	1	3	3
29	M	10	14	7	12
30	F	8	16	5	6
31	F	9	11	6	8
32	M	12	14	5	6
33	M	8	14	2	9
34	F	12	12	8	9
35	M	8	13	10	11
36	M	14	15	7	10
37	F	12	18	7	12
38	F	11	10	5	1
39	F	10	18	10	11
40	F	13	14	5	9
41	F	9	10	8	10
42	F	15	14	8	11
43	F	12	17	8	7
44	F	17	7	4	9
45	F	9	7	7	11
46	F	6	11	1	4
47	M	5	12	4	11
48	F	9	13	4	5
49	F	7	14	6	9
50	F	15	15	13	16
51	F	13	17	1	1
52	F	7	11	2	5
53	F	13	14	8	13
54	F	11	14	8	11
55	M	10	14	7	14
56	F	9	11	4	7
57	F	12	12	2	5
n=57	M= 30% F=70%	10.6 DS=3.3	13.72 SD=3.3	6.12 SD=2.5	9.04 SD=3.1

APPENDIX: 5.5

Main Study: Experimental Group Dataset

Subject	Gender	Pre-Treat KAS	Post-Treat KAS	Pre-Treat CES	Post-Treat CES
1	F	7	15	6	9
2	F	10	15	3	7
3	M	12	19	0	9
4	F	17	16	5	16
5	F	12	18	5	16
6	F	11	16	4	16
7	F	12	17	8	18
8	F	13	18	7	18
9	F	15	19	7	12
10	F	14	19	4	14
11	F	16	18	9	14
12	F	13	16	6	18
13	F	11	16	2	11
14	F	12	19	3	11
15	F	16	16	4	14
16	M	17	17	4	18
17	F	10	16	8	15
18	F	8	15	2	6
19	F	12	17	12	19
20	F	10	20	6	14
21	F	14	18	10	13
22	F	12	15	5	14
23	F	13	14	1	7
24	F	9	16	1	7
25	F	17	21	5	12
26	F	12	17	2	20
27	F	13	13	3	11
28	F	9	15	2	11
29	F	10	17	5	17
30	M	9	12	5	16
31	F	14	17	4	12
32	M	8	19	8	18
33	F	10	17	3	6
34	F	13	14	7	9
35	F	12	16	6	12
36	M	12	17	9	14
37	F	11	17	4	16
38	F	11	17	4	7
39	M	13	17	2	10
40	F	12	17	5	15
41	F	13	17	4	16
42	F	8	19	3	12
43	F	14	14	5	6
44	F	12	18	6	6
45	M	8	14	4	9
46	F	10	15	5	11
47	F	6	15	3	11
48	F	15	15	14	20
49	F	12	18	5	19
50	F	12	18	4	11
51	F	13	17	6	19
52	F	15	17	3	10
53	M	16	18	5	17
54	F	12	15	13	12
55	F	14	15	5	12
56	F	15	18	4	14
57	F	12	20	2	12
58	F	13	18	6	12
59	M	16	16	3	19
60	M	18	19	14	15
61	F	18	19	6	10
n=61	M=20% F=80%	12.31 SD=2.8	16.77 SD=1.8	5.18 SD=3.1	13.11 SD=3.6

APPENDIX: 5.6

Main Study: Paired 't' Test Results

Control vs Experimental Pre/Post KAS scores
Control vs Experimental Pre/Post CES scores

Paired t-Test X₁: Con_Pre_KAS Y₁: Exp_Pre_KAS

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	-1.1	-2	.0479

Note: 4 cases deleted with missing values.

Paired t-Test X₂: Con_Post_KAS Y₂: Exp_Post_KAS

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	-3	-6.3	.0001

Note: 4 cases deleted with missing values.

Paired t-Test X₃: Con_Pre_CES Y₃: Exp_Pre_CES

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	1.1	2.2	.0333

Note: 4 cases deleted with missing values.

Paired t-Test X₄: Con_Post_CES Y₄: Exp_Post_CES

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	-4.2	-5.9	.0001

Note: 4 cases deleted with missing values.

APPENDIX: 5.7

Main Study: Paired 't' Test Results (within Groups)

Experimental Pre vs Post KAS scores

Control Pre vs Post KAS scores

Experimental Pre vs Post CES scores

Control Pre vs Post CES scores

Paired t-Test X₁ : ExPreK Y₁ : ExPostK

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
60	-4.5	-12.5	.0001

Paired t-Test X₂ : ConPreK Y₂ : ConPostK

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	-2.8	-5.5	.0001

Note: 4 cases deleted with missing values.

Paired t-Test X₃ : ExPreCause Y₃ : ExPostCause

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
60	-8.1	-15.3	.0001

Paired t-Test X₄ : ConPreCause Y₄ : ConPostCause

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	-2.9	-8.7	.0001

Note: 4 cases deleted with missing values.

APPENDIX: 5.8

Main Study: KAS/CES Differences vs Treatment 't' Test Results

Paired t-Test X₁ : Exp_KAS_Diff Y₁ : Con_KAS_Diff

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	1.9	2.8	.0074

Note : 4 cases deleted with missing values.

Paired t-Test X₂ : Exp_CES-Diff Y₂ : Cont_CES-Diff

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
56	5.3	8	.0001

Note : 4 cases deleted with missing values.

APPENDIX: 5.9

UPS Common Question Responses

Q	Question	Group C/E	SA (n) %	A (n) %	U (n) %	D (n) %	SD (n) %	Result %
2	I don't enjoy researching materials from textbooks.	C	(3) 12	(5) 21	(2) 11	(11) 46	(2) 8	54 (Disagree)
		E	(6) 13	(11) 2	(17) 31	(18) 31	(2) 3	34 (Disagree)
3	I think this kind of computer based CD-ROM package makes learning easier.	C	(5) 21	(12) 50	(7) 29	(2) 9	-	71 (Agree)
		E	(15) 28	(28) 52	(9) 16	(2) 3	-	56 (Agree)
4	I didn't need to use the help function very often to complete the problem.	C	(10) 42	(9) 38	(2) 8	(2) 8	-	80 (Agree)
		E	(21) 39	(26) 48	(2) 2	(5) 9	-	87 (Agree)
7	The filing cabinet in the water research centre provided me with more information about the causes of algal growth in the river than any of the other available resources.	C	(12) 50	(9) 38	(2) 8	(1) 4	-	88 (Agree)
		E	(10) 19	(31) 57	(9) 16	(2) 3	-	76 (Agree)
10	I think that the facility to measure various features including levels of nutrients in the river was helpful in learning about the role of such factors in the development of algal blooms.	C	(5) 21	(12) 50	(3) 12	(4) 17	-	71 (Agree)
		E	(7) 13	(39) 72	(5) 9	(2) 3	(3) 5	85 (Agree)
15	Learning by using computer software packages is easier than reading a textbook or listening to a teacher.	C	-	(13) 54	(4) 17	(7) 29	-	54 (Agree)
		E	(8) 15	(20) 37	(15) 27	(8) 15	(2) 3	52 (Agree)
17	I prefer learning using visual media/representations such as, video clips, graphs, pictures etc.	C	(10) 42	(9) 38	(4) 17	-	-	80 (Agree)
		E	(7) 13	(34) 63	(6) 13	(6) 13	-	76 (Agree)
22	I found that I got lost while working my way through the package and often needed to access the help function.	C	-	-	-	(10) 42	(140) 58	100 (Disagree)
		E	(1) 2	(5) 9	(2) 2	(31) 57	(13) 24	81 (Disagree)
23	I prefer using text based materials to collect information about a topic.	C	(1) 4	(6) 25	(8) 33	(8) 33	(1) 4	37 (Disagree)
		E	(10) 2	(15) 27	(10) 19	(19) 35	(7) 13	48 (Disagree)
24	I needed quite a deal of help from the teacher to get started on this package.	C	-	(2) 8	-	(18) 75	(3) 12	87 (Disagree)
		E	(3) 5	(13) 24	(1) 1	(30) 56	(6) 11	(67) (Disagree)
25	The teacher had difficulty in showing us how to use this package and in helping us with problems we had.	C	-	-	-	(7) 29	(17) 71	100 (Disagree)
		E	-	(3) 5	(4) 7	(20) 37	(27) 50	87 (Disagree)
27	I feel that simulating the "real world" is a more interesting way to learn about things than simply reading about them or being told about them.	C	(1) 29	(14) 58	(2) 8	-	-	87 (Agree)
		E	(15) 27	(28) 52	(5) 9	(3) 5	-	79 (Agree)
29	I think that I have learned more about ecology in general from the package than I would have learned if I studied the work in the normal classroom or using textbooks.	C	(3) 12	(11) 46	(5) 21	(4) 17	(1) 4	58 (Agree)
		E	(7) 13	(27) 50	(17) 31	(3) 5	-	63 (Agree)
32	I think the best thing about the Exploring the Nardoo package in general is that it lets you explore and choose your own areas to research if you wish.	C	(12) 50	(7) 29	(2) 8	-	-	79 (Agree)
		E	(19) 32	(35) 65	-	-	-	98 (Agree)
33	I found the layout in the package easy to follow and had no trouble finding my way around.	C	(7) 29	(17) 71	-	-	-	(100) (Agree)
		E	(10) 19	(29) 54	(6) 11	(9) 16	-	73 (Agree)
36	I think the package was too detailed and complex. I didn't know where to start or how to go about solving the problem.	C	-	(2) 8	(1) 4	(14) 58	(6) 25	83 (Disagree)
		E	-	(8) 15	(5) 9	(30) 56	(11) 20	76 (Disagree)
37	A good feature of this package was that the graphics were clear and easily understood.	C	(6) 25	(16) 67	(1) 4	-	-	92 (Agree)
		E	(15) 27	(31) 57	(5) 9	(3) 5	-	84 (Agree)
38	I found the layout in this package confusing because there were too many choices and pathways. I didn't know where to start.	C	-	(3) 12	(1) 4	(14) 58	(5) 21	79 (Disagree)
		E	(1) 2	(7) 13	(7) 13	(35) 65	(4) 7	72 (Disagree)
39	I looked at all the video clips before I looked at anything else.	C	-	(2) 8	(3) 12	(11) 46	(7) 29	75 (Disagree)
		E	-	(5) 9	(1) 1	(34) 63	(11) 20	83 (Disagree)
40	I browsed through the whole package so that I would not miss anything. Then I worked on researching the set problem.	C	(2) 8	(5) 21	-	(10) 42	(5) 21	63 (Disagree)
		E	(3) 5	(15) 27	(2) 2	(26) 48	(3) 5	53 (Disagree)
44	I think most of the media materials were very useful and provided good support in solving the set problem.	C	(7) 29	(11) 46	(3) 12	(1) 8	-	75 (Agree)
		E	(11) 20	(34) 63	(6) 11	(3) 5	-	83 (Agree)
45	I became frustrated and didn't get round to completing all the sections because I found it difficult to find the materials I needed to answer some of the parts of the set problem.	C	-	-	(4) 17	(12) 50	(7) 29	79 (Disagree)
		E	(1) 2	(7) 13	(2) 2	(37) 69	(6) 11	80 (Disagree)
46	I became frustrated and didn't work through all the sections of this package because it did not interest me.	C	-	(1) 4	(4) 17	(12) 50	(6) 25	75 (Disagree)
		E	(4) 7	(7) 13	(37) 69	(6) 11	-	80 (Disagree)
50	I had no difficulty in obtaining enough information to solve the problem from the filing cabinet, video clips, radio reports and the newspaper articles.	C	(13) 54	(11) 46	-	-	-	100 (Agree)
		E	(22) 41	(25) 46	(3) 5	(3) 5	-	87 (Agree)

APPENDIX: 5.10

**UPS Experimental Simulation Specific Questions:
Responses**

Q	Question	Group Exp	SA (n) %	A (n) %	U (n) %	D (n) %	SD (n) %	Result %
1	I learned the most about the growth of algae in the package by running the simulation.	Exp	(7) 13	(21) 39	(7) 13	(17) 31	(2) 3	52 (Agree) 34 (Disagree)
5	While using the blue-green algae simulator I felt that I had control over its operation.	Exp	(4) 7	(3) 56	(5) 9	(13) 24	(1) 2	63 (Agree)
6	The controls on the simulator were easy to use.	Exp	(9) 16	(35) 65	(3) 3	(5) 9	(1) 2	81 (Agree)
8	I preferred using the simulator to discover the causes and effects of algal blooms in rivers than any of the other resources available to me in the package.	Exp	(3) 5	(18) 33	(9) 16	(22) 41	(1) 2	38 (Agree) 43 (Disagree)
9	I found using the simulator confused me rather than helping me.	Exp	-	(8) 15	(11) 20	(30) 56	(4) 8	64 (Disagree)
11	I found using the simulator was very simple and easy.	Exp	(4) 7	(31) 57	(5) 9	(10) 19	-	64 (Agree)
12	I learned more about algal growth by reading the references and using the media sections of this package than I did by using the simulator.	Exp	(7) 13	(18) 33	(12) 23	(17) 31	-	46 (Agree) 31 (Disagree)
13	My understanding of the process of algal growth in rivers was improved by “ seeing it happen before my eyes” in the simulator.	Exp	(5) 9	(34) 63	(9) 16	(4) 8	-	72 (Agree)
14	When using the blue-green algae simulator, I preferred to use it in the ‘ graph mode’ rather than the animate mode’ .	Exp	(2) 3	(21) 39	(14) 26	(13) 24	(1) 2	42 (Agree) 26 (Disagree) 26 (U)
16	I was not able to gain useful information from the simulator until I had used the help section.	Exp	-	(5) 9	(9) 16	(32) 59	(6) 8	66 (Disagree)
18	I experimented with the different controls on the simulator before I tried to use it to research to problem.	Exp	(8) 15	(39) 72	(3) 5	(4) 7	(2) 3	87 (Agree)
19	I had access to the simulator but did not even try to use it because I am not good on computers.	Exp	-	(2) 1	(5) 9	(31) 57	(16) 30	86 (Disagree)
20	I am good at maths but found the simulator too difficult to use.	Exp	-	(6) 8	(14) 26	(17) 31	(15) 29	60 (Disagree)
21	Simulating the conditions that may produce blue-green algal blooms gave me a better understanding of the process of blue-green algal over-growth in rivers.	Exp	(10) 19	(35) 65	(5) 9	(1) 2	(1) 2	84 (Agree)
26	I could understand the process of blue-green algal blooms more easily by looking at the output from the numerical data windows in the simulator.	Exp	(2) 5	(23) 43	(13) 24	(10) 19	(4) 7	48 (Agree) 26 (Disagree) 24 (U)
28	I think that the blue-green algae simulator helped me to understand the causes and effects of excessive algal growth in the Nardoo river.	Exp	(7) 13	(36) 67	(7) 13	(4) 7	-	80 (Agree)
30	I think using the blue-green algae simulator is essential to understanding algal blooms.	Exp	-	(19) 35	(10) 19	(20) 37	(4) 7	35 (Agree) 44 (Disagree)
31	The function of each of the controls on the simulator was clear.	Exp	(3) 5	(31) 57	(13) 24	(7) 13	-	62 (Agree)
34	I don’ t think it necessary to use the simulator to fully understand the causes and effects of algal blooms.	Exp	(5) 9	(26) 48	(8) 15	(11) 20	-	57 (Agree)
35	Some of the problems could not be answered fully unless you used the simulator.	Exp	-	(10) 19	(20) 37	(23) 43	(1) 2	37 (Undecide) 45 (Disagree)
41	The ability to swap between the different kinds of output from the simulator, graphic, animation and numeric, was useful and helped me better understand the process at work.	Exp	(8) 15	(26) 48	(14) 26	(3) 5	-	73 (Agree) 26 (U)
42	I think the graphs produced by the algal bloom simulator helped me most in understanding the process.	Exp	(3) 5	(21) 39	(12) 23	(17) 31	(1) 2	44 (Agree) 33 (Disagree)
43	I feel that the blue-green algae simulator is an important part of the whole package.	Exp	(3) 5	(30) 56	(12) 23	(8) 15	-	61 (Agree) 23 (U)
47	I don’ t think you can fully understand the processes involved in the development of blue-green algal blooms without using the simulator in this package.	Exp	(1) 2	(10) 19	(16) 30	(22) 41	(3) 5	30 (Undecide) 46 (Disagree)
48	I found the animated output, (depiction of algal growth as it occurred), from the simulator helped me to best understand the process.	Exp	(1) 2	(10) 19	(14) 26	(27) 50	-	21 (Agree) 26 (Undecide) 50 (Disagree)
49	I found the graphical output generated in the simulator helped me most in understanding the process.	Exp	(3) 5	(19) 35	(14) 26	(17) 31	(2) 3	40 (Agree) 26 (Undecide) 34 (Disagree)

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