A METHOD FOR IMPUTING ECONOMIC VALUE TO ECOLOGICAL GOODS AND SERVICES PROVIDED BY THE KNYSNA RIVER

A thesis submitted in fulfillment of the requirements for the degree of

MASTERS IN SCIENCE

of

RHODES UNIVERSITY

by

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January 2008

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ABSTRACT

The purpose of this thesis was to develop a method by which economic value can be imputed from an economic activity to a non-market ecological function or service which contributes to that economic activity. The Knysna River in South Africa was chosen as the ecological function which supported three economic activities from which value was to be imputed; these were the Knysna Municipal Water Supply, Fish Production in the Knysna Estuary and Production of Indigenous Forest within the Knysna Catchment. Three underlying assumptions and two functional operations were required in order to implement the suggested method. The underlying assumptions were:

- The ecological and economic activities considered are within a single catchment.
- The allocation of value imputed for a specific economic activity to the ecological function or service under consideration (in this case the Knysna River) is proportional to the total contribution of ecological functions or services contributed to the economic activity.
- The valuation of the economic activity for the purposes of obtaining a price-quantity point on a demand function is to be full cost pricing with no producer surplus.

The two functional requirements were:

- Diagram or map the linkages between an economic activity and the supporting ecological functions.

- Determine the consumer surplus related to an incremental change in quantity under a demand function where the original price and quantity are known.

A value from each of the economic activities was imputed to the Knysna River. However, the method was not tested. Nonetheless applying the equations and collecting the required data allowed several methodological needs to be clearly pointed out. The most acute deficiency was difficulty in obtaining secondary data from governmental agencies, commercial representatives and existing published academic research to ensure a robust price. Also, scientific information was not sufficiently available for allocating ecological contributions to the economic activities. Even with the shortage of credible data the method appears to allow non-market ecological functions to be valued in context of an existing economic system.

ACRONYMS AND ABBREVIATIONS

AE	Actual above ground evapotranspiration
CE	Choice experiments
CIF	Cost of Indigenous Forest
CM	Choice modeling
CNC	Critical natural capital
CS	Consumer surplus
CSS	Conservation Support Services
CVM	Contingent valuation method
DEAT	Department of Environmental Affairs and Tourism
DIN	Dissolved inorganic nitrogen
DWAF	Department of Water Affairs and Forestry
EC	Ecological contribution
EE	Ecological economics
EIA	Environmental impact assessment
ERF	Equivalent riverflow
ES	Environmental service
FC	Sustainable fish catch
FP	Fish Production
GIS	Geographic information system
GUMBO	Global Unified Metamodel of the Biosphere
HPM	Hedonic pricing method
IF	Indigenous Forest
KB	Knysna Basin
KR	Knysna River
KRCA	Knysna River Catchment Area
MA	Millennium Ecosystem Assessment
MAP	Mean annual precipitation
MB	Marginal benefits
NAAP	Net annual above-ground productivity
NCEE	Neoclassical environmental economics
NEMA	National Environmental Management Act
NOAA	US National Oceanic and Atmospheric Administration
NWA	National Water Act 1998
OC	Opportunity cost
PES	Payment for environmental services
SANParks	South African National Parks
SAWS	South African Weather Service
TCM	Travel cost method
TEV	Total Economic Value
TV	Total Value
UNEP	United Nations Environmental Program
VES	Value of environmental services
WCED	World Commission on Environment and Development
WTP	Willingness to pay

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ACKNOWLEDGEMENTS

The support of many people was required for this thesis but whatever their contribution any errors or misapplication are my responsibility. I am grateful for the efforts and patience of my advisors and specifically would like to thank Dr James Gambiza, Department of Environmental Science, and Professor Geoff Antrobus, Department of Economics, Rhodes University. Prof. Antrobus contributed greatly to the development of the economic ideas, reviewing the substance of the economic aspects of the study, providing suggestions for resources and suggesting the format for presenting equations and diagrams. Dr. Gambiza spent many hours working with me on the scientific context and suggesting methods and resources for integrating the science and economics of the thesis. I would also like to extend grateful appreciation to Professor Brian Allanson (RU, Retired) for sharing his wide ranging and insightful knowledge of the Knysna Estuary with me. I would also say that Professor Allanson has been supportive and generous in his willingness to read and re-read my original drafts, discuss with me the estuarine system and thereby introduce me to an understanding of the Knysna Estuary which I would not have otherwise obtained. Of great importance to me was the time and advice of Professors of Rhodes University, Denis A. Hughes and Alan K. Whitfield. Each freely contributed time for discussion, research material and insights into the ecological system. I would also specifically acknowledge the advice, interest and time of doctoral candidate and instructor at Rhodes University, James Juana, whose contribution to my understanding of the mathematical dimension of economics allowed me to make a transition between science and economics.

To the Knysna office of SANParks Johan and Marie Baard, Armin Seydack and other members of the staff who spent a great deal of time pulling together indigenous forest data, revenues and cost, thank you! A special thanks to my friend and former Park Warden Peet Joubert who has been with me from the beginning of this project and has spent hours locating sources and discussing with me the connections between economics of the Knysna Basin and River. And to the Knysna Municipality, particularly city engineer, Neil Perring, thank you for graciously allowing me access to engineering reports, water and rainfall data and taking the time to discuss with me the water distribution system and water requirements of the Municipality.

I would also like to thank the two anonymous independent reviewers of the thesis. Their comments were thoughtful, insightful and helpful. Their comments brought a focus to the material which has expanded my own understanding of ecological contributions to economic products.

And finally I would like to thank my wife Hilary and daughter Sophie for being supportive and giving me time off from family duties for these last three years.

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CHAPTER 1

1 INTRODUCTION

1.1 General Introduction

The National Environmental Management Act (NEMA) (107 of 1998), section 2(3) provides that "Development must be socially, environmentally and economically sustainable" (Republic of South Africa 1998a). It has been difficult for the Department of Environmental Affairs and Tourism (DEAT) to comply with NEMA's mandate and address the issue of economic sustainability in the context of environmental impact because of lack of capacity (SAN Parks & DEAT 2001) and because to do so may, in certain instances, place the DEAT in conflict with local government's decision to allow development (Erasmus *et al*. 2007). Recently the Constitutional Court of South Africa ordered DEAT to determine the sustainability where such determination is required for development (Erasmus *et al.* 2007). Erasmus *et al*. (2007) specifically instruct DEAT to determine the economic cost to the environment.

It is the purpose of this thesis to suggest a method by which economic value can be imputed from an economic activity to an ecological function or service which contributes to the economic activity. Three assumptions have set boundaries for the process described herein. First, the economic and ecological activities considered are within a single catchment. Second, the allocation of imputed value shall be in the same proportion as the ecological function or service under consideration is to the total ecological contribution to the economic activity. Third, the valuation of the economic activity for the purposes of obtaining a price-quantity point on a demand function is assumed to be at full cost pricing with no producer surplus. The price-quantity point is required for the calculations used for imputation of value to ecological functions and services. Chapter 3, Materials and Methods, describes these equations and the data used.

Some comments are required here in connection with the basic assumptions described above. The use of a catchment as a physical unit for identifying the related ecological and economic activities has the benefit of containing natural functions such as riverflow, rainfall, prevailing winds, soil, flora, fauna and in most instances known elevations above sea level. This is not to say that there are not biological overlaps with other catchments, including removal from and contributions to adjacent and distant catchments. Bees, birds, humans, and wind are examples of transporters for biological diversification.

The allocation of economic value based on ecological contribution to a specific economic activity can be more complex than the examples employed here. In this thesis the examples are simple economic activities based on functions and services within the local catchment. More complex economic activities, such as manufacturing processes utilizing materials from outside the catchment or creating pollution impacting areas outside the catchment, required statistical and scientific tools which time limitations for this thesis did not allow to be applied or developed.

Finally, the use of values based on full-cost pricing and without producer surplus raised issues related to the method(s) for determining the full cost of commercial inputs sans producer surplus. This is not an insurmountable concern. It can, however, be tedious in the sense of reviewing commercial inputs and determining or estimating consumer surplus for each input. A more intractable matter in commercial production is the valuation of costs of environmental inputs into production where less than full value is paid for the environmental input. One example of this is in pollution control where costs are incurred for reducing pollution but not eliminating manufacturing or life cycle pollution completely. These partial cost issues are not addressed in this thesis; but, again as a set of concerns, they are not insurmountable.

1.1.1 The Focus of the Study

The Knysna River catchment on the southern coast of South Africa was chosen as the physical location for gathering information for the purpose of developing a method for imputing economic value to the flow of the Knysna River. The Knysna River flow was one ecological input that contributed to three separate economic activities within the catchment. The three economic activities chosen were: 1) the Knysna municipal water supply, 95 % of which is obtained from the flow of the Knysna River; 2) fish production in the Knysna Estuary which is contributed to by the flow of the Knysna River; 3) indigenous forest production which is contributed to by rainfall as an equivalent river flow (ERF) of the Knysna River. Each of the three economic activities utilizes riverflow in a different manner as a contribution to the economic product. At this point it may be helpful to note that each of the economic products is created by the ecological system within the catchment. In the usual and customary sense a manufacturing process is not involved in the creation of these products. However, in another sense, the interactions of the biological and abiotic inputs are a variable, complex and elaborate process. It is a challenge to tease out the principal contributions by the ecological system, whether the process is manufacturing or a natural structure and function.

In each of the three economic activities the effort was to determine the contribution of the Knysna River flow to the end product as a portion of the total ecological contribution. In the use of water for the municipality the contribution was 100% riverflow. However in the other two products, fish and indigenous forest, riverflow was one of other biological and abiotic contributions.

After the ecological contribution of the riverflow was determined as a proportion of the total ecological contribution it was quantified in economic terms by allocating the same portion of the total economic value of the ecological contribution to the economic product. The total economic value of the ecological contribution was determined by application of a series of equations derived from a procedure for integration under a demand curve provided by Professor Robert A. Young (hereafter referred to as Young's equation) (Young 2005a). This procedure is described in the following sections on materials and methods and calculations. The effect of applying the foregoing calculations is to address certain difficulties in valuation when applying the sustainability rules required by NEMA (Republic of South Africa 1998a).

1.1.2 Objectives

The method for valuation suggested herein is described in three examples. Underlying the functional description of these examples is an intention that the method is transportable, meaning that it can be applied in most cases where ecological valuation is required; that it is simpler and less expensive to apply than other methods for valuation currently in use and that it is more credible. In this thesis the effort is to describe simple applications of the method in order for future iterations to be encouraged through subsequent application of economic and scientific procedures. There has been no attempt to establish credibility in the sense of testing the method. The suggestion is made that one procedure to test the method for imputing value is via a dynamic systems model whereby various databases can be employed for responsiveness to scientific and statistical standards; these and other economic equations can be tweaked and substituted in order to assure conformance with reality.

There are two fundamental concepts used in the development of the method to assign monetary value to ecosystem services which are herein defined in the context of Blignaut and de Wit (2004a), to wit:

a) Consumer Surplus is defined as: “The net benefit realized by consumers when they are able to buy a good at the prevailing market price. It is equivalent to the difference between the maximum price consumers would be willing to pay and that which they actually pay for the units of the good purchased. Graphically, it is the triangle above the market price and below the demand curve.”
b) Marginal Benefit is defined as: “The increase in total benefit consequential to a one-unit increase in the production of a good.”

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

2.1.1 Perspective on Literature Review

There is difficulty with current methods for attributing economic value to certain non-market ecological functions and services which support economic activities such as development (Larson 1993; Patterson 2002). Because development is specifically required by South African law to be sustainable, it seems appropriate to investigate a new method for imputing value to those ecological functions and services which support existing or proposed development. In this literature review note will be taken of the current applicable South African law which requires there be social, environmental and economic sustainability in development. Further, a selection of the current frameworks and methods for valuing ecological functions and services will be identified. Following which, certain deficiencies with frameworks and methods used for evaluation will be described. Finally, a method will be suggested for imputing economic value to specific ecological functions and services which occur and contribute as inputs to economic activity within the context of a single catchment.

2.1.2 South African Law and the Global Context

The South African constitution requires environmental evaluation of development to be based on ecological sustainability (Republic of South Africa 1996) . The legislation of South Africa expands the term to include three components of sustainable development. As defined by NEMA (Republic of South Africa 1998a) these elements are ‘‘… the integration of social, economic and environmental factors… so as to ensure that development serves present and future generations….”. Further, NEMA states, “Development must be socially, environmentally and economically sustainable” (Republic of South Africa 1998a). Although the words of the legislation are clear, implementation of the economic element of sustainability has fallen short in environmental decision making. Two reasons for the failure to integrate the economic and ecological systems appear to be that there is a need for further research in order to "… understand the basic functions which ecosystems provide and translate these into the various socio-economic and cultural… values to society" (Ledoux & Turner 2002) and second, because both economic and ecological systems are complex (Costanza *et al.* 1993) without clear linkages between the two in many areas (Fromm 2000). Other reasons for South Africa's failure to bring clear focus to the economic value of ecological contributions may be that there is a lack of manpower and political will to implement the sustainability criteria on the part of the South African administering agencies (SAN Parks & DEAT 2001; Cowling 2005a).

On an international scale sophisticated efforts are being undertaken to grapple with the transdisciplinary nature of a growing global economy embedded in a stressed environment; such research is being funded and actively conducted (Boumans *et al*. 2002; Patterson 2002; Ropke 2004). Global efforts such as the Millennium Ecosystem Assessment (MA) bring powerful assistance to both international and local decision makers because of the detailed analysis of the links between the environment and economies (UNEP 2005). The inclusive representation and collaboration evidenced by the MA, in addition to wide ranging analysis, created typologies and language tools which the world community can use to address complex problems. Further, the Stern Review on the Economics of Climate Change (released on October 30, 2006) associated global warming with the world's growing industrial output and in so doing demonstrated specific inadequacies in substance and methods by which the world governments and businesses are addressing the relationship between economic and ecological systems (Stern 2006). The international community is clearly concerned with the need for all economies to identify ecological costs, eliminate or internalize those costs and reduce the impact on society and the environment. In developing countries, including South Africa with its bifurcated economy, at a local level, there appears to be a need for a simplified, relatively inexpensive, method for economic valuation of the contribution of ecological functions and services to local development activities (Blignaut & De Wit 2004b).

2.2 Current Methods for Valuing Ecological Contributions to the Economy

2.2.1 Overview

The economy is now thought of by some as being embedded in the ecological system as well as arising out of nature (Ropke 2004; Schabas 2005a). This view will be adopted for the purposes of this thesis although it is not the view of neoclassical economists (Schabas 2005b).

The embedded nature of the economy has created an interface between science and economy which has in turn revealed transdisciplinary complexities (Costanza *et a.l* 1993; Baumgartner *et al*. 2001; Daly & Farley 2004a). Two significant aspects of this interface which underlie many of the difficulties in valuation are the conditions observed as thresholds and the presumed non-market contribution to the economy of certain functions and services of the ecological system (Ledoux & Turner 2002).

Thresholds have a dramatic impact on value and on the environment (Islam, Munasinghe, & Clarke 2003). Non-market contributions by the ecological system to the economy create ambiguity in decision making and policy (Baumgartner *et al.* 2001; Blignaut & De Wit 2004b). In this thesis thresholds will not be a focus. Instead, non-market values (Blignaut & De Wit 2004b) of ecological inputs into economic products will be addressed. Specifically, the thesis will concentrate on methods for determining non-market values of water as it is found in the Knysna River.

2.2.2 Framework Diagram

One technique for viewing methods of valuation is via a framework diagram. It is possible that a framework, at best, is an over simplification of ecological-valuation relationships and, at worst, is an inadequate method of demonstrating the actual relationship between values and ecosystem goods and services. Nonetheless, by some, frameworks are considered to be powerful tools (De Groot, Wilson, & Boumans 2002; Ekins & Simon 2003; Blignaut & Lumby 2004). As a positive aspect, the type of framework represented by Figure 1 distinguishes, as categories under "Total Economic Value" (TEV), different "use" and "non-use" values and illustrates in this category multiple interfaces between people and the environment through a suite of ecosystem goods and services. Further, the framework depicted by Figure 1 is useful because it provides a method, within the concept of TEV, for organizing one's thoughts and avoiding double counting when assessing a subcategory of TEV.

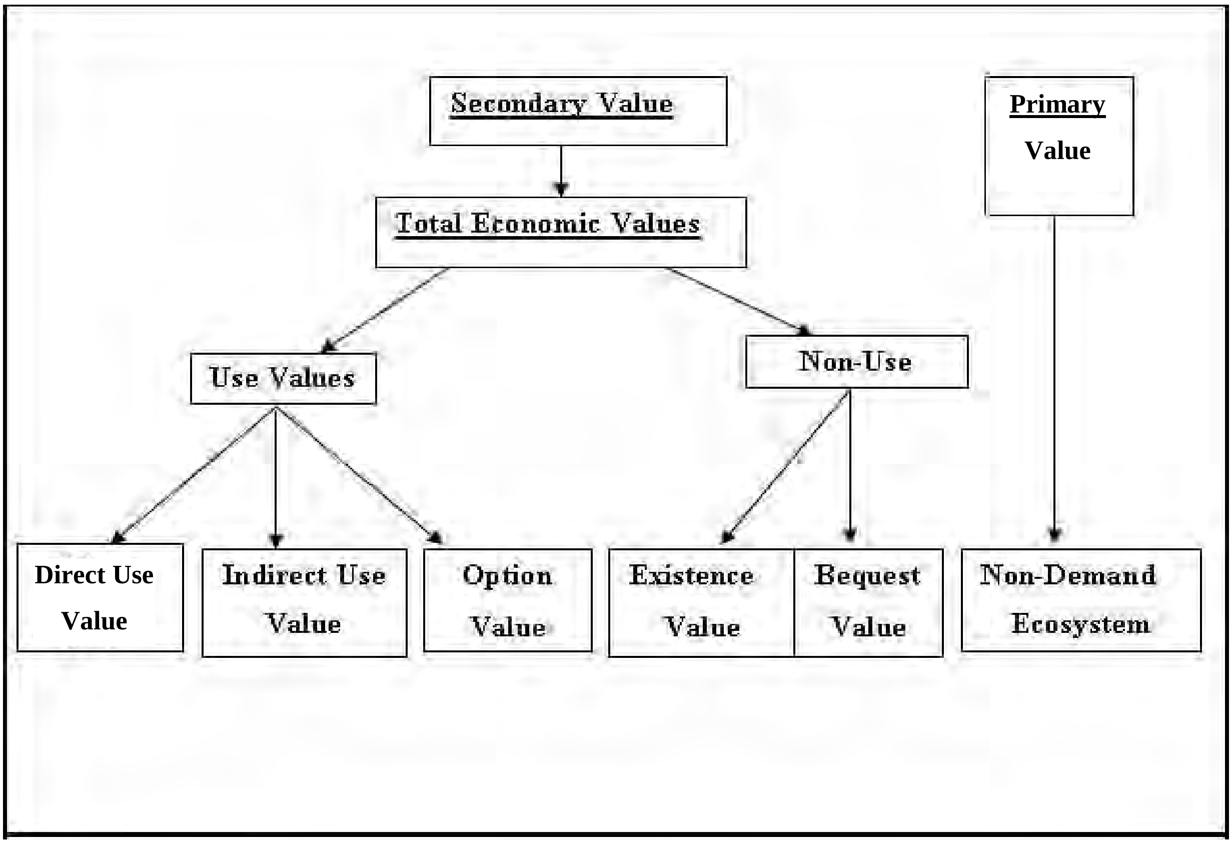

FIGURE 1. A categorization of environmental values. Adapted from: Blignaut & de Wit, (2004a)

There are however inadequacies in the construction and use of the frameworks as depicted by Figure 1. which is an adaptation of Figure 3.2 of Blignaut & de Wit (2004a); itself a further adaptation from a text by Turner, Pearce & Bateman (1994). Although useful as a visualization of the categories of environment values, Figure 1 presents a disconnected relationship between what is labeled as primary value and secondary value of the environment. A disconnected relationship between the ecological system and the embedded economic system does not actually exist. Any economic product will have a connection with what is labeled as a "non-demand ecosystem". Consequently, by employing frameworks as depicted in Figure 1, difficulty is created in perceiving the accurate relationship between economic value of a specific product and contributions provided by functions or services of the environment. A suggested resolution of this disconnection is that the contribution of the primary value of the ecological system to a specific economic product must be recognized. Blignaut & de Wit (2004a) comment on relating economic value to ecological functions and services, "…although it is conceptually straight forward to include the value of natural and environmental resources in economic analysis, it needs to be highlighted that various different philosophies exist on how this should actually be done. In many cases there are fundamentally different positions on what constitutes value and what does not. It is our view that a careful exposition of the monetary value of the environment is a very important step forward, but that these results should be generated and interpreted within the context of the specific problem." The criticism of "frameworks" is not to suggest that economists do not consider total value TV (Primary Value plus TEV). However, it is a criticism of "frameworks" that all value and all economic valuation techniques are based on the value of ecosystem goods and services to people (Fromm 2000; Nuppenau 2002; Cavuta 2003). Fromm (2000) uses a categorization where the third category is designated as 'services for human use' and categories one and two are for the functionality of ecological systems. In regard to contribution to human welfare he states, "…the economic relevance of structures and functions of ecosystems and the resulting necessity for including them in the total economic value was demonstrated: It follows from their input functions for the production and individual values and the protection services for human capital, man made capital and natural capital (as output) (Fromm 2000)."

The second inadequacy of the framework represented in Figure 1 (or some variation thereof) is that it presents "TEV" by typologies which are categorized as "use" or "non-use". These constructs reflect little, if any, linkage of the contribution of ecological functions and services to economic activities. The terminology extends to words such as existence value, consumptive use and non-consumptive use which supposedly reveal the activities of a consumer and not the input of the ecological system. The discrepancy in the framework (or model) can be understood more clearly in terms of "pure" existence value which sounds useful in terms of the framework but actually has less usefulness in the context of people's real choices (Larson 1993). If the effort to value ecological contributions to the economy is for the purpose of sustainability it is necessary to maintain the focus on the viability of functions and services provided by the ecological system (Ekins & Simon 2003; Daly & Farley 2004b). In order to reveal economic value contributed by the ecological system, the issue is, 'What are the specific ecological functions and services which contribute to a specific economic activity?' One example of addressing this question would be the valuation of carbon sequestration via a dynamic systems economic-ecological model which would reveal the interactions between ecological and economic processes (Kundhlande, Adamowicz, & Mapaure 2000). Such modeling would require credible input, i.e. what are the specific contributions of the environment (Prisley & Mortimer 2004)?

Another framework which incorporates ecological functions and services but does not attempt to aggregate and weigh up the economic values is illustrated in Figure 2 (De Groot, Wilson, & Boumans 2002).

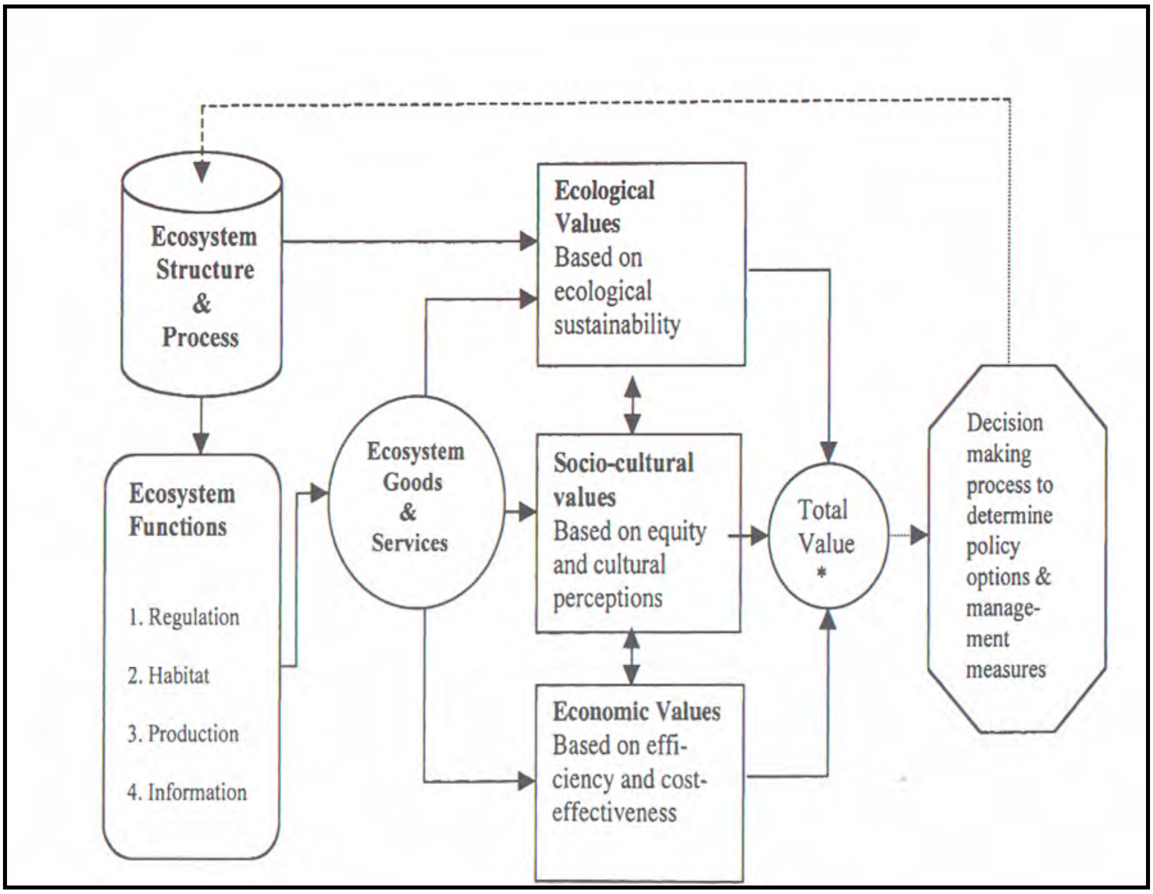

FIGURE 2. Framework for valuing environmental functions, goods and services. Adapted from: De Groot *et al*. (2002)

The de Groot *et al*. (2002) framework and paper is helpful because Table 1 (in section 2.2.4, hereafter) describes in detail 23 ecological functions and the related services which refer back to the framework (Figure 2). The difficulty with the de Groot *et al*. (2002) framework is that economic values, ecological values (based on ecosystem structures and processes) and socio-cultural values (based on equity and cultural perceptions) appear as three separate types of values without any indication as to where (or under what conditions) transition between values takes place. De Groot *et al*. (2002) acknowledge the complexity of applying economic value only to sustainable use of ecological functions and services and move on to say that the focus of the paper is to suggest linkages between methods for valuation and presumably sustainable functions and services provided by the ecology. De Groot *et al*. (2002) refer to the work of Limburg *et al*.

(2002), Howarth & Farber (2002), Wilson & Howarth (2002) and Farber *et al*. (2002) to further discuss the values identified by the framework.

Limburg *et al*. (2002) address the concept of different values by suggesting that ecological economists must "…understand and appreciate the inherent complexities of ecological and economic systems, particularly as the dynamics of the latter increasingly affect those of the former" and "…no single valuation scheme will work well over all circumstances." In summary, the value of frameworks is limited and in most cases they fail to present an accurate picture of the relationship between the ecological system and the embedded economic system. The method of valuation suggested in this thesis will address this failure.

2.2.3 Current Techniques for Valuing Ecological Contributions

The recent need for valuation of ecological functions and services arises out of the application of the principle of sustainable development. Prior to the Bruntland Report, produced by the World Commission on Environment and Development (WCED), sustainability was generally understood to mean economic sustainability (WCED 1987). The change in interpretation was to view sustainable development as being organized around the three elements of economics, environment, and social development (WCED 1987; Republic of South Africa 1998a).

Today, almost twenty years later, most ecological functions and services do not have market values. This condition has created two factors which have led to the evolution of neoclassical environmental economics (NCEE) and possibly, the creation of ecological economics (EE) (Muller 2001). The first of these factors is the assumed conflict between ecology and economics (Schabas 2005c) and the second comprises methods by which economics assimilates ecological issues into its analysis and theoretical structures (Muller 2001). According to Muller (2001) EE is one of the strongest critics of NCEE and the methodological critique is the most focused criticism. There are two primary methods issues for EE. The first is that NCEE is reductionist orientated and insists on monetary valuation and criteria. The second methods issue raised by the pragmatic section of EE is that the enlightened branch of the NCEE has not lived up to its methodological potential (Muller 2001). In regard to the second methods issue, Muller (2001) contends there are two illustrations of failure to live up to such potential: a) undeveloped techniques such as contingent valuation methods and b) the reluctance to recognize ecological constraints as expressed by the safe minimum standards criteria.

Muller's (2001) concern with undeveloped valuation techniques [(a), above] may have been partially addressed subsequent to 2001 by choice experiments. The evolution of choice modeling (CM) as a tool for environmental valuation has attracted considerable research attention (Hanley, Mourato, & Wright 2001; Sturm & Weimann 2006a). Although there are variants of CM, the approach known as choice experiments (CE) (where the consumer is asked to choose between two or more alternatives and one of the choices is the *status quo*) perhaps has the potential to resolve some of the biases associated with standard contingent valuation (Hanley, Mourato, & Wright 2001). However, if the analysis presented by Hanley, Mourato and Wright (2001) is accurate, CE are not as yet sufficiently robust to resolve the deficits found with contingent valuation nor are CE an answer to environmental valuation. Further, current research seems to suggest that human behavior is more complex than the standard characterizations of consumer choice theory of NCEE which in turn leads to the possibility of rethinking and consideration of further reformulation of consumer choice theory (including CE) as it relates to environmental valuation (Gowdy & Mayumi 2001; DeShazo & Fermo 2002c; Caldas, Costa, & Burns 2007).

Although EE does not have the answers to deficits in choice theory or environmental valuation (Gowdy & Erickson 2005a), within the context of the two methodological failures claimed by EE, there are specific definitions and connections which relate to both NCEE and EE (Sugden 2001; Boyle & Bergstrom 2001; Carson, Flores, & Mitchell 2001). A point of connection as well as a focus of criticism between NCEE and EE is their commonly held methods of non-market valuation. This commonality leads Muller (2001) to conclude that NCEE is not the vehicle with which to complete the valuation exercise necessary for a transformation of the human-ecological relationship. Although there is a vicious debate (Gowdy & Erickson 2005c), Muller (2001) concludes that EE is not sufficiently theoretically underpinned to take up the task of paradigm shift for non-market valuation.

In effect this conflict appears to dictate a period of uncertainty in non-market valuation of ecological goods and services (Sturm & Weimann 2006b; Caldas, Costa, & Burns 2007). As further emphasis, the functional uncertainty and lack of confidence in valuation techniques can be seen most specifically in developing countries and countries in transition (Rietbergen-McCracken *et al*. 2000). In a series of case studies from Africa and Asia, Rietbergen-McCracken & Abaza (2000) point out in detail the weaknesses in valuation techniques which arise out of process and context when applied in developing and transition countries. In summary, it can be stated that the capability to make viable links between the cultural, economic and ecological components of sustainable development turns on developing credible methods for valuation (WCED 1987; Dietz & van der Straaten 1992; Wilson & Howarth 2002).

2.2.4 Application of Valuation Techniques

Two assessments arise when considering application of monetary valuation techniques. The first is whether or not it is appropriate to place a monetary value on an ecological contribution. The second assessment is what technique can be applied and what quality the output is.

Regarding the first assessment, in order for valuation techniques to be credible the question must be asked, 'When is application of monetary value to ecological functions and services appropriate?' This question assumes there are instances when ecological functions and services have no monetary value or, even though there is monetary value, it should not be applied. Following on to this assumption is the further implication that where monetary valuation is not appropriate some 'other' valuation method is applicable and that these 'other' valuations,"…are not additive…[to the monetary value[1]] they are a different dimension of value" (Turner 2001). The foregoing is just another way of addressing the ongoing debate of where to draw the line when valuing non-market ecological functions and services. In responding to this dilemma Turner (2001) is quite clear that the ecological and economic systems are jointly determined and for either or both systems to remain healthy the ecological systems must be protected. Turner (2001) acknowledges the weaknesses in the contributions of science and economics in their attempts to identify and value the thresholds of ecology. Turner (2001) then concludes that because it is not possible to apply monetary values to the full range of ecological contributions, an interim solution is necessary. He suggests a transitional method for protecting ecological systems, one which requires adherence to flexible criteria such as the Precautionary Principle and a Safe Minimum Standard where the burden is placed on developers to prove that the criterion has been observed (Turner 2001).

The difficulty with suggesting that application of valuation techniques is only credible when outside the limitations of the Precautionary Principle or Safe Minimum Standard is for the reason that such limitations create alibis for retarding economic and environmental policy by saying

[1] Brackets are mine.

‘more research is needed’ (Dietz & van der Straaten 1992). In order to install dependable valuation techniques it will be necessary for the National Government to exhibit a robust political will which compels tying economic and environmental policy in design as well as execution. The effect of tying such policies will be to override the vested traditional standards of Gross Domestic Product, employment and balance of payments, among others (Dietz & van der Straaten 1992; Maasdorp 2001).

The first assessment is critical, but in South Africa, today, monetary valuation is not being undertaken in many instances because government agencies charged with the responsibility for determining sustainability do not have the guidelines or tools to know when to insist on monetary valuation (SAN Parks & DEAT 2001). In July 2007, the Constitutional Court of South Africa ruled that the government must balance environmental and development needs by using the principle of sustainable development. In so doing the environmental authority is required by law to tie economic, environmental and social criteria and consider individual as well as cumulative impacts. The Court also said that in making the authority’s decision the Precautionary Principle “… is applicable where due to unavailable scientific knowledge there is uncertainty as to the future impact of the proposed development” (Erasmus *et al*. 2007).

The second assessment has to do with functional application of a specific valuation technique to assess the value of ecological services provided humans. If there is a market for the ecological function or service the market value will apply. Otherwise, it will be necessary to apply a valuation technique to suit a particular condition.

Figure 3 is a graphic description of alternative valuation techniques used to assess environmental goods and services when there is a change in productivity or a change in environmental quality. These are not all of the techniques available nor are they all of the ecological contributions to which the techniques may be applied. The graphic (Figure 3) is adapted to show that certain valuation techniques may be applied when there is a known relationship (link) between a specific ecological contribution and a microeconomic activity. The assumption in this graphic is that a change in environmental quality or a change in economic productivity is caused by some other change (sometimes referred to as an impact). An impact never invokes just one change. It will create several other changes and by the same rule, impacts are caused by combinations of conditions. A simple example will illustrate the point, to wit: if there is a chemical spill in an estuary the spill will not only kill fish but may reduce the number of recreational users of the estuary. As a result of the chemical spill any valuation of the environmental damage or damage to economic productivity cannot be considered as a single value or a stable value, but a dynamic value (Costanza *et al*. 1997; Stahel 2005c).

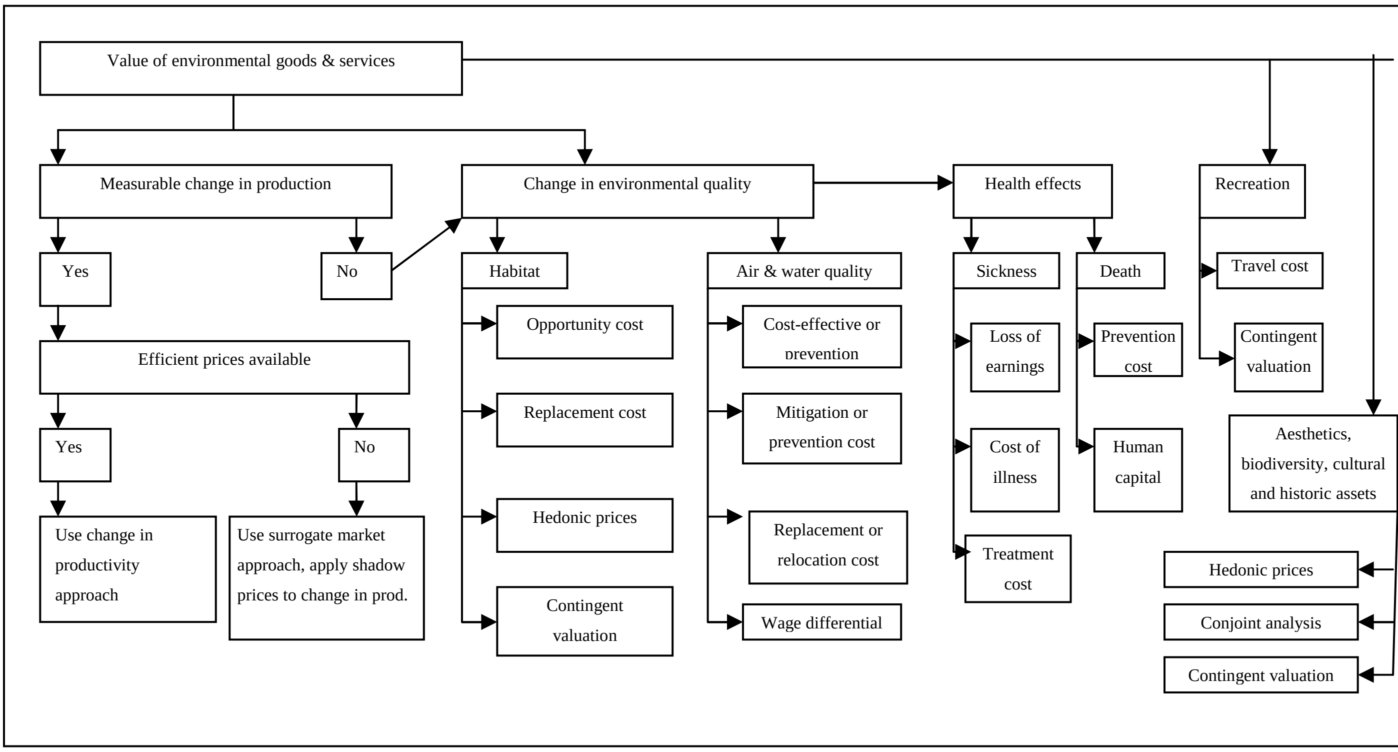

FIGURE 3. Alternative valuation techniques for environmental goods and services. Adapted from Blignaut and de Wit (2004)

The dynamics of valuation, the approximation of the environmental impact to ecological thresholds and whether there is available a non-distorted market price of the involved ecology are three significant variables in assessing the application of a specific valuation technique. Nonetheless, among environmentalists and economists, there is almost no functional consensus of criteria for applying valuation techniques. Some have attempted to assess methods based on various economic theories (Blignaut & Lumby 2004; Daly & Farley 2004c) for the purposes of discussion or analysis. However, no real substance in application criteria has evolved. Therefore, because of pressure to achieve sustainability and, with it, the perceived complexity in choosing and applying valuation techniques, new procedures are continuously sought and researched (O'Connor 2000). In addition to the valuation techniques set out in Figure 3, Table 1 provides an overview of techniques formulated using mixed criteria.

TABLE 1. Mixed criteria environmental valuation techniques for unique applications.

COMMON NAME	DESCRIPTION	CITATION	COMMENT
DELPHI	USES GROUP JUDGMENT BASED ON DIFFERENT SPECIALTIES	(CURTIS 2005)	APPROPRIATE FOR COMPLEX CONDITIONS
MULTIPLE CRITERIA ANALYSIS	IDENTIFIES OPTIONS AND MEASURES THE IMPACTS	(CURTIS 2005)	USEFUL FOR CHOOSING BETWEEN ALTERNATIVE POLICIES OR PROPOSALS
GUMBO	GLOBAL UNIFIED META MODEL OF THE BIOSPHERE	(BOUMANS *et al.* 2002)	DYNAMIC SYSTEMS MODEL TO SIMULATE INTEGRATED EARTH
DELIBERATIVE PROCESS	CITIZEN JURIES	(O'CONNOR 2000)	CONTRIBUTIONS BY AFFECTED SOCIAL GROUPS TO FIND A COMMON SOLUTION
DISCOURSED BASED VALUATION	SMALL GROUPS OF CITIZENS VALUE PUBLIC GOODS	(WILSON & HOWARTH 2002)	EMPHASIZES SOCIAL JUSTICE
SYNTHESIZES OF PREVIOUS STUDIES*	BASED ON SEVERAL STUDIES OF DIRECT AND INDIRECT WILLINGNESS TO PAY (WTP)	(COSTANZA et al. 1997)	GLOBAL STUDY – 17 ECOSYSTEM SERVICES
DYNAMIC SYSTEM	ENLARGES THE SCOPE OF ECONOMIC VALUATION TO INCLUDE DYNAMIC & CHANGING CONDITIONS	(STAHEL 2005B)	IMPOSES SPATIAL AND TEMPORAL VALUES ON TRADITIONAL ECONOMICS
COST BENEFIT ANALYSIS (CBA)*	CONVERTS STREAM OF VALUES TO PRESENT VALUE BENEFITS AND COSTS	(JOUBERT *et al*. 1997; MULLINS *et al*. 2002; VAN ZYL & LEIMAN A. 2005)	CBA DOES NOT PRESENT AN EASY FORMAT FOR COMPARING PROJECTS AND STAKEHOLDER PREFERENCES
INTERMEDIATE RESOURCE VALUE	VALUATION OF AN INTERMEDIATE ECOLOGICAL SERVICE AS THE PRESENT VALUE OF FINAL GOOD	(KAISER & ROUMASSET 2002)	USES MICROECONOMIC EQUATIONS TO VALUE INDIRECT ECOSYSTEM SERVICES THAT LACK MARKET PRICES
REPEATED NESTED LOGIT (RNL) RANDOM-UTILITY MODEL	LINKS REPEATED PARTICIPATION DECISIONS WITHIN A NESTED STRUCTURE OF SITE CHOICE	(GRIJALVA *et al*. 2002)	FIRST US STUDY TO APPLY RNL TO ESTIMATE RECREATION DEMAND ON NATIONAL SCALE
LOCAL IDENTIFICATION AND VALUATION OF ECOSYSTEM GOODS AND SERVICES	LOCALS IDENTIFY ECOLOGICAL GOODS AND SERVICES AND VALUE	(RODRIQUEZ, PASCUAL, & NIEMEYER 2005)	DIFFERENT FROM CITIZEN JURY BECAUSE ONLY LOCAL KNOWLEDGE USED

*Not a true valuation method, but a procedure for combining methods.

The valuation methods set out in Figure 3 and Table 1 are intended to represent a selection of current methods which are in use for the purpose of valuing ecological functions and services which do not have a market value. Because of the variety of methods and the diverse applications of those methods, the next section will criticize a selection of the methods suggested in Figure 3. The criticism will have the additional purpose of laying the predicate on which to justify further research into a simpler, credible approach to valuation.

2.2.5 Criticism of Selected Valuation Techniques

As mentioned before, a valuation method or technique is an attempt to estimate the value of an ecological contribution to an economic activity where the ecological contribution has no market value. This section will address the limitations of selected valuation techniques mentioned in Figure 3. The selected valuation techniques reflect anthropologic values which have only a thin link with the values of the ecological contributions to the economic system The link (or connection) between nature’s services and people is seen as the value of those services to people. To establish a value of the human use of ecosystem services is an anthropogenic view of what valuation techniques are actually doing. Stated more specifically, “…economic valuation is an anthropocentric process that does not value the environment *per se*, but assesses the preferences individual consumers hold for a particular change in some specified level of environmental quality” (Boxall & Beckley 2002). From the foregoing it can be said that current valuation techniques do not assess value to the ecosystem which contributes to the economic system with regard to a specific economic product. Instead, current valuation techniques account for ecosystem goods and services in order to provide values to determine change in human welfare (Blignaut & De Wit 2004b). The criticisms that hereafter follow will address the effectiveness of current valuation techniques to place an economic value on the ecosystem goods and services which provide benefits for humans. As will be seen, these valuation techniques are laden with inadequacies and expenses. Further, current techniques leave unclear what constitutes value and the scope of quantification to be undertaken (Blignaut & Lumby 2004; Blignaut & De Wit 2004b).

2.2.5.1 Opportunity Cost

Opportunity cost (OC) is defined as the benefit given up by not using a resource in the best alternative way. OC is considered a powerful tool in economic terms because each time a decision is made OCs are incurred (Lipsey, Courant, & Ragan 1999c). In the wider context, opportunity costs would not be considered failure to receive money payments, but would in the ultimate sense be sacrificed alternatives (Browning & Browning 1992). Nonetheless, it is not an efficient tool for establishing the value of ecological contributions to economic activity. OC is more akin to cost benefit analysis than a method for ecological valuation. It reflects an integration of many different factors / values. Effectively it functions as a form of multi-criteria analysis used as a decision making tool when non-market ecological functions or services conflict with the economic use of a resource common to both. An example would be when timber production conflicts with biodiversity representation and persistence (Faith *et al*. 2003).

On closer examination it appears that OC is whatever value can be agreed upon or negotiated as the value of the alternative use. The effect of a negotiated OC is to shift the burden of the true environmental cost. One example of the use of OC to transfer the burden of environmental cost is in the context of payment for environmental services (PES). Often times PES is negotiated in lieu of valuing the full flow of functions and services provided by the ecological system. In developing countries the environmental service (ES) users require the ES providers to agree to receive payments less than the true value of ES but equal to the value of a more narrow range of benefits which the ES providers are accustomed to receiving from the local environment (Wunder 2005).

A second example of the use of OC as an valuation tool to shift value for ecological functions and services occurs in efforts to apply OC in environmental impact studies across disciplines (as an example, science and economics) and scales of time and space. The effect of the shift can be seen when the ecological resource(s) demanded are non-market resources and a partial value is established which allows an increased quantity of the resource(s) to be used thereby depleting the resource(s) to such an extent that the ecological threshold is violated. This scenario has functionally shifted the burden (cost) to both the environment and those individuals who espouse bequest value in the resource(s) valued or those resource(s) affected by violation of the threshold. Although some researchers contend that OC is a viable tool for multi-scale and multi-discipline decision making (Faith *et al.* 2003; Hein *et al*. 2006), the detailed criteria and procedures for applying OC to combined science and economic issues at various scales in a consistent and repeatable manner does not yet exist. In summary, although OC appears to present a platform for multi-criteria analysis (Faith *et al*. 2003) it is here suggested that OC is not in and of itself a robust tool which can deal with the multi-criteria complexities of economics and ecological systems (Bowers 2005).

2.2.5.2 Hedonic Prices

The hedonic pricing method (HPM) when used to value ecological functions and services can be described as a method to derive an implicit price for an environmental good from analysis of goods for which markets exist and which incorporate particular environmental characteristics (Ledoux & Turner 2002). This method is based on the, "…assumption that the price of some marketed good is a function of its different characteristics, and an implicit price exists for each of the characteristics" (Young 2005a). If used in a well defined or small area, such as a catchment, the HPM has good potential to reveal non-market value within specific differentiated products, such as houses with environmental amenities. HPM is a focused tool for valuation. If the issue is valuation of certain environmental improvements, i.e. water quality, HPM may be sensitive to housing purchasers but not be sensitive to recreational beneficiaries of the improvements (Young 2005a).

Another element pointed out is that the HPM is a two stage process (Young 2005a). First it is necessary to develop the hedonic price equation which should be empirically determined from localized data. The second stage is the development of a model of a demand equation which will provide estimates of the consumers' value of the environmental attribute. Because of the intense use of localized data in the two stage process, the narrow focus of the demand model and the high expense of resources, time and skill required to obtain a credible result, the HPM is not used as often as the travel cost method and the contingent valuation method. Further, HPM would also appear not to be as applicable to those developing countries hampered with a failure of effectively functioning real estate markets[2]. While there may be exceptions, an effectively functioning real estate market would suggest that occurrences and prices of transactions would be available and data on property characteristics and neighbourhoods features are not expensive or functionally difficult to obtain (Young 2005a).

2.2.5.3 Travel Cost Method

The travel cost method (TCM) can be described as, "A revealed preference approach to valuing recreational sites that derives a demand schedule from statistical analysis of the costs of travel" (Young 2005a). It is one of the first methods used by economists to estimate the demand for environmental amenities (Field & Field 2002). Because tourists are sometimes willing to pay

[2] South Africa appears to have a reasonably efficient real estate market although the legal infrastructure is antiquated.

more than they actually spend TCM can be used to estimate the consumer surplus associated with visiting a recreational site. However the procedure is not as straight forward as the preceding statement might lead one to believe (Young 2005a). The difficulties lie in implementing the basic model when the recreationist's travel is multi-destination, to wit: 1) constructing a proper data base which includes defining the population, identifying the cost / expenses and other socioeconomic information to be included in the study, preparing the questions, training interviewers and compiling the data; 2) Creating a regression equation which represents the individual's demand for the designated site based on the data collected; 3) Allocating the data to the designated site and calculating the demand of the overall population (Turpie *et al*. 2005; Young 2005a). An example would be the application of the TCM to the town of Knysna, South Africa. The town of Knysna is a major destination (but not the sole destination) for local, national and international tourists. Attempting to place an economic value on the contribution of the Knysna Estuary or Knysna River to trips to Knysna is complicated by factors such as visitors usually have multi-destinations and it is one of several places to which they travel. Further, when travelers arrive in Knysna they have different venues or purposes for being there. Also, most travelers are in groups of one sort or the other, i.e. families or tour buses or school groups and within each group individuals will, based on an assortment of factors, allocate different values to the estuary or river. The differing agendas for members of groups coming to the Knysna Basin have been documented (Turpie & Joubert 2003; Dimopoulos 2005). Because of the narrow focus of the TCM and because of the expense in money and resources required to properly prepare and analyze a TC study, it would appear to be, standing alone, an inefficient tool.

2.2.5.4 Contingent Valuation Method

The contingent valuation method (CVM) can be defined as, "An expressed preference method of valuation which asks individuals the value (in monetary terms) of specified changes in quantities or qualities of environmental goods and services…[and][3] can be especially useful where non-use values are important" (Young 2005a). The procedure appears to work in one of two methods upon asking an individual what he or she would pay based on some hypothetical change in the environmental condition. The first method is an estimate of total value under stated conditions of certainty, and then estimating non-use values in the absence of any use opportunities based on the same conditions of certainty (Boyle & Bergstrom 2001). The second method is a menu

[3] Brackets are mine

approach where the respondent is asked for total value, then to allocate values over a menu of non-use values prepared by the interviewer (Boyle & Bergstrom 2001). Boyle & Bergstrom (2001) suggest there is active internal debate over which of these two is the better method and so far there appears to be no satisfactory answer. Both of these methods are outside the context of CEs which are an iteration of CVM and which will be discussed below.

Without addressing the merits of the internal debate there are other substantial questions revolving around whether the CVM is a credible method for estimating non-use values of ecological functions and services. The questionable integrity of the CVM is focused in two general areas. The first is the hypothetical nature of the question and the second is the reliability of the answer, assuming the question is valid. There, again, appears to be no satisfactory resolution which establishes the credibility of CVM even though much published research exists developing the issues pro and con (Bateman & Willis 2001). While the debate becomes more acrimonious, use of CVM is increasing because of the institutional acceptance in the US and a growing application of the method in Europe (Bateman & Willis 2001). Increased use is also driven by a global economy and an urgent need to assess value of ecological, non-market inputs into economic activity (Bateman & Willis 2001). For the purposes of this thesis there are apparently three intractable issues with the CVM. First is the nature of valuation based on a hypothetical question. To be somewhat simplistic but realistic a hypothetical question[4] means, 1) there is no actual problem, 2) no one is going to pay for the problem to be resolved and 3) no one is going to receive payment for the problem or its resolution. In the context of CVM these three realities of the hypothetical question cannot be dissipated. In the context of a hypothetical question, unattached to a real market, it appears reasonable to say that it is not possible to either judge the quality of the responses or to calibrate the response in order to have a useable number (Diamond & Hausman 1994).

The second intractable issue is the lack of credibility found in the response to the survey. This focus is most aptly put forward by the US National Oceanic and Atmospheric Administration (NOAA), a branch of the US Department of Commerce, in a report commissioned to assess the reliability of CVM (Arrow *et al*. 1993; Young 2005a). Arrow *et al*. (1993) stated, “CV studies can produce estimates reliable enough to be the starting point of a judicial process of damage

[4] In some instances the question posed can describe a proposed public policy with some degree of accuracy but the implications of this proposed policy can only be suggested.

assessment, including lost passive use values.” The panel making the report was not enthusiastic in their support of the CVM and followed the foregoing statement with a series of guidelines, one of which required that the respondent must understand the decision they were asked to make and the analysts should understand the basis on which the answer was given (Young 2005a). It is, to say the least, too much to expect a reasonably informed citizen to understand the basis for the decision he or she is asked to make about a hypothetical question when it appears that experts cannot come to agreement on understanding the basis for non market values of the environment. To put the credibility of valuation by CVM in another context, “Even if it were possible for the experts to resolve all these uncertainties (which it is not) and disseminate that information to the population at large, people have no experience with markets in such goods and services, and would still have a very difficult time assigning meaningful exchange values” (Daly & Farley 2004a).

The third intractable issue relevant to CVM is the cost in money, time and resources. South Africa and other developing countries are in need of credible, readily available, efficient tools in order to make decisions which address development and sustainability. CVM has none of these characteristics. If conducted properly it may be helpful when no other procedure is available. In developing countries the technical difficulties and financial costs of CVM are compounded and out of reach of local development initiatives and budgets for environmental impact assessments. Each individual project requires that the criteria for design and conduct of surveys be met, sample size and informed responses be assured, interviewees be trained and supervised and that special skills are available for analysis. The NOAA guidelines emphasize that the application of CVM requires a significant research effort, advanced skills and substantial budget (Portney 1994; Young 2005a) which make it impractical for developing countries and any but larger projects in the developed countries.

2.2.5.5 Choice Experiments

Choice experiments (CE) are a variation or extension of the standard CVM (Adamowicz *et al*. 1998d). The basic difference is that rather than asking people to choose between a base case and a specific alternative, CEs ask that a choice be made between cases that are described by attributes (Adamowicz *et al*. 1998c). In most cases one of the alternatives in CE is a *status quo* choice of the currently feasible situation, which thereby, it is suggested, makes the CE consistent with utility maximization and demand theory (Hanley, Mourato, & Wright 2001).

CE has been used in transportation and market research for several years (Hanley, Mourato, & Wright 2001). Within the last ten years it has begun to develop credibility in measurement of passive use values in environmental economics. In this connection passive use value relates to a change in environmental value not related to an observable behavior (Adamowicz *et al*. 1998b). Although, hereafter, certain aspects of CE will be discussed this thesis will not address CE other than in the context of valuing ecological contribution to economic activity.

What are the benefits of CE compared to CVM? If the CEs are designed to conform to standard economic theory[5] it is contended that the benefits over those provided by CVM are basically threefold. First, the incremental benefits to consumers from individual attributes can be characterized. Second, higher quality valuation information can be collected at a lower cost. Third, the consumer's underlying utility function of a good may be more completely characterized (Adamowicz *et al*. 1998a; DeShazo & Fermo 2002b). Notwithstanding the purported benefits of CE, experience (including research experience) with CE in environmental valuation is still relatively limited (Hanley, Mourato, & Wright 2001; Ferrini & Scarpa 2007a) and consequently there are several concerns which pertain to CVM and CE. Hanley *et al*. (2001) have listed the jointly recognized sensitive areas as: 1) hypothetical bias, stating, "…there is little reason to suppose, *a priori*, that it [CE] performs any better than CV in this regard;" 2) sensitivity to scope (are the WTP values sensitive to the size of environmental change being offered?), whereby the test for scope in CE is internal and weaker than the external test for scope in CVM; 3) sensitivity of estimates to study design, stating, "…design issues are as important in CE and in CVM;" 4) ethical protesting, stating, "…CE might reduce the incidence of ethical protesting as the choice context can be less 'stark' than direct elicitation of willingness to pay. However, …this point has yet to be proven;" and 5) expense, stating, "…CE studies can reduce the expense of valuation studies…."

In summary it appears that study design is the focus of research which appears to have potential for enhancing the credibility of CE as a tool for environmental valuation (DeShazo & Fermo 2002a; Sturm & Weimann 2006c; Siikamaki & Layton 2007; Ferrini & Scarpa 2007b).

[5] Some CE may not conform to economic theory, i.e. if the good valued is not essential the CE must provide a "choose none" alternative.

2.3 Discussion of Literature

This review of literature dealing with monetary valuation of ecological contributions to economic activity revealed a lack of consensus as how best to value the non-market contribution of ecological functions and services to the micro economy (Bateman & Willis 2001). All of the methods discussed have made active and credible contributions to economic valuation. Specifically, research in connection with CE appears to be currently addressing primary concerns which revolve around expense, hypothetical bias, attribute identification and valuation and study design in connection with economic valuation of environmental changes. The literature, however, does not confirm that since the middle 1960s[6] a great deal of functional progress in the use of CVM for ecological valuation has been made. However, conceptually, the debate has moved from a purely economic venue to a transitional effort with various labels such as resource economics, environmental economics and ecological economics among others (Blignaut & De Wit 2004b).

One of the significant developments in ecological evaluation has been in the area of understanding that the 'economy is embedded in the environment' (Gowdy & Erickson 2005a; Ropke 2005b). The conceptualization of the 'embedded' characteristic of the economy has a helpful and far-reaching implication for valuing non-market environmental services and functions which have inputs into the production function of economic activity. Stated another way, the ecological system is acknowledged as a contributing factor to production in every economic activity (Hanley 2001; Baumgartner *et al*. 2001; Patterson 2002; Barbier 2007).

The literature reviewed suggests that viewing ecological services and functions as one (or more) of the contributors to production presumes an open system for both the ecological functions as well as the economic functions. Further, although the open system concept is based on the second law of thermodynamics it does not impose a valuation of the ecology that is separate from consumer pricing (Huettner 1976). From the foregoing review a conclusion can be drawn that a system dynamics model based on an integrated catchment production input analysis will allow valuation of ecological inputs based on consumer preference (Cameron 1997; Peterson 2003; Everard 2004). Further, support for this conclusion and empirical evidence of the interdependency of the ecological systems and the economy can be found in two reports on

[6] The National Oceanic and Atmospheric Administration (NOAA) report was issued in January 1993 (Hanley 2001)

climate change issued within the last 12 months by the Government of the United Kingdom and the United Nations, respectively (Stern 2006; Working Group III 2007).

> “Making development more sustainable by changing development paths can make a major contribution to climate change mitigation, but implementation may require resources to overcome multiple barriers. There is a growing understanding of the possibilities to choose and implement mitigation options in several sectors [in order][7] to realize synergies and avoid conflicts with other dimensions of sustainable development” (Working Group III 2007).

The foregoing literature suggests there has been little research focused on economic valuation of interdependent ecological functions and services at a microeconomic level or at the scale of a localized ecological system or of a specific development site (Curtis 2005). There appears to be no single equation, system or model developed for economic valuations of project specific, interdependent, ecological functions and services. In this connection, Richard Cowling stated, “As far as I know no one has mapped the features that deliver services that have been quantified in terms of their ecological and economic flows” (Cowling 2005a).

The current status of valuation of ecosystem goods and services presumes that in almost every circumstance adequate economic valuation of an environmental impact or natural resource will require more than one valuation technique in order to consider the multitude of values and obtain TEV. Figures 1, 2 and 3 illustrate some of the multiple interfaces between people and the environment and reflect the presumed requirement to use more than one economic valuation technique in order to obtain TEV. Figures 1 and 2 represent TV as being composed of TEV plus ‘other values’ provided by the ecosystem. Figure 1 suggests that the ‘other value’ is “Primary value” or non demand ecosystem value. Figure 2 suggests that the ‘other value’ is a combination of Ecological Value (based on ecological sustainability) and Socio-cultural Values (based on equity and cultural perceptions). All economic value and economic valuation techniques leading to the compilation of TEV are based on demand for ecosystem goods and services which have value to people. These values can also be called ‘utilitarian values’. Under the current view of economic valuation techniques, those ecosystem goods and services which are the non-demand ecosystem goods and services are said to not add economic value to human life and therefore have no economic value. The forgoing statement although historically accepted, represents a

[7] Brackets mine.

contentious view for at least two reasons. The first is that while the non-demand ecosystem goods and services may not add economic value to human life, such "Primary Values", "Ecological Values" or "Socio-cultural Values" (hereafter, primary values) may be invaluable or priceless in the sense that they are perceived as separate from TEV but are a part of the holistic ecological system. The second reason is that because the economic system is embedded within the ecological system there is no clear-cut distinction between the ecosystem's primary value and the indirect use value. Primary values are considered by some to be highly relevant in economic terms even though the economic aspects cannot be captured by market value preferences. Therefore the properties of the ecosystem which are represented by primary values should be integrated into the indirect use value (Plan 1999; Fromm 2000).

The scope of this thesis does not address the question of whether all ecosystem goods or services add value to human life and are therefore part of TEV. However, an underlying assumption for this thesis is that all ecosystem goods and services <u>do</u> add value to human life and therefore potentially provide contribution to the TEV of any specific economic product (Fromm 2000; Nuppenau 2002; Cavuta 2003).

Figures 1, 2 and 3 raise another issue related to TEV and TV and that is the distinction between 'Use Value' and 'Exchange Value'. Use Value arises from the actual use of a resource or product and can be either direct or indirect. Whereas Exchange Value is a non-physical abstraction representing the value of a product in terms of it being exchanged for another product as opposed to being used. Generally Exchange Value relates to money but not always (Daly & Farley 2004a). Karl Marx would suggest that Exchange Value is the quantitative aspect of value whereas Use Value is the qualitative aspect of value (Daly & Farley 2004a; Marx 2008). This means that Exchange Value represents marginal utility of a product (or a resource) and Use Value is represented by total utility of the product. To combine the statement, Exchange Value is marginal Use Value. Therefore, when monetary value is available for a marginal unit of ecological service then Use Value can be measured (Farber, Costanza, & Wilson 2002).

In the context of this thesis the monetary price of water (as demonstrated later in this thesis cost rather than price was used) is considered to be the Exchange Value, e.g. the price per unit of water is the marginal use value of water in the Knysna River for a specific product. If water is abundant the unit value can be very low but the total value of water because it is a necessity will be indeterminate (Farber, Costanza, & Wilson 2002; Daly & Farley 2004a). However, if water in the Knysna River is scarce i.e., when the available quantity is less than the critical threshold, (Turner *et al*. 2003) the price per unit can be very large and no meaningful marginal Use Value will be available. Consequently, under the circumstances of scarcity, Use Value will also be indeterminate. The inability to identify a marginal Use Value of water when the availability of the ecosystem resource falls below a critical economic or biological threshold, raises two issues regarding the relationship between Use Value and TEV applicable to this thesis (and in any ecosystem valuation exercise). The first is: How and which valuation techniques should be applied when the ecosystem under consideration falls below some critical economic or biological threshold? The second is: In the context of "Exchange Value (Marginal Use Value) and "Use Value," are there different components for TEV and Use Value when considering the same economic product and same ecosystem goods and services?

In regard to the first issue, this thesis will not address valuations where the ecosystem falls below a critical economic or biological threshold. It will be assumed that all parts of the ecosystem of the Knysna River are operating above critical threshold levels. In regard to the second issue, Use Value is considered to be a portion of TEV but not all of TEV (Ledoux & Turner 2002; Turner *et al*. 2003). Figure 1 represents TEV to be composed of Use and Non-Use Values. The latter represents intrinsic human value that arises, not because of usage or the potential thereof but because of the conclusion that nature in its on right should be conserved. The boundaries between Use and Non-Use Values are not clearly defined and conceptually the Non-Use Values fall out side the application of traditional economics. Valuation can, however, take place because what is being valued as TEV is the provision of an aggregation of interdependent ecosystem services and not the environment itself (Ledoux & Turner 2002; Turner *et al*. 2003).

Following on from the foregoing, in this thesis Use Value will be equated with TEV. Further, because the embedded nature of the economy requires a healthy functioning ecosystem for the delivery of marginal units of service flow, Primary Value[8] will, as mentioned above, also be assumed to be a part of TEV.

[8] This may be a debatable assumption because it leads to the conclusion that the ecosystem is being valued and not the goods or services provided by the ecological system. Nonetheless, this assumption will be engaged for the purposes of this thesis.

An implication within the literature is that there is an apparent need (and an opportunity) to better understand how to value the non-market ecological contributions to economic activities. Further, the literature appears to suggest that, because the economic system is embedded in the ecological system, it would be possible to establish specific linkages between an economic activity and the contributing parts of the ecological system. As a result of mapping linkages between the ecological system and a specific economic product it would appear to be possible to understand both ecologically and economically the value of the ecological contributions. A method for imputing economic value of ecological contributions to specific economic activities is proposed in the following chapter.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Introduction

Numerous methods have been suggested for use in valuing the constituent parts of the ecological functions and services (Wilson & Howarth 2002; Curtis 2005; Stahel 2005a; Hein *et al*. 2006). Some of the more common methods are listed in Ledoux and Turner (2002). Notwithstanding that some of these methods have been in use for 40 years, there is still great debate about their applicability, validity and accuracy (Pearce 1998; Ledoux & Turner 2002). Furthermore, the transferability of the information derived from valuation studies using the suggested methods has not been uniformly established (Ledoux & Turner 2002). The foregoing problems are exacerbated when the current valuation methods are used in the context of an environmental impact assessment (EIA) or strategic EIA because they are expensive, time consuming and difficult to apply with consensus among the stakeholders. This deficiency in valuation methodology is a recognized concern (Villa *et al*. 2002; Hein *et al*. 2006). De Groot *et al*. (2002) stated, "… there are several important theoretical and empirical issues that remain to be resolved."

Further, De Groot *et al*. (2002) have suggested that the interconnectedness of ecological functions and services and economic valuation can be addressed via a dynamic system analysis as in the Global Unified Metamodel of the Biosphere (GUMBO) model (Boumans *et al*. 2002). The GUMBO model was designed to study the dynamic interlinkages between social, economic and biophysical systems and to provide a flexible computer platform for alternatives envisioned by end-users (Boumans *et al*. 2002). Notwithstanding GUMBO's holistic approach to valuation it has limitations from the prospective of linking ecological and economic values at a microeconomic level. Because the design intention of GUMBO was to address marginal pricing at a global scale it would not be useful for a site specific analysis to determine economic / ecological impacts or sustainability of a local development (Turner *et al*. 2003).

Further, from a microeconomic standpoint, the operating parameters established for the model would render the system not useful because, "…the assumptions necessary for a marginal analysis approach to pricing rarely hold in the real world, [even though] they do approximately hold [at a global scale]…" (Brackets mine) (Boumans *et al*. 2002). David Pearce (1998) has written that the GUMBO model would not be useful in arriving at marginal values because, "…Costanza and his co-authors have violated all of the principles…in deriving their estimates of the value of environmental services". In effect, GUMBO does not provide localized, hands-on, explicit combinations of economic, social and ecological information that is most needed in site specific and regional transactions in order to understand the limitations and trade-offs applicable to sustainability (Wilson & Howarth 2002; Hein *et al*. 2006).

Ledoux & Turner (2002) stated, "that the concepts of functional diversity and functional value diversity offer sound and practical foundations for a management strategy aimed at … sustainable utilization…. The basic notion is that ecosystem processes, composition, and functions provide outputs of goods and services, which can then be assigned monetary economic and/or other values…." Notwithstanding the lack of new methodology for assigning economic value to ecosystem functions, composition and processes, there have been suggestions by researchers which give direction for further investigation (Howarth 1997; Howarth & Farber 2002; Wilson & Howarth 2002; Hein *et al*. 2006). In Figure 4 below Howarth and Farber (2002) identify the marginal benefits (MB) derived from provision of an environmental service (S) such as an amenity.

The features Howarth and Farber (2002) point out are 1) that the areas A + B equal the "…full value of nature…" given by the level of services S_0, i.e. the total area under the MB curve and 2) that the value of environmental services (VES) is the product of P_0 and S_0, i.e. the area B under the MB curve. In the Howarth and Farber (2002) paper, S represents environmental services that convey a direct benefit to the consumer. S does not include those functions of environmental services that provide utility via consumption of produced goods. Examples given for direct environmental services S are the enjoyment of clean air and water, pleasant views and recreational opportunities. S would not include the benefit of clean water to commercial fisheries because the value of clean water would be accounted for in the production of fish.

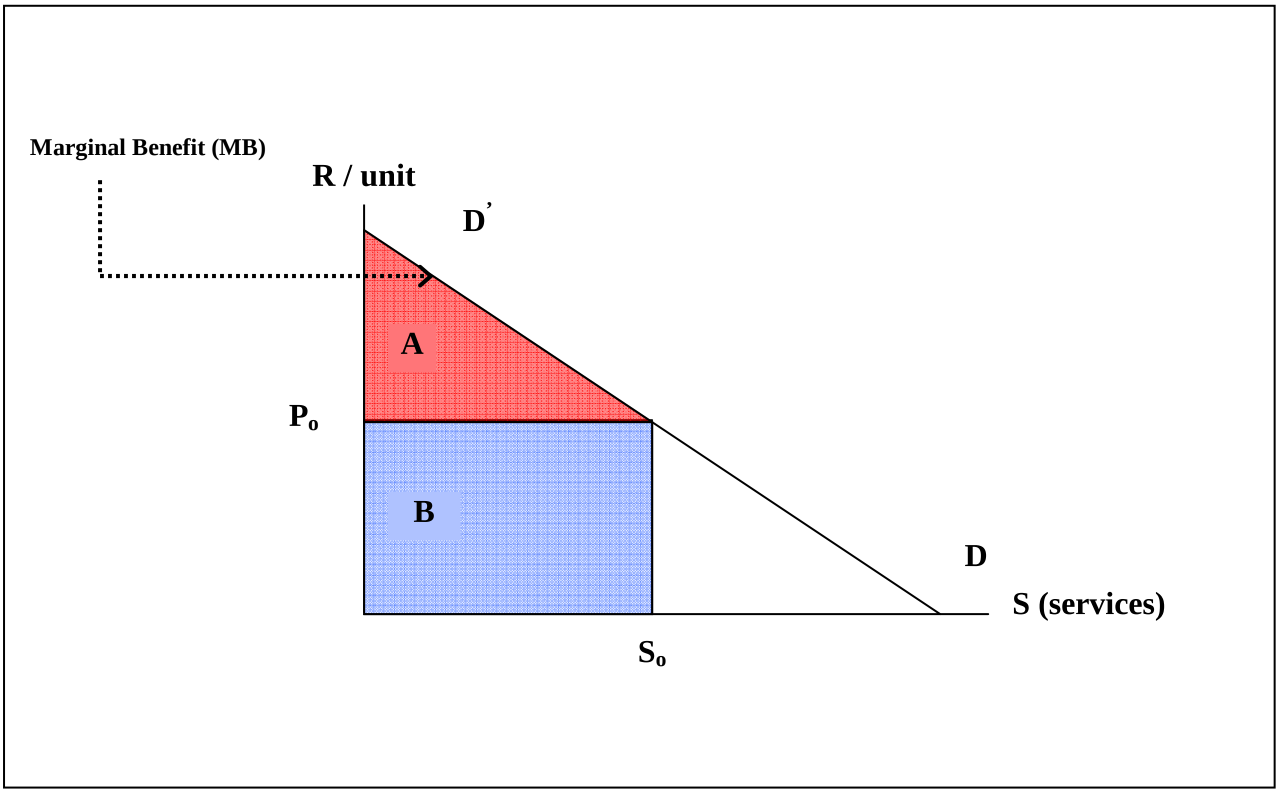

FIGURE 4. A heuristic model of ecosystem valuation. The symbols and equations are: A + B = Total Benefits. A is defined as consumer surplus (CS) and B as the value of direct environmental services. P_o is defined as the price per unit of ecosystem services (S_o) at the margin. Source: Howarth and Farber (2002).

From the foregoing it would appear clear that the combined areas of A + B include the value attributable to consumer surplus for those direct environmental services considered but would not include value for indirect environmental services that the ecological system provides in order to replenish and maintain itself and the related consumer surplus. Further, Figure 4 does not provide a representation of those services that the ecological system provides in order to replenish and maintain itself, i.e. the ecological reserve or critical natural capital (CNC) (Ekins *et al*. 2003; Ekins, Folke, & De Groot 2003).

As a more integrated model, consider the following Figure 5, a modified version of Figure 4 which has been prepared as a representation of the Knysna River (KR). Herein the dotted line T represents services provided by the ecological reserve for the KR (in this case the ecological reserve is sometimes regarded as primary value, threshold or CNC). Dotted line M represents the maximum flow of the KR and dashed line D represents the minimum domestic in-home use of residents when added to the ecological reserve. The areas A and B do not include river flow attributable to the ecological reserve nor is river flow greater than S_0 (Area C) included.

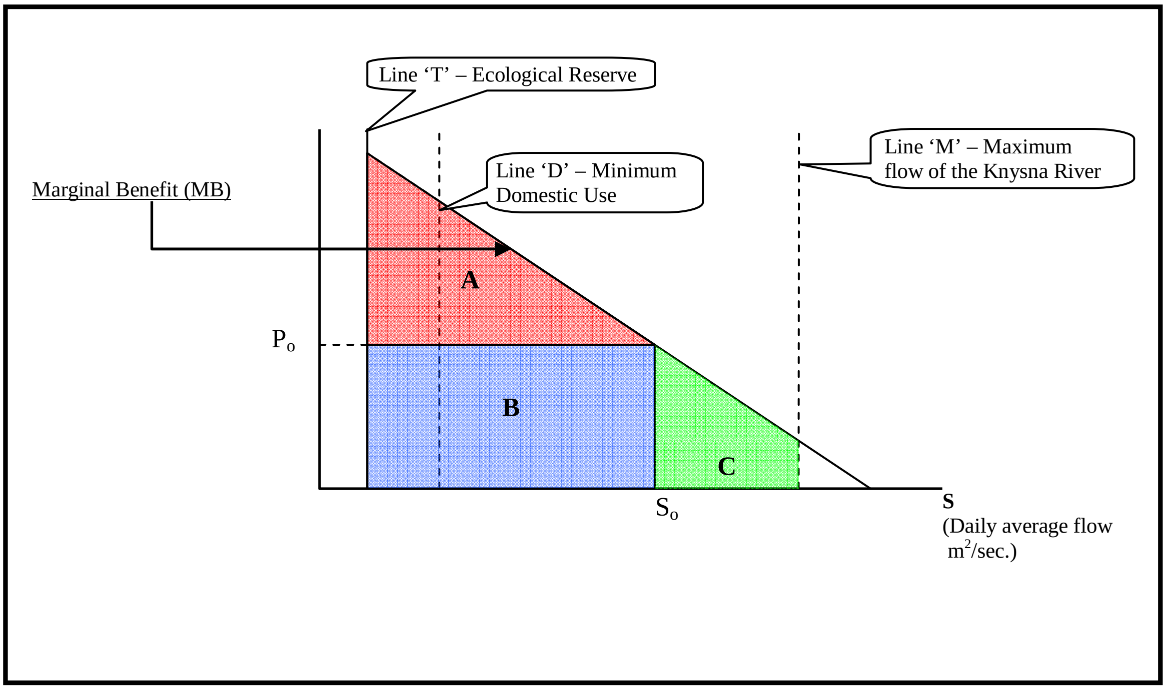

FIGURE 5. Modified model of ecosystem valuation, showing the ecological reserve (T) as a threshold, maximum flow (M_x) and domestic use (D). P_o is price per unit of ecosystem service (S_o) at the margin. Adapted from: Howarth and Farber (2002).

Figure 5 is a more accurate model than Figure 4 because it represents the area before line T and area C as the benefits of the river's functions to the ecological systems. In the diagram the MB does not extend over the area represented as the ecological reserve. Further, in reference to Figure 5, Howarth & Farber's (2002) structure (Figure 4) will not apply to the model of the KR as it is now presented. According to Howarth and Farber (2002) areas A and B are represented as the direct benefits of the river's functions which arise from flow in excess of the ecological reserve and which provide directly for human health and welfare (Farber, Costanza, & Wilson 2002; Ekins *et al*. 2003; Ekins & Simon 2003). As mentioned above, "… *S* would include services such as the enjoyment of clean air and water, pleasant views and recreational opportunities. It would not include indirect services such as the provision of timber and raw materials or the benefits of water quality to commercial fisheries…." (Howarth & Farber 2002). The repositioning of the ecological reserve and area C removes them from area A and allows them to be represented as thresholds. The remaining area A in Figure 5 represents the CS (in this case the ecological value) of those economic activities supported by the KR.

Further with regard to the structure of Figure 5 the benefits represented by the area C between S_0 and the maximum flow (dashed line M_x) are ecological benefits which may or may not be available directly for human health and welfare[9] because area C in most cases represents flood water. It should also be noted that the dashed portion of line MB (between lines T and D) indicates that the marginal value of the CS for minimum domestic use of water is estimated[10].

As mentioned earlier in this section, there is little agreement on methods and techniques for valuation of ecological services and/or functions at the microeconomics level. In developing countries primarily, but also in developed countries, there appears to be an urgent need to find a credible, low cost, simple system for understanding the economic value of local ecological contributions to related economic activities. In this connection the model represented by Figure 5 suggests a basis from which it may be possible to identify and quantify within areas A and B the economic values of environmental services and functions at the margins (Howarth & Farber 2002; Ledoux & Turner 2002; Allanson 2005a; Gowdy & Erickson 2005b).

In the context of the Knysna River the model clearly suggests that the areas outside A and B, i.e. the ecological reserve and the flow of flood water, are connected to the economic activities represented by areas A and B. Notwithstanding the connection and interdependence between critical natural capital (Chiesura & De Groot 2003; Cowling 2005b) and the economic system, this project will be limited to developing a method for revealing the economic value of the ecological contribution represented by area A in Figure 5.

3.2 Study Area

The local setting for this project was on the southern coast of South Africa in the unique economic and natural setting of the Knysna River Catchment Area (KRCA) or Knysna Basin (KB) as it is sometimes known (Figures 6, 7, 8). The primary economic feature of the KB is Tourism and Retirement, the focus of which is in the town of Knysna and its satellite

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[9] These benefits could be captured for humans by inserting a dam in-stream at the sacrifice of the ecological benefits of high velocity runoff during floods (Allanson 2005e).

[10] An estimate in this connection has two aspects. First, the marginal benefit curve (or demand curve), as a straight line is estimated. The second aspect is that the elasticity of demand for minimum domestic water requirements may be very inelastic.

communities that are situated in or on the Knysna Estuary and within the KB (Knysna Ratepayers Association 2000).

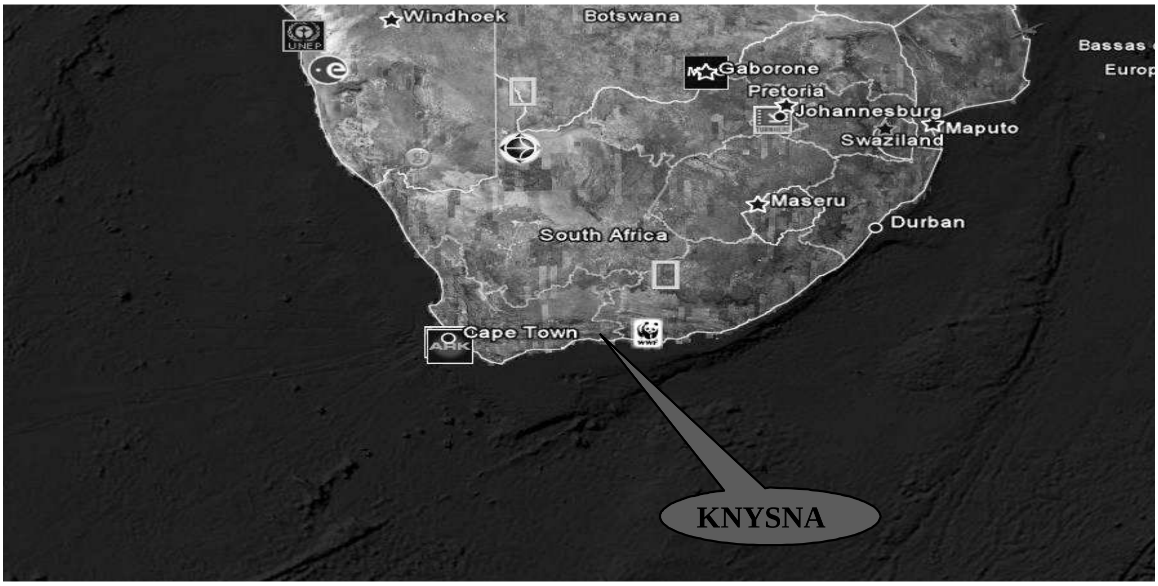

FIGURE 6. Study area location on the southern coast of South Africa in the Knysna basin. Adapted from Google Earth (Maps) 21/04/2008

The Knysna River, the Knysna Estuary and the Knysna Forest, all situated in the KB, are now part of the South African National Park System and are considered important in terms of biodiversity (Joubert 2005c). The State represented by the Department of Water Affairs and Forestry (DWAF) owns the flow of water in the KR under the requirements of the National Water Act 1998 (NWA) (Republic of South Africa 1998b). As owner of the river flow the State is required by the NWA to establish an ecological and human reserve as a minimum flow (Republic of South Africa 1998b). In this context the town of Knysna receives at least 90 % of its fresh water from the excess flow of the river (Perring 2004).

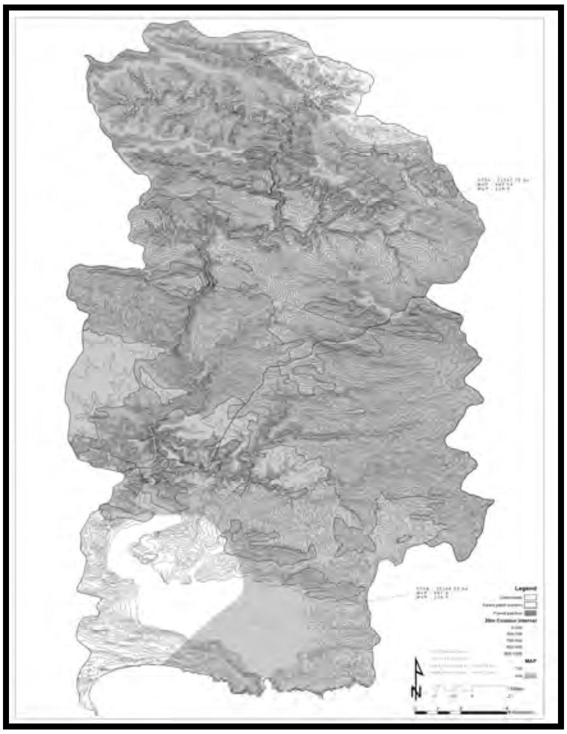

FIGURE **7.** Study area showing Knysna catchments with Knysna River and tributaries enhanced in darker contrast. Adapted from: CSS, Grahamstown 2007.

The KB is located on the Indian Ocean coast, 500 km East of Cape Town. The basin consists of the KR and its tributaries, the Knysna Estuary and the small streams which flow into it and the catchments of the river and the estuary. The Knysna River flows through the estuary and into the ocean at 34^{o} 03'S latitude and 23^{o} 04' longitude.

FIGURE 8. Study area: stylized representation of the Knysna River catchments in the context of the Knysna estuary and adjoining catchments.
Adapted from Knysna Municipality documents, 2004

The river is approximately 56 km long (Largier *et al*., 2000) and arises from its headwaters at an altitude of approximately 1038 m at 33^{o} 48' 06" latitude and 23^{o} 00' 20" longitude (Kruisvallei, 3323 CC). The river drains a small catchment of about 400 km^{2} (Largier *et al*., 2000) and the combined drainage area of the KR and the Knysna Estuary is 526 km^{2} (National Parks Board 1994).

The Gouna River is the main tributary of the KR. It is approximately 20 km long (Kruisvallei, 3323 CC) and flows into the KR approximately 2.5 km upstream of the tidal reach. The tidal reach is at Charlesford Rapids and is about 19 km from the Knysna Heads (Largier *et al*., 2000). The combined Gouna and Knysna Rivers supply 90% of the water for the town of Knysna (Perring, 2004).

The town of Knysna is located on the North shore of the estuary. The only paved access to the town is via the National Road (N2) which passes along the entire length of the North shore and crosses the estuary at its western extremity.

South of the N2 the estuary is elongated East-West. Where the N2 crosses the western end the elongation changes to North-South. The estuary continues North approximately six km to the Charlesford Rapids (Kruisvallei, 3323 CC) which is the maximum tidal reach and considered to be the furthest extent of the estuary (Allanson 2000).

Upstream of the tidal reach the KR flows approximately 40 km almost due south out of the Outeniqua Mountains between the longitudinal lines of 23^{o} 00' and 23^{o} 05' (Kruisvallei, 3323 CC). The mountains are steep and well vegetated. Most vegetation is indigenous and plantation forest (Largier, Attwood, & Harcourt-Baldwin 2000; Allanson *et al*. 2004).

Largier *et al*. (2000) found the KR to be characterized by a very small sediment and nutrient load. He also noted that the annual rainfall within the catchment was in excess of 1000 mm which resulted in a mean annual runoff of 10^{8} m^{3} - 3 m^{3} s^{-1} on average at the Charlesford Weir but most of the flow was around 1 m^{3} s^{-1}. Largier *et al*. (2000) conducted their study from 1996 to 1998. During this three year period the only flow-gauging station in operation was located on the Knysna River at the DWAF weir K5H002, at the Millwood Forestry Station (33^{0} 54' 24" latitude and 23^{0} 01' 54" longitude). The flow of the river at this point represents 133 km^{2} or approximately one third of the total catchment and because it was the only monitoring point on the river it provides a low confidence estimate of total river flow.

Subsequent to the Largier *et al*. (2000) study the DWAF in 2002 installed a second gauging station at the Charlesford Weir K5H003 (33^{o} 59' 48" latitude and 23^{0} 00' 10" longitude). The stated purpose of installing the gauge at K5H003 was to monitor the low flow into the estuary (DWAF 2004; Allanson *et al*. 2004).
At the time of writing this thesis there is no gauging station on the Gouna River. The previous gauging station was discontinued in 1984 (Hughes 2004).

3.2.1 Socio-Economics of the Area

The town of Knysna had its beginnings as a relatively poor, low population coastal village whose main industry and source of employment was boat building, timber extraction and sawmilling. In the original town of Knysna, up until the 1950's, most businesses, schools, homes and industrial activity were crowded into a strip of development around the edge of the estuary. After the 1950s formal and informal residential areas were built back from the edge of the estuary. Since 1996, the physical area of the municipality increased several thousand square kilometers. By 2004 the municipality extended along the N2 to the West to include the smaller villages of Sedgefield, Karatra and Rheenendal, South towards the sea to Brenton, and Buffalo Bay and to the East, along the N2 taking in most of the area which originally lay between Knysna and Plettenberg Bay (Knysna Ratepayers Association 2000; Perring 2004).

Between the years 1980 and 2002, the timber and sawmilling business declined in Knysna because the local sawmill operators failed to maintain up-to-date equipment which could compete efficiently with sawmills located to the West in the nearby towns of George and Mossel Bay. By 1996 there were only two of the large sawmills remaining in Knysna.
One sawmill (Concordia) burned in 1998 and was not rebuilt (Van Tonder 2004) and the other mill (Thesens) shut down operations between the years 2000 and 2002 for economic and environmental reasons. As a result of the loss of the Thesen sawmill more than 1000 people were left unemployed without hope of immediate reemployment in the basin in the same or comparable jobs (Stander 2000).

Beginning in 1996 the National Government's efforts to attract tourists and develop tourism in South Africa began to have great effect in Knysna. As a result of the government's campaign the Garden Route (including Knysna) became a booming national and international tourist destination. A new economic profile reflects that Knysna is now a prime area for tourist, up-market retirement, elderly health care and residential real estate sales and leasing (Knysna Ratepayers Association 2000; Turpie & Joubert 2003; Turpie *et al*. 2005).

In the context of the unprecedented growth there are apparently two threats to the Knysna Estuary which are brought about by human use. The first is increased peak riverflow into the estuary due to changes in land use and the second is the decreased low riverflow due to water extractions. These threats have the potential to affect the productivity and water movement in the estuary (Largier, Attwood, & Harcourt-Baldwin 2000). Therefore the question before the governmental agencies is whether to manage the system so that it continues to function as it has in the past and draws upon the resilience of nature, or to enter into a management style where one needs to develop in-depth and predictive understanding of the system in order to make wise decisions about how to change the system (Largier, Attwood, & Harcourt-Baldwin 2000). This latter model takes much more study than has been done to date and it means taking on the responsibility of nature for healthy functioning and beneficial use of the estuary (Largier *et al*. 2000).

3.3 Methods and Techniques

3.3.1 Links between the Ecological and Economic Systems of the Knysna Basin

To demonstrate the use of Figure 5 it was necessary to map (Rouget *et al*. 2003; Cowling 2005b) links (Isard 1968; Dietz & van der Straaten 1992; Barabasi 2003; Cowling 2005b) between a portion of the Knysna River ecological system and the Knysna Basin’s economic system. This representational linkage is shown in Figure 2 as an abstraction and as existing links in Figure 9. In these figures, no attempt has been made to show either a qualitative or quantitative value of the linkage. The purpose of the figures is to show the complexity and active connectivity of the ecological and economic systems. It is clear from observation that most links (or the service / function provided by the link) have no market value. The use of the river flow by the Knysna

Municipality and farming operations are not exceptions because in the Knysna Basin there are no charges to the city or farmers for use of river water.

An accurate valuation of the flow of the Knysna River would require the links represented in Figure 9 to be valued. Although the issue of double counting must be addressed, if the linkages are correctly identified double counting will not occur. Further, an accurate representation of the links between the river flow and the economy of the Knysna Basin would require installation of additional links such as those representing the connection between, as an example, river flow and existence, option or primary economic values.

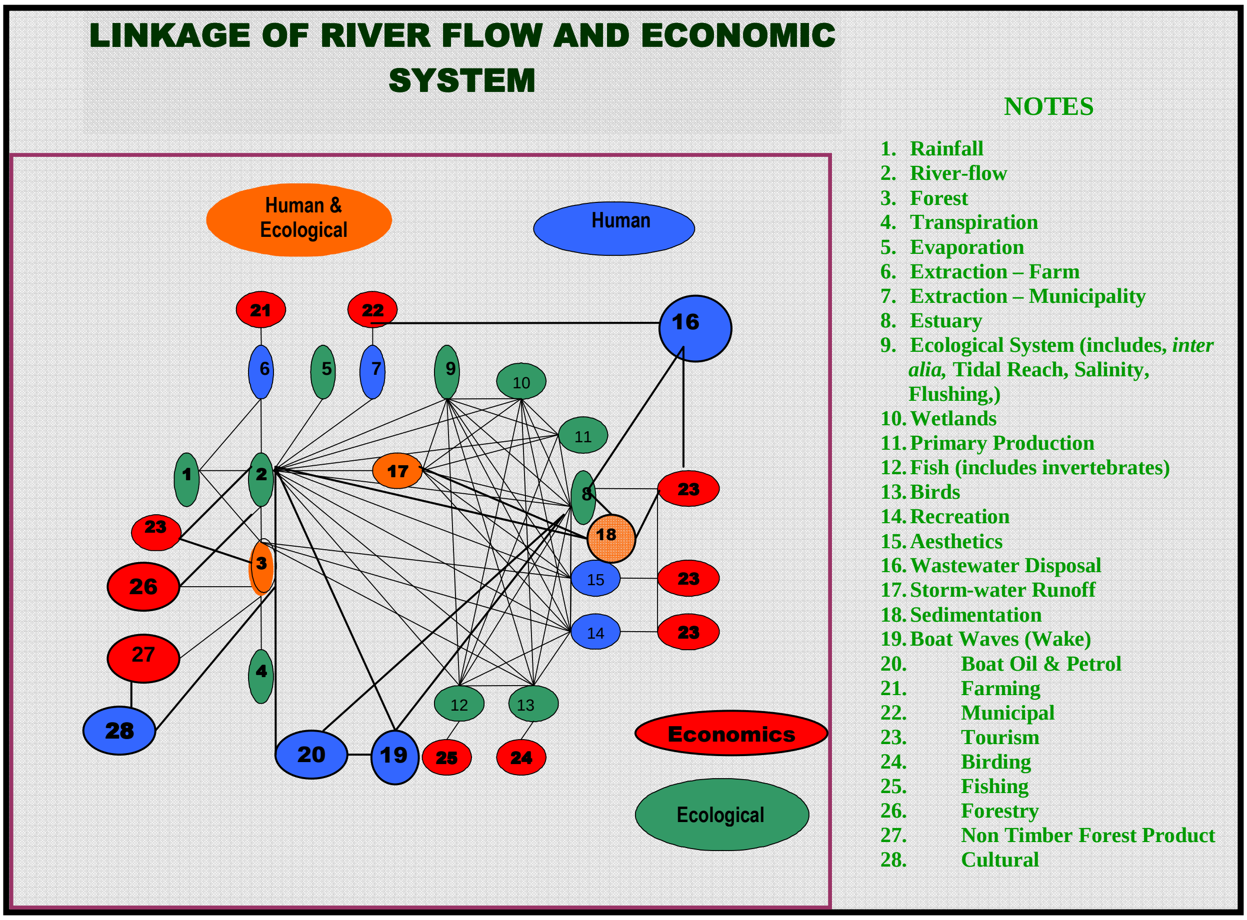

FIGURE 9. Representations of the linkage between the Knysna River flow and economic system within the Knysna basin.

However, such a comprehensive valuation effort is beyond the scope of this thesis. Rather, three representative links between Knysna River flow and Knysna Basin economic activities from Figure 9 have been chosen to demonstrate the valuation process. The three selected economic activities are:

- Municipal Use
- Fish Production (sometimes, Fish Extraction)
- Indigenous Forestry (hereafter, sometimes, Forestry**)**

With reference to each of the foregoing economic activities, the links between the river's contribution to the economic process will be represented in graphic format as Figure 10 (Municipal Use), Figure 11 (Fish Production) and Figure 12 (Forestry). The three activities were selected because they demonstrate linkages between the ecological system and economic system which take place solely within the Knysna Basin. The activities are also instructive because each economic process requires the use of river flow in a different manner. For example, the Municipal Use is a private use of the water in that it is extracted from the river to the exclusion of every other biological or economic use. The second example, Fish Production, represents a public goods[11] use of river flow in the sense that other activities are using the river flow at the same time it is contributing to fish production without impinging on other uses. Forestry is the third example. In this instance rainfall is diverted from the river to be used for forestry as evapotranspiration. In each example the river flow contributes as one of the inputs of production (Barbier 2007) to each of the three economic activities. The proportionate contribution of the river to each economic activity was determined[12] and the cost associated with the production of the economic goods or services was allocated to river flow. Young's equations (Young 2005c) were used to estimate the consumer surplus (the value of the ecological service or function[13] (Daly & Farley 2004d) which is related to the river's allocated portion of the cost of producing

[11] Public Goods are defined as, "goods or services that, if they provide benefits to anyone, can, at little or no additional cost, provide benefits to a large group of people…." (Lipsey, Courant, & Ragan 1999a).

[12] There will be a detailed explanation of the method for determining the proportionate contribution of the river flow later in this section.

[13] The distinction between ecological function, system and service is not clear at times. This relationship is described in Chapter 6, Daly & Farley (2004). When the term service or function is used the reference is specifically to those ecological activities which support the economic activity from which economic value will be imputed. Even this somewhat focused meaning is not clear at times. However, if properly addressed, it would appear to eliminate the double counting issue.

the goods or services. The consumer surplus is the ecological value of the Knysna River used to produce economic goods and services. The full value of the ecosystems services (total value of the services and functions) produced by the river was computed as the consumer surplus plus the cost actually incurred to access the product or the benefit of the product (Howarth & Farber 2002).

Each of the following three networks demonstrates the linkage between the river flow and one of the economic activities. The networks are stylized and not intended to be anything more than a visual representation of some of the nodes that participate in the production of the final product. Notwithstanding the lack of accuracy, it can be said that each node represents an entire set of variables as well as an input into the final product. Consequently, each network is within itself a dynamic system dependent, to a greater or lesser degree, on the functionality of the nodes.

3.3.2 Municipal Use

Knysna Municipality extracts water from the Knysna River for distribution within the boundaries of the municipality. The extractions from the river are not metered (Perring 2004). The distribution system is old in many parts of the city and there are losses within the system. There is a lack of agreement as to the causes of the water losses within the system. However, of the water pumped into the system 65% is returned to the Waste Water Treatment Plant (Hill *et al*. 1995) . The Municipal Engineer estimates that 10% of the water pumped from the river is lost before reaching the reservoir (Perring 2004).

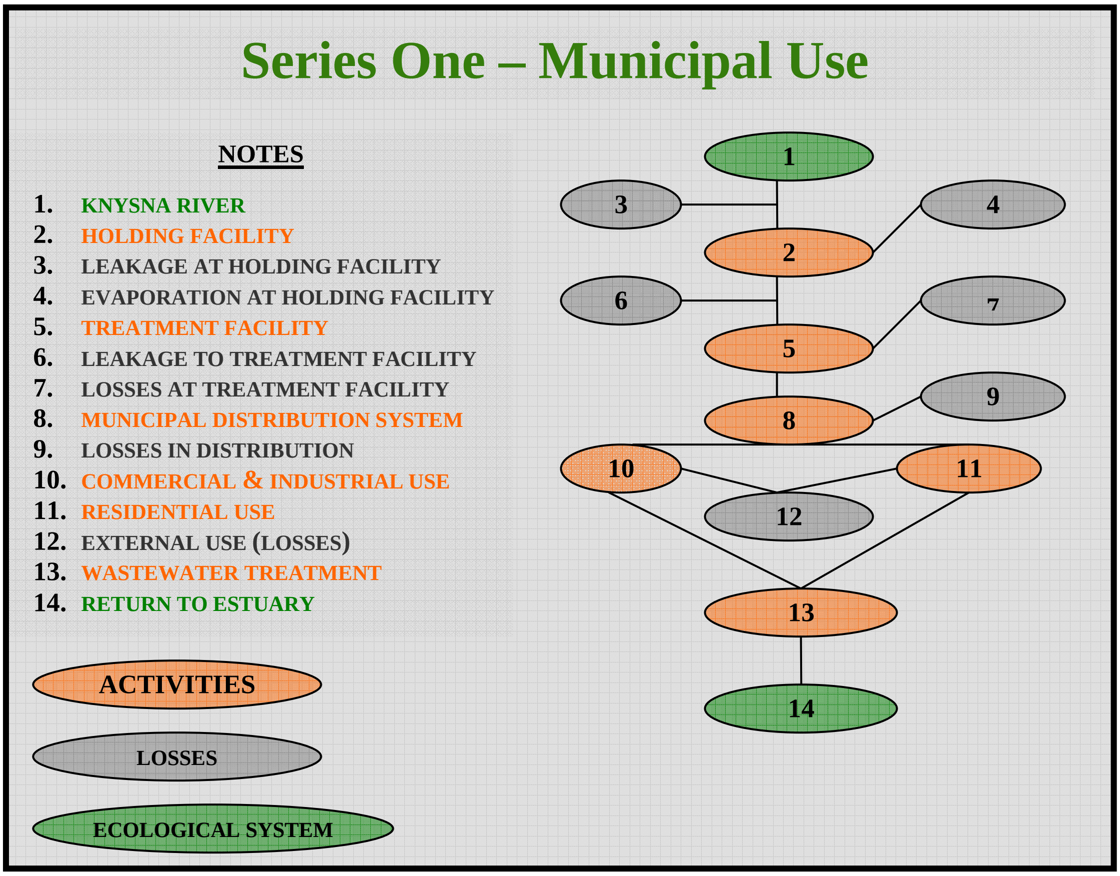

FIGURE 10. Network of activities and losses related to Municipal Use of Knysna River flow.

There are no estimates of the evaporation losses in the reservoir but there is general agreement that some evaporation takes place. Some water is pumped to the industrial area and used for construction within the municipality. This water is not returned to the system for treatment. Approximately 20% of domestic water is used outdoors and not returned to the system for treatment (Pieterse 2004). In effect approximately 58.5% of the water extracted from the river (not including water which is evaporated in the reservoir and treatment plants) is returned to the Waste Water Treatment Plant and discharged into the estuary. This water is of less quality than the water extracted from the Knysna River (Pieterse 2004; Allanson 2005a). The network and links shown in Figure 10 indicate the cost and losses associated with water use by the Knysna Municipality.

3.3.3 Fish Extraction

The fish production network (Figure 11) is composed of biological nodes except for the final node (No. 14) which is harvesting fish. There are several nodes which are impacted by human activities and under certain circumstances can negatively impact the estuary's production of fish. For example, the shape of the Knysna Estuary is changed by development around the edges and by deposit of silt in the river and estuary resulting from construction activities within the basin. In this project the variations contributed by human activities were not considered. However, in a dynamic systems model the variations caused by human and ecological activities and the natural and economic thresholds would be considered.

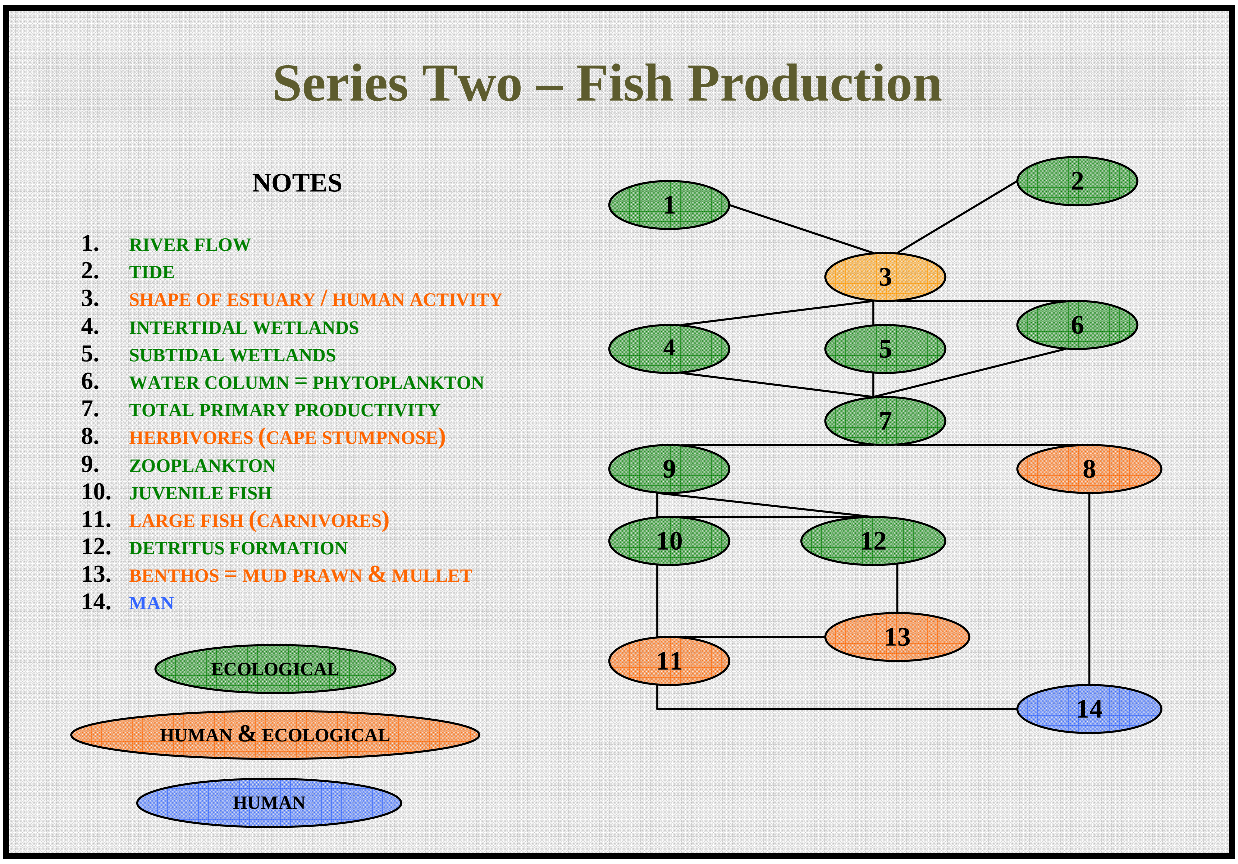

FIGURE 11. Network of human and ecological activities in Fish Production.
Source: Adapted from Prof. Brian Allanson. (Allanson 2005a; Personal Communication 1-12-05)

3.3.4 Forest Use

The Indigenous Forest Network represents the use of rainfall for the benefit of the Indigenous Forest (IF) as an extraction of riverflow (Figure 12). The IF intercepts the rainfall before it reaches the river and converts the rainfall to evapotranspiration. If the IF were not in place some other vegetation pattern with a greater or lesser retention of rainfall would exist. The IF can be compared with the municipality. The municipality takes water (rainfall) it uses after it has reached the stage of riverflow whereas the IF takes the water (rainfall) it uses before it has reached the stage of riverflow. The use of rainfall in this manner brings up a question of whether the rainfall taken up by the IF is a Public Good. The IF may be a Public Good because, if it is used sustainability, it produces the benefits indicated on the following network. This question is not addressed in this thesis but must be answered in the context of a dynamic systems model.

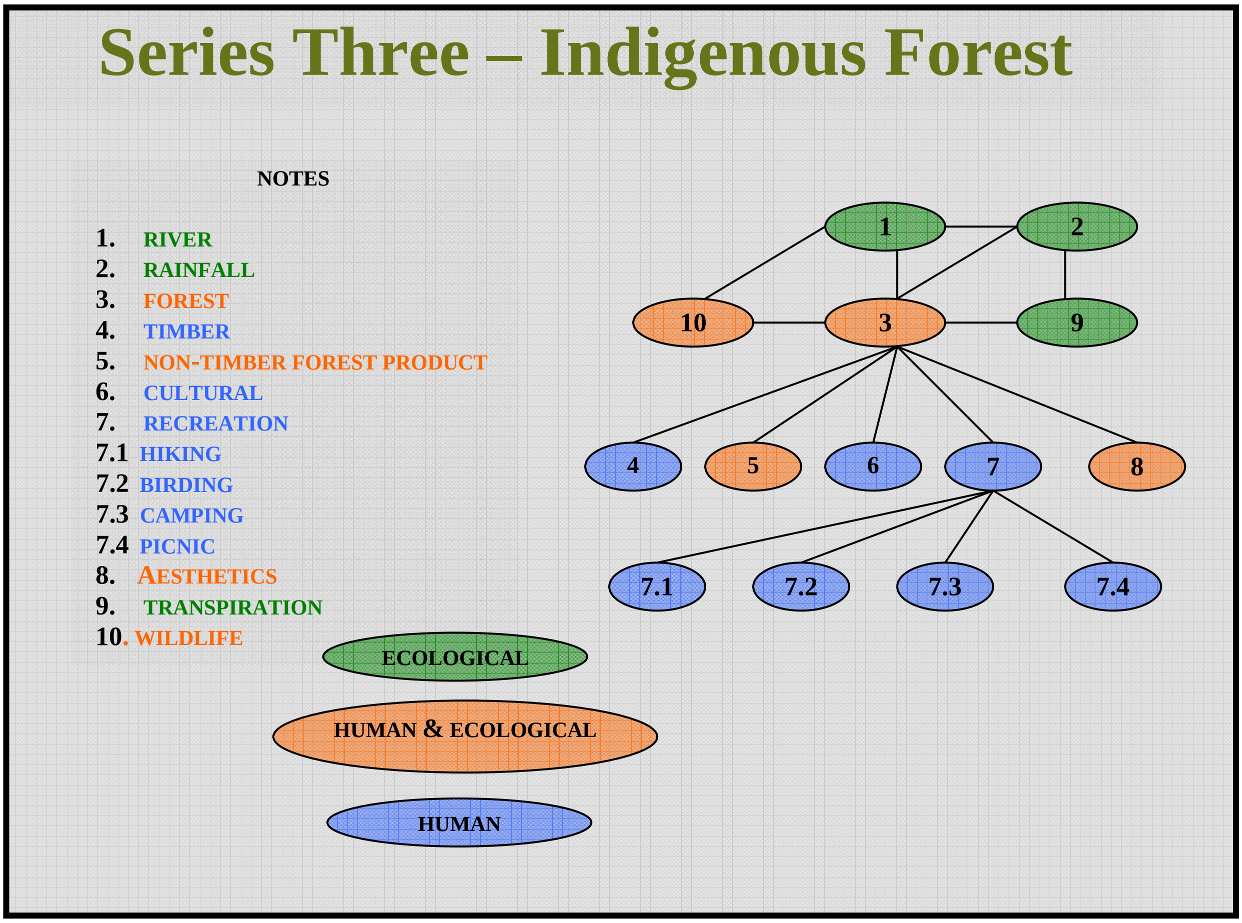

FIGURE 12. Network of rainfall, riverflow, transpiration and forest in Forest Production.

Because each of the three economic activities use riverflow in a different manner the equations for attributing and imputing value from the economic activity to the selected ecological activity (the river in this case) are different and require separate and unique data collection and calculation of the biological contribution of the riverflow to the economic product. Therefore, the methods for data collection and calculation of riverflow contribution relative to each economic activity will be described separately. After the collection of data and the calculation of the riverflow (biological) contribution to the economic activity, the next step will be to impute economic value to the riverflow by using Young's equation (Young 2005c) as described in the following section.

3.3.5 Young's Equation

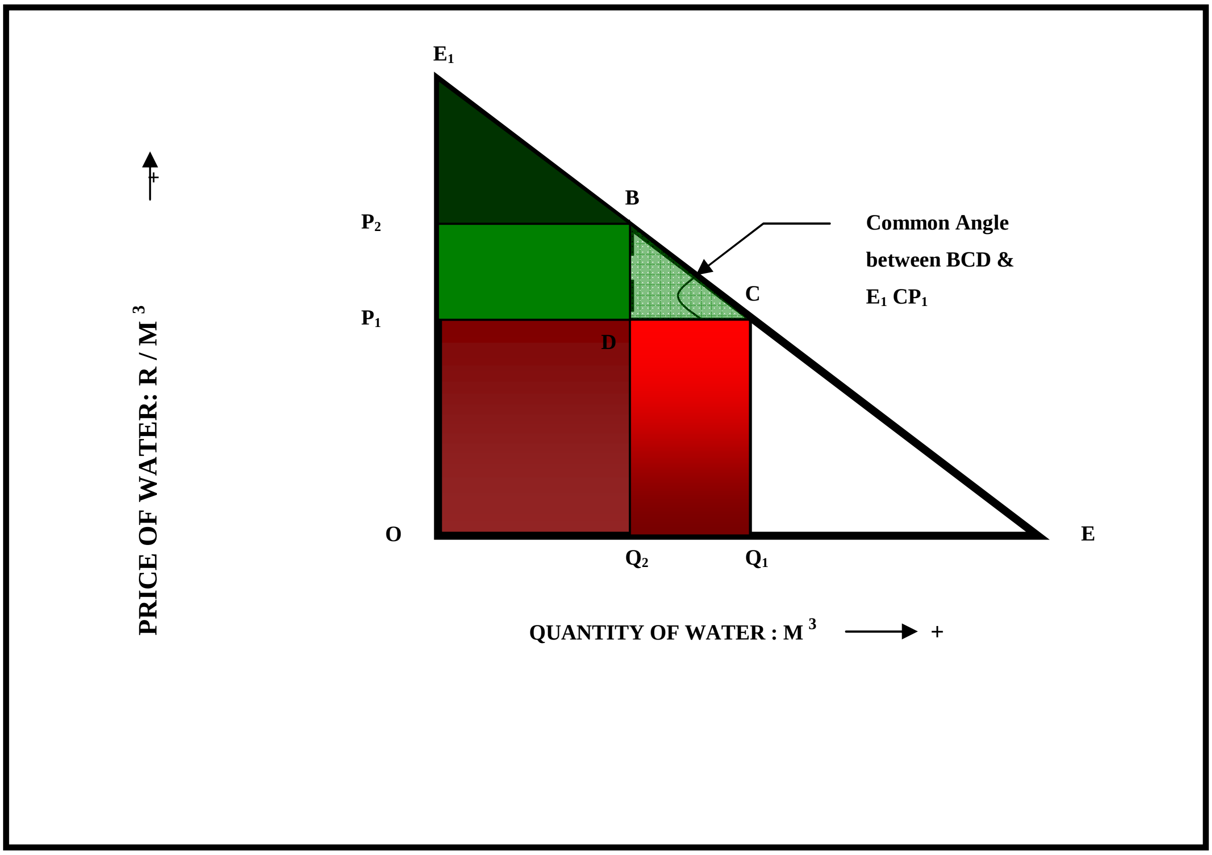

FIGURE 13. Incremental consumer surplus and common angle. The area bounded by BCD is the consumer surplus or the ecological value of the incremental volume of riverflow between Q_1 and Q_2. The angle BCD is common with ACP_1.

Young's equation is used to calculate the consumer surplus foregone when the quantity (Q_1) of water taken from the river is reduced to a lesser amount (Q_2). Figure 13 is a stylized representation of Figure 5. In Figure 13 the slope of the straight line demand curve (AE) is negative and is represented by angle AEO. A straight line demand curve is not generally representative of the relation between price and quantity but it will be assumed to be sufficient for this thesis.

Another consideration for Young's equation is elasticity of demand. Elasticity of demand is a measure of responsiveness of demand for a commodity to a change in price. The straight line demand curve, in this case, indicates that the elasticity of demand will vary from zero at the quantity axis to infinity at the price axis over the price range represented by AO and quantities of water represented by EO (Lipsey, Courant, & Ragan 1999b). Therefore in this case a constant elasticity of demand would not exist over the demand curve because of the variance. Nevertheless, a constant elasticity of demand will be assumed over the increment of quantity represented by $Q_1 – Q_2$ in Figure 13[14] (Lipsey, Courant, & Ragan 1999b; Young 2005c).

Young's equation will calculate the area under the demand curve for the incremental difference in water quantity between Q_1 and Q_2. This area (A) is described as BCQ_1Q_2 and includes the total benefit of the river flow (Young 2005c). The consumer's cost of the incremental reduction is $P_1 (Q_1 – Q_2)$. The consumer surplus associated with the total benefit of the incremental area is shown as BCD and is obtained by the equation: $CS = A – P_1(Q_1 – Q_2)$ (Young 2005c). The CS is equivalent to the value of the water flow in the river or, stated from another perspective, CS is the ecological value of the river related to the contribution of the river to the economic activity (Howarth & Farber 2002). The effect of calculating CS of the incremental area and the common angle between BCD and ACP_1 will allow the calculation of the CS at P_1 which is shown as ACP_1[15]. Calculation of the area of ACP_1 will provide an estimate of the value of the river flow (ecological value in economic terms) of the contribution of the river to Municipal Use, Fish Production and Indigenous Forest Production.

Young's equation is set out in Figure 14 below with the related assumptions.

The methods for determining the contribution of riverflow to the three economic activities will be described in the following sections 3.3.3, 3.3.4 and 3.3.5. Thereafter in Chapter 4 calculations of the economic value of the contribution of riverflow to each of the economic activities will be determined, using Young's equation.

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[14] Because the elasticity of demand varies over the demand curve a question was raised as to the impact on the incremental area a change in elasticity might have on the application of Young's equation. In response to this question a spread of elasticity values between (-.10) and (-2.00) were used to calculate incremental areas (A_i) holding all other terms constant. The result is found at Appendix A. Where the X axis is elasticity and the Y axis is incremental area.

[15] For calculations in this paper I have used the cotangent of angle C of BCD in order to calculate the area of ACP_1. However, there are other techniques for making the calculation.

YOUNG'S EQUATION

$$A = \frac{(P_1)(Q_1^{x})}{1 - x}(Q_2^{1-x} - Q_1^{1-x})$$

WHERE: With reference to Figure 9,

- **A = Incremental Area under the Demand Curve (total benefit)**
- **Q_1 = Quantity of Water in Cubic Meters (M^3)**
- **P_1 = Price of water at Q_1 in Rands per M^3**
- **Q_2 = A hypothetical reduction in quantity of water from Q_1**
- **P_2 = A hypothetical price of water at Q_2 in Rands per M^3**
- **X = 1 / E**
- **E = Elasticity of Demand and E is not equal to '- 1.0'**
- **The slope of Demand Curve (AE) is linear, but E is assumed to be constant.**

To estimate Consumer Surplus for the increment considered the cost to the consumer

FIGURE 14. Young's equation. This equation will calculate the incremental area under the demand curve (A) represented by water quantity $Q_1 – Q_2$ (Young 2005c).
Source: Adapted from equation 7-2 Young (2005a)

3.3.6 Municipal Use – Methods

Of the three economic activities addressed in this thesis, use of water by the Knysna Municipality, is the most straight forward. The water is extracted from the river by the Municipal Water Department and sold to the consumers within the Knysna Municipality at a charge for cost of extraction, storage, treatment and distribution. There is no charge for the water (Perring 2004) to the municipality or consumer. However, hereafter the term water charge will be used with the understanding that the term is referring only to cost related to extraction, storage, treatment and distribution unless specifically stated otherwise.

Before 2003 there was a sliding scale which reflected three levels of water charges to the consumer (Knysna Ratepayers Association 2000). Since 2003, charges to the consumer have been on a sliding scale which is reflected in nine levels of escalating rates for increasing consumption of water (Nortje 2007). There is no charge for the first 0–6 kilolitre (kL) of water delivered per month[16]. Thereafter rates increase eight levels as the consumption per month for each connection increases. Rates to each connection range from R3.99 kL^{-1} for 7–10 kL to R11.58 kL^{-1} for all consumption in excess of 60 kL per month. In 2004 the average rate for the first 60 kL was R6.249 kL^{-1}. In 2007 the average rate for the first 60 kL was R6.701 kL^{-1}. By using the average rate concept to offset the cost of free deliveries it is the intention of the municipality to cover cost of extraction, storage, treatment and delivery (Pieterse 2004).

The procedure used herein was adapted from Young (2005a) with modifications to the original procedure to obtain an ecological value of the riverflow for the full extraction by the Knysna Municipality. For the purpose of using Young's equation (Figure 14) the following assumptions were made:

- The average figure for water charges included cost related to extraction, storage treatment and distribution but excluded cost for water or profit (Perring 2004).
- The average water charge of R6.25 m^{-3} was designated as P_1.
- The total water consumed for 2004 was Q_1. Total consumption was calculated using data furnished by the Knysna Municipality for raw water produced from the treatment plant.
- Q_2 was set at 20% less than total consumption.
- Price elasticity of demand was assumed to be inelastic at '-.31'.

In justification of the inelastic price elasticity of demand it can be pointed out that the chosen value for elasticity was a compromise between domestic indoor use (-.13) and domestic outdoor use (-.38) which have been suggested as values for South Africa (Nieuwoudt, Backeberg, & Du Plessis 2004). Other researchers have used similar values reflecting inelasticity for domestic and municipal use (Gibbons 1997; Espey, Espey, & Shaw 1997; Young 2005c).

The Espey *et al*. (1997) study in areas with increasing block rates (such as Knysna) found demand to be significantly more elastic than in other models. This appears contrary to the Knysna experience where the increasing block charge (with the first block free to everyone) has no apparent influence on gross demand. As a suggestion it might be said that Knysna is a holiday and tourist destination with a wealthy base of permanent residents (Turpie *et al*. 2005). The resident population of Knysna was approximately 50 000 in 2000 (Davis 2005). According to the

[16] 6 kL effectively provides up to 7 kL of water per month.

City Engineer resident population growth was estimated to be between 8 and 10% for the foreseeable future. There has been an increase in water consumption for both indoor and outdoor uses and Knysna has been on water restrictions beginning in 2004 until the early months of 2007 when some of the restrictions were provisionally removed (Perring 2004). The rate structure alone has not been sufficient to curb the gross demand. The foregoing may reflect the statement that "…demand is a function of willingness to pay as well as the ability to pay …." In the context of free water to meet basic needs and a low rate on the second block charge (R3.51 kL^{-1} for 4 kLs in 2004) and an overall average price of R6.25 kL^{-1} in 2004, the rate structure would appear to suggest that there is no real need for either the wealthy or poor to seek a substitute to municipal water therefore an inelastic demand would exist.

- Leakage from the system is identified in the following areas:
    - Leakage from the extraction pumps and pipes estimated at 10% of total extractions (Perring 2004)
    - Evaporation from the holding ponds not defined (Perring 2004).
    - Leakage from treatment plant not defined (Perring 2004)
    - Leakage from municipal distribution systems has been estimated at 30% (Young 2005c). In this study Knysna Engineering Department acknowledged loss of water but could not identify the amounts or the causes of loss.
- After reviewing the total municipal consumption, deliveries from the treatment plant and losses from extraction at 10%, total leakage from the overall system was assumed to be 31.4%.
- Total consumption for 2004 was assumed to be domestic consumption because the industrial consumption of water in Knysna was approximately 13.3% of the total for 2006 (McCartney 2007) and it was assumed industrial consumption did not change significantly between 2004 and 2006.

After applying Young's equation to determine the incremental Area, the equation numbered 7-3 (Young 2005c) and stated as: $CS_i = A - P_1(Q_1 - Q_2)$ was applied to calculate the consumer surplus for the increment (CS_i) shown as BCD in Figure 13.
Following on, the value of CS_i was applied to $CS_i = (Q_1 - Q_2)(P_2 - P_1) / 2$, in order to determine the value of $P_2 - P_1$ in BCD of Figure 13 which made possible the calculation of the common angle (C) between BCD and ACP_1 in Figure 13 and consequently the value of the CS for Q_1P_1 or CS_{Q1}.

A second iteration of Young's equation was required because of system leakage equivalent to 31.4% of total extractions. In the second iteration Q_3 was equal to total extractions and Consumer Surplus (CS_{Q3}) = Q_3^2 (Tan C) ÷ 2

Therefore the ecological value per unit of riverflow after consideration of 31.4 % leakage is: $CS_{Q3} \div Q_3$ = Rand kL^{-1} riverflow.

3.3.7 Fish Production – Methods

To apply an economic equation to a function of the Knysna River (in this case the production of fish in the Knysna Estuary) it is necessary to quantify the contribution riverflow makes to fish production. There are several ecological functions, in addition to river flow, which contribute to fish production and consequently the economic value of the fish. Only riverflow will be assessed in this paper. Identifying and quantifying the relative ecological input of riverflow requires an understanding of the inputs which create the biotic and abiotic environment known as the Knysna Estuary.

The following diagram, Figure 15, demonstrates inputs and contributions to fishery stock production in a tidal river estuary (Odum & Odum 1981). This diagram is not intended to be definitive or for any purpose but to show the potential contributions and ecological interactions to fish production in a tidal estuary.

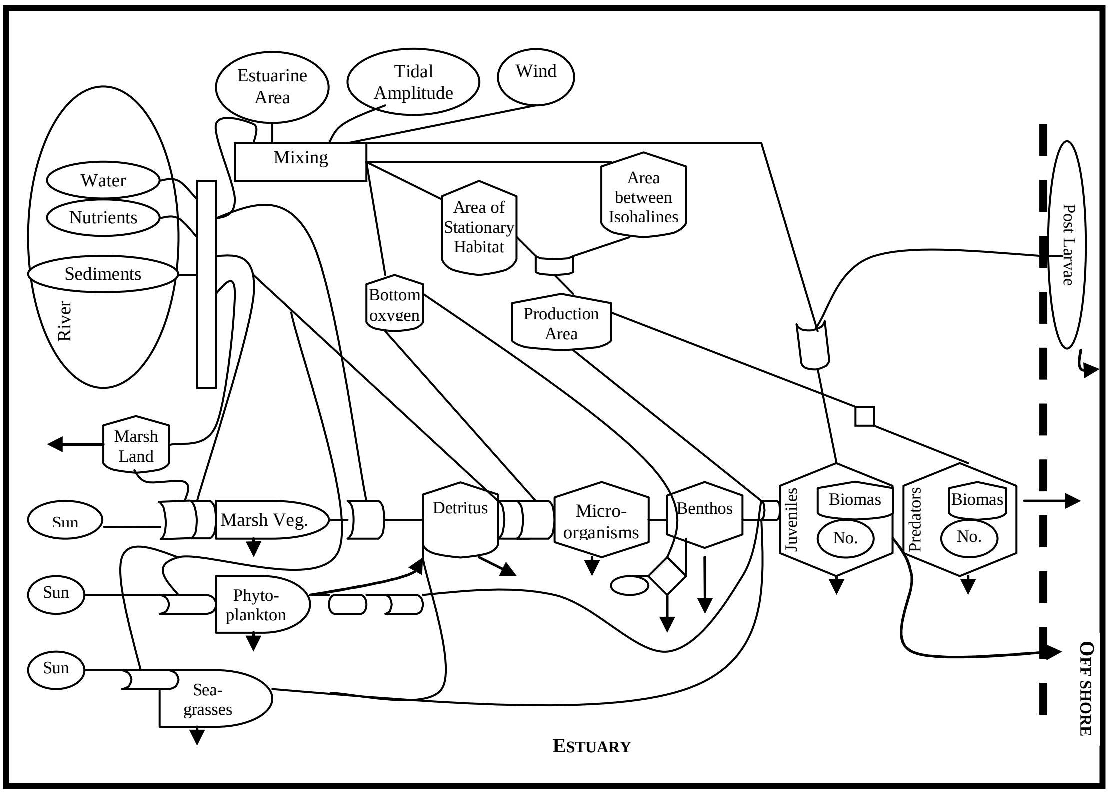

FIGURE 15. Energy flow diagram for an estuary. The energy flow diagram shows the pathways of potential effects of estuarine conditions on production of fishery stocks. The diagram is another method of mapping the interaction of the ecological system to produce fish. There was no economic mapping associated with the original diagram.
Source: Odum and Odum (1981).

The relationship between fish production in the estuary and the flow of the river is dependent on trophic, spatial and temporal requirements (Allanson 2005a) which are constrained by the overlap of the dynamic components of the environment with the stationary habitat component (Peterson 2003). The utilization of each of these abiotic and biotic factors is variable within and between species (Iverson 1990). The effect of the overlap of the dynamic and stationary environmental components is to produce a favorable production area (Browder & Moore 1980; Peterson 2003). Further, the shift in direction of the dynamic component (which can be caused by environmental events or anthropologic activities) and variability in the spatial and temporal extent of overlap with favorable stationary production area within an estuary may be a defining characteristic of estuarine productivity (Boyer, Fourqurean, & Jones 1997; Peterson 2003). Peterson (2003), citing others, states that “the maintenance of the complexity and heterogeneity of habitats and their spatial arrangements have (sic) been suggested to be vitally important to healthy and productive …estuarine ecosystems….” Peterson (2003) then posits that the spatial and temporal connectivity of habitats may influence overall estuarine productivity.

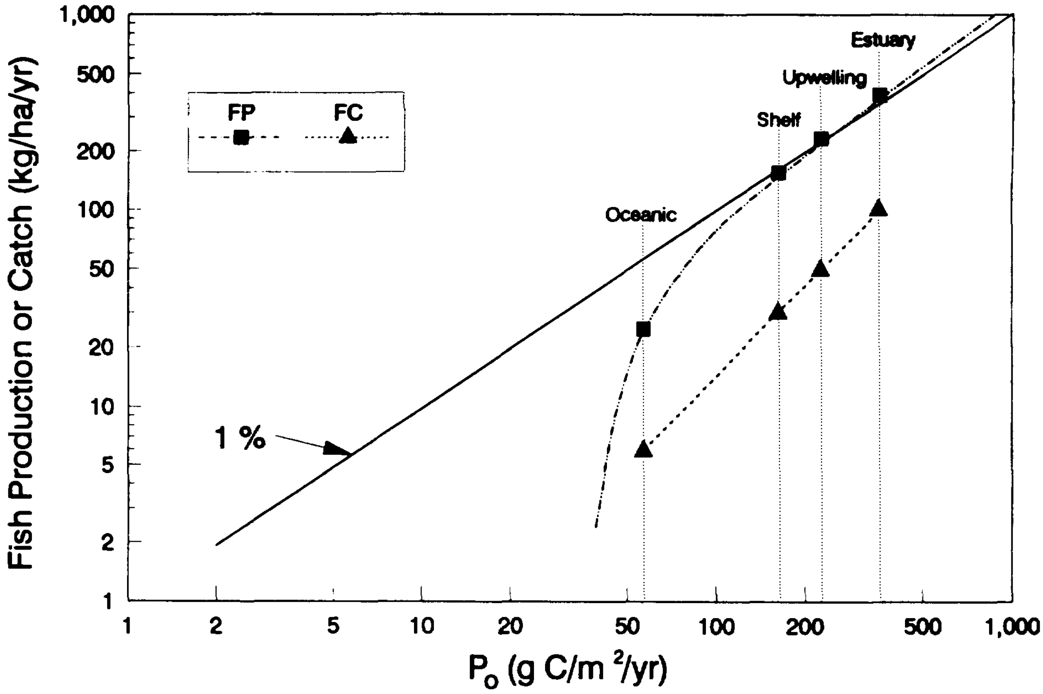

FIGURE 16. A graphic representation of the relation between fish production and sustainable fish catch. Nixon's (1988) and Iverson's (1990) equations predict fishery production and fishery catches in relation to primary production. Where Fish Production (FP), Fish Catch (FC) and Primary Production (P0) are set out in the following manner: FP = (0.083PO – 3.08). E2n. c2, where PO is g C m ^{2} yr $^{-1}$, E2 is nitrogen transfer efficiency (0.28), n is assumed to be trophic level 2.5, and C is the factor to convert g C m ^{2} yr $^{-1}$ to fish biomass (g wet wt m ^{2} y $^{-1}$) here taken to equal 36.0. Fishery catch is predicted from Nixon's (1988) equation: loge FC = 1.55 loge PO – 4.49, where FC is catch in kg ha $^{-1}$ yr $^{-1}$ and PO is primary production in g C m ^{2} yr $^{-1}$ (Houde & Rutherford 1993).

The foregoing leads to the suggestion that estuarine productivity in the context of a specific estuary, such as the Knysna Estuary, may be a function of a complex interaction among river flow, tidal prism and stationary habitat area (Browder & Moore 1980; Mattson 2002; Flannery, Peebles, & Montgomery 2002). Houde & Rutherford (1993) using equations and ten estuarine studies reiterated that, "…estuaries are highly productive with respect to fishery resources and that fisheries productivity and yields are related to relatively high primary production that itself is supported by high nutrient inputs." Houde and Rutherford (1993) point out that sustainable fish yields depend upon primary production and that studies exist which document the relationship between sustainable fish catch and primary production. The regression equations adopted by Houde and Rutherford (1993) were developed by Iverson (1990) (showing the relationship between fish production and primary production), Nixon *et al*. (1986) and Nixon (1988) (showing the relationship between sustainable fish catch and primary production). The relationships between fish production, fish catch and primary production are graphically setout in

Figure 16. These relationships demonstrate the linkage which allows the calculation to be made of Knysna River's ecological input into the estuary's fish production.

The equations developed for global estimates of fish production and sustainable fish catch and which are related to primary production are the following:

Equation 1: Fish Production

$FP = (0.083P_o - 3.08) \cdot E_2^n \cdot c_2$ (Iverson 1990; Houde & Rutherford 1993)

Where:

P_o = primary production (g C m^{-2} yr^{-1})

E_2 = nitrogen transfer efficiency (0.28)

n = assumed to be trophic level 2.5 because "…this classification represents 90% of the global ocean fish production that occurs in oceanic food chains." (Iverson 1990)

c_2 = the factor to convert g C m^{-2} yr^{-1} to fish biomass (g wet wt m^{-2} yr^{-1}), assumed to be 36.0 (fish carbon is assumed to be 10% wet wt (Nixon *et al*. 1986))

Equation 2: Sustainable Fish Catch (FC) is predicted from:

$\log_e FC = 1.55 \log_e P_o - 4.49$ (Nixon 1988; Houde & Rutherford 1993)

Where:

FC = kg ha^{-1} yr^{-1}

P_o = primary production (g C m^{-2} yr^{-1})

In applying the foregoing equations it should be noted that Iverson (1990) used a C:N mass ratio of 6:1 to convert flux of sediment trap particulate C to flux of particulate new N instead of the Redfield *et al.* (1963) average of 5.7:1. The C:N mass ratio of 6:1 has been confirmed as being appropriate for the Knysna Estuary by Prof. Brian Allanson (Retired)(2005b). Further, it is also significant that the estuaries used by Nixon *et al*. (1986) to develop the regression equations for fish production and sustainable fish catch are located on the East and Gulf coasts of the United States where data relating to primary production is more available than South Africa (Whitfield 2006).

Certain data from the Knysna Estuary were available for utilization with the Iverson (1990) and Nixon *et al*. (1986) equations 1 & 2, above. Lamberth and Turpie (2003) determined an estimated fish catch for certain geographical groups of South African estuaries one of which groups features the Knysna Estuary. Using the information provided by Lamberth and Turpie (2003) it was possible to calculate the estimated fish catch in the Knysna Estuary and the contribution the Knysna Estuary made to inshore marine fishing. The cost of estuarine and related inshore fish catch for the Knysna Estuary was calculated using data provided by McGrath *et al*. (1997). Switzer (2003) estimated total annual loading of dissolved inorganic nitrogen (DIN) for the Knysna Estuary for 12 consecutive months in the years 2000 and 2001 and as a separate determination, the contribution of the Knysna River to the total DIN for the estuary in the same period. The total annual load of DIN was estimated to be 14247 kg and the contribution of the Knysna River was 1774 kg yr^{-1} (12.45%). For the purpose of this thesis Switzer's data for the year 2000 were used because it was most closely associated in time with Lamberth and Turpie's (2003) fish catch and cost data.

The application of the Iverson (1990) and Nixon *et al*. (1986) equations (respectively, Equations 1 and 2) to the Knysna Estuary requires that the values for new (annual) N input found in Switzer (2003) be converted to C using the C:N biomass ratio of 6:1 (Dugdale & Goering 1967). These conversions resulted in 85 482 kg for total C in the estuary and 10 644 kg C (12.45%) contributed by the Knysna River.

There is insufficient data on South African estuaries to develop equations comparable to Houde and Rutherford (1993) (Whitfield 2006) Therefore, the fish catch equation developed by Nixon *et al*. (1986) was used with the available South African data to determine whether an estimated fish catch produced by Equation 2 above was reasonably close to the estimated fish catch by Lamberth and Turpie (2003). The application of the foregoing Equation 2 estimated fish catch to be 1.47 kg ha^{-1} whereas Lamberth and Turpie (2003) estimated fish catch within the estuary to be 78 kg ha^{-1}. The difference of approximately 76.5 kg ha^{-1} appeared to be unsupportable and therefore it was assumed that Equations 1 and 2 above were either not applicable to South African estuarine and inshore fisheries or the carbon estimates by Switzer (2003) were not accurate or the calculations of Lamberth and Turpie (2003) were not accurate. Because the data provided by Switzer (2003) and Lamberth and Turpie (2003) were more focused on local conditions they were chosen to be used for these calculations.

The catch and cost data provided by Lamberth and Turpie (2003) were used to derive the cost of the fish catch contributed by the Knysna River within the estuary and the related inshore marine fishery. Thereafter a relationship of 12.5% was used to determine the total cost allocated to the river flow for the purpose of applying Young's equation. And, finally, the total value of the fish catch contributed by the Knysna River was reduced to Rand kL^{-1} of riverflow yr^{-1} (year 2000) to determine P_1 with which the demand curve in Figure 13 and Young's equation in Figure 14 was applied for the purpose of determining the ecological value of the riverflow for fish production in the Knysna Estuary.

3.3.8 Forestry – Methods

The economic value of the flow of the Knysna River which contributes to indigenous forest production within the drainage area of the Knysna River is the value of the rainfall utilized by the forest and prevented from migrating to the river. An analogy to forest use is the extraction of water from the KR by the Knysna Municipality. The difference of course between municipal use of river flow and forest use is that the municipality takes water from the river after rainfall has entered the river flow whereas the forest utilizes a portion of the rainfall before it reaches the river.

The forest used for valuation of river water contribution is the indigenous forest maintained by DWAF within an area drained by the Knysna River. Switzer (2003), citing Reddering (1994) and the South African Forestry Company Limited established that the Knysna River drains approximately 332 km^2 out of a total Knysna Basin catchment area of 400 km^2.

The area of indigenous forest within the Knysna River drainage region is approximately 13121 hectares. The size and locations of indigenous forest within catchments K50A and K50B were obtained from the South African National Parks (SANParks) in Knysna and Conservation Support Services (CSS 2007) in Grahamstown. Johan Baard with SANParks (Baard 2006) provided the information in digitized and Excel formats from Geographic information system (GIS) data maintained by DWAF.

It has been assumed that forest production as used herein has two meanings. The first meaning is an economic use where cost and income are produced via timber sales and recreational activities. The second meaning is that described by Rosenzweig (1968), as the net above ground productivity in grams m^{-2}. The economic use is clearly embedded in the ecological production (Costanza *et al*. 1993; Anderies 1998). Further, it has been assumed that the indigenous forests are mature, stable, climax communities (Rosenzweig 1968).

It should be pointed out that in addition to the indigenous forest there are substantial areas of fynbos, commercial forest plantations and agricultural activities such as cropland and pastures within the drainage area. Further, some of the indigenous forest lies within the catchments but outside the jurisdiction of the DWAF and SANParks. From a review of the GIS overlays it appears that areas of indigenous forest within the catchments but in private control are in small strips in the upper part of Catchment K50A. The privately controlled areas were estimated to be approximately 1% of the total indigenous forest within Catchments K50A and K50B. For the purposes of this project, commercial activities other than the indigenous forest and indigenous forest not within the jurisdiction of the public agencies both will not be considered.

3.3.8.1 Rainfall Data

Annual rainfall in the mountainous portion of the drainage area of the Knysna River is higher than in the immediate area around the estuary (Hughes 1982; Switzer 2003; Joubert 2006). Hughes commented on the systematic errors which occur in the measurement of point rainfall at DWAF and South African Weather Service (SAWS) gauging stations in or adjacent to the Knysna River catchments. These errors arise because of two related reasons. The first is that the height of the mountains (up to 1600 m) rising from the coast within a distance of 50 to 60 km has a considerable influence on the local weather and weather patterns within the area of a single catchment causing rainfall to vary widely within a catchment. As a result of variations in rainfall an individual weather station gauge may not be representative of the area between it and the next nearest gauge. The second reason is that because of the nature of the terrain and remoteness of the area rainfall gauges were not installed in the higher elevations and therefore gauge density is not sufficient to accurately record the diversity of rainfall within those areas of the catchments (Hughes 1982).

Hughes (1982), in a study to establish a method to more accurately estimate rainfall in the mountainous region adjacent to the South coast, used rainfall data for monthly totals of rainfall from 1900[17]. One result of the study was an equation based on a multiple linear regression using four independent variables and four dependent variables. The equation allowed Hughes to produce a series of isohyets showing generalized rainfall trends for the higher elevations of the

[17] It was assumed Hughes (1982) used eighty years of data – up until 1980. The paper does not identify the most recent year within his data.

Knysna River catchments[18]. Figure 2 of Hughes indicates that rainfall varies from 800 mm to 1100 mm per year in the areas of indigenous forest between altitudes of 300 meters and 1200 meters above sea level.

In an effort to compare Hughes' (1982) rainfall data with current rainfall patterns, SAWS rainfall data were obtained from 1995 to August 2006 (inclusive) from five forestry stations identified by Hughes in producing the isohyets for Catchments K50A and K50B. The data for eight months of 2006 were used for the purpose of demonstrating the varied nature of rainfall within the catchments within a short period of time. Table 2 reflects mean annual precipitation (MAP) in each station for 11 years and 11 years 8 months, respectively, compared to the mean average precipitation used by Hughes for approximately eighty years (1900–1980).

The rainfall data for the eleven years 1995–2005 places 4 out of 5 gauging stations in a lower isohyet category than represented in Hughes' (1982) Figure 2. When the eleven years eight months are compared to Hughes' data, 3 out of 5 gauging stations are moved to a lower isohyet category.

TABLE 2**.** Estimated rainfall in the Knysna catchment. Comparison of Hughes' (1982) MAP (1900-1980) to 11 years (1995-2005) and 11 years eight months (1995-08/2006) at stations used for developing the isohyets lines for Catchments K50A and K50B. Source: DWAF rainfall data and Hughes (1982)

RAINFALL DATA (mm)	**1995-2005 MAP**	**1995-8/2006 MAP**	**HUGHES (1982) MAP**
Station			
0030265W	1010.9	1050.1	1136.0
0030297W	1055.3	1093.8	1161.0
0030088A	861.1	867.3	926.0
0029863W	1003.8	1031.3	1057.0
0029805W	784.1	813.2	810.0

The difference in MAP when comparing data for eleven years to data for eleven years and eight months is dramatic and reflects the variance in rainfall in the catchments. Although there appear to be noticeable differences between Hughes' MAP and the current rainfall patterns, Hughes'

[18] Hughes produced isohyets for a series of catchments between George and Knysna. Catchments K50A and K50B were two catchments within the series.

isohyets were chosen to estimate the rainfall within the indigenous forest because of the short term variations in rainfall and because of, over the long term, the credibility attributed to eighty years of accumulated rainfall data.

Hughes' (1982) Figures 1 and 2, clearly show rainfall in the indigenous forest areas at altitudes between 300 m and about 900 m to range between 750 mm and 1150 mm annually. This is the same pattern of rainfall and altitudes that existed in the Groenkop indigenous forest (Hughes 1982; Dye *et al*. 2005). From a review of Hughes isohyets and a digital map of the catchment with related altitude contours provided by CSS (2007) it was concluded that there was an estimated average rainfall of 950 mm MAP for the drainage area of the Knysna River. Area wide, the total volume of rainfall was calculated to be 315.685 x 10^6 m^3 yr^{-1}. Using the same method as above, 124.646 x 10^6 m^3 yr^{-1} was the rainfall over the area of indigenous forest within the drainage area calculated by multiplying 950 mm MAP by the area of indigenous forest (13121 ha) (CSS 2007) within the total drainage area. It should be pointed out that there are substantial discrepancies in data and methods used for estimating rainfall for the same areas of indigenous forest. CSS (2007) used 850 mm MAP for the averages within Catchment K50A and 882 mm MAP for averages within Catchment K50B. The CSS MAP estimates were approximately 100 mm less than the estimates derived from Hughes (1982). The Hughes isohyet data were chosen for this project because CSS estimates for K50B included data from areas near and on the estuary which was not in the drainage area and which are historically lower rainfall areas. Further, the CSS estimates used a data base which incorporated large area averages rather than catchment based averages as suggested by (Grogens & Hughes 1982; Hughes 1982). A map of the Knysna Catchments including indigenous forests with contour lines reflecting altitude at 20 m intervals is shown in Figure 17 below (CSS 2007).

3.3.8.2 Rainfall Estimations

There are very few studies of rainfall use by indigenous forest in the Knysna area and none specifically in Catchments K50A and K50B (Brown 2006; Seydack 2006; Everson 2006b). However, there are several acceptable schemes for quantifying rainfall use by forests (Leigh 1999a). In this project two possibilities were investigated. One of the most reliable techniques for estimating rainfall use is to subtract annual runoff (river flow) from annual rainfall within the drainage area (Leigh 1999b). As Leigh points out, the rainfall minus runoff method requires a sufficiently long period of data collection so that changes in the amount of water retained by the soil are minimal when compared to the quantities of rainfall and runoff.

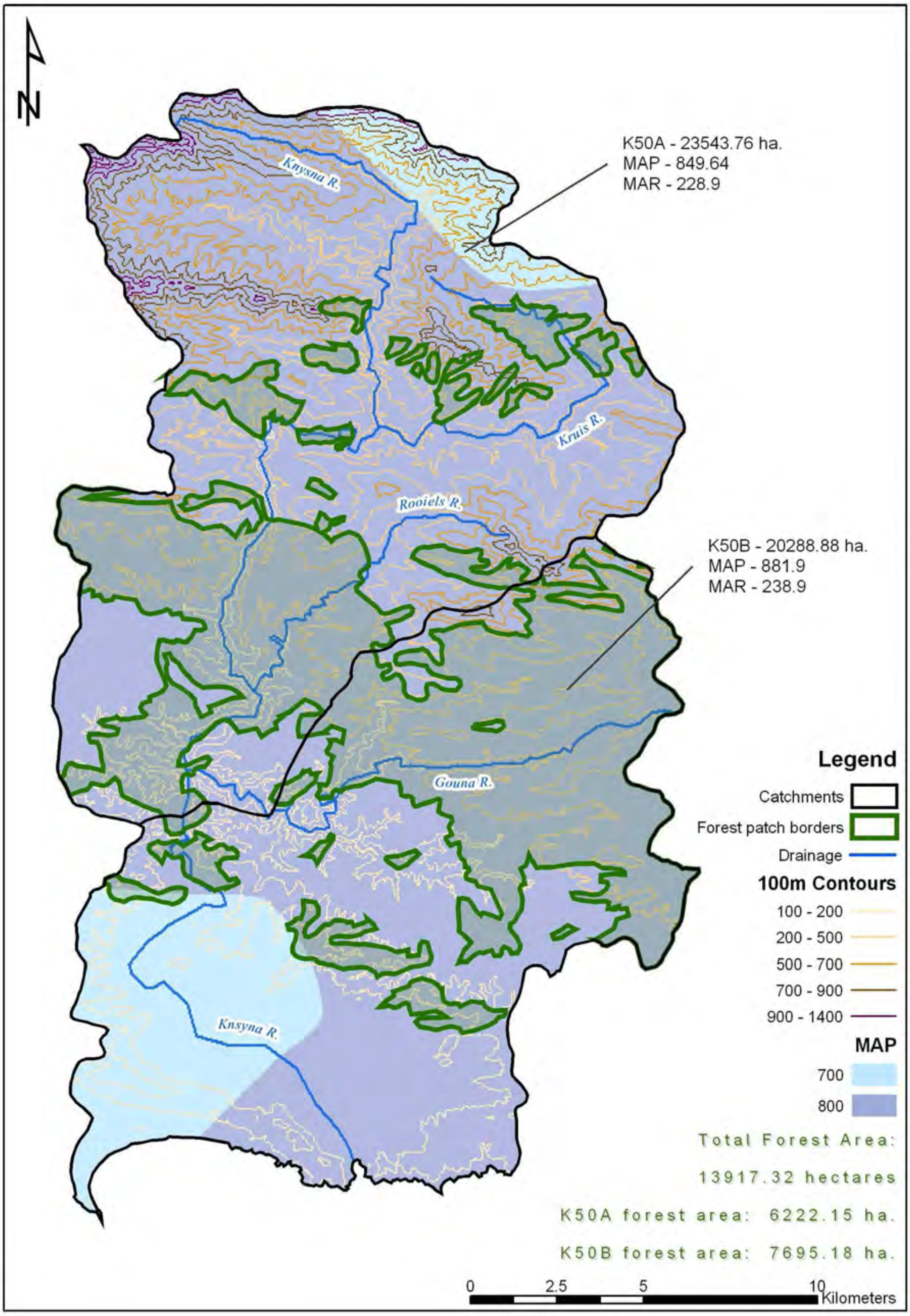

FIGURE 17. Contour map of Knysna catchment with rainfall and area. Source: CSS (2007)

Switzer (2003) estimated the total runoff for the Knysna River drainage area before abstractions by the municipality as being 5.1578947 x 10^7 for 2000 and 4.4680851 x 10^7 for 2001. In 2002 DWAF estimated mean annual runoff for Catchment K50A (this did not include Catchment K50A) to be 5.0850000 x 10^7 m^3 yr^{-1} (DWAF 2002). The DWAF (2002) estimate was undertaken for the purpose of determining the reserve and resource classification for the Knysna River pursuant to the requirements of the National Water Act (Republic of South Africa 1998b). The estimate was considered by DWAF to be of low confidence and neither the data nor the method for creating the estimate was indicated. In an effort to verify the runoff values the methodology suggested by Switzer (2003) was applied with DWAF river flow data for years 1989–2000 to create a linear trend line for MAR in the drainage area. The runoff values for the trend line ranged between 6.000 x 10^7 and 5.600 x 10^7 m^3 yr^{-1}. Because Switzer (2003) estimated runoff for only two years, and because the DWAF estimate included the flow for the Gouna River (the main tributary for the Knysna River) the DWAF estimate of 5.085 x 10^7 m^3 yr^{-1} was chosen to be applied as total drainage area runoff for K50A and K50B (DWAF 2002). Also, the baseline year was assumed to be 2000 for the purposes of this thesis.

The rainfall estimate for the indigenous forest was 12.4646745 x 10^7 m^3 yr^{-1}. The runoff attributed to the indigenous forest was based on a ratio of indigenous forest area to total drainage area which resulted in an estimated volume of 2.0077885 x 10^7 m^3 yr^{-1}. It is acknowledged that using a simple ratio of drainage area to indigenous forest may not produce an accurate estimate of runoff attributable to the indigenous forest. Total runoff may be greater in fynbos areas or areas where soil structure is less absorbent (Switzer 2003) thereby, in the context of the Knysna Catchment, allocating less actual runoff to the areas of indigenous forest. Runoff of 2.0077885 x 10^7 m^3 yr^{-1} was subtracted from rainfall of 12.4646745 x 10^7 m^3 yr^{-1} for a remainder of 10.4568860 x 10^7 m^3 yr^{-1} as an estimated quantity of rainfall used by the indigenous forest.

The second method for estimating rainfall use is described in an interim unpublished Water Research Commission Report identified as Project K5/1462 (Dye *et al*. 2005) The report illustrates a proposed model for estimating evapotranspiration over Groenkop Forest (an indigenous forest) near George, South Africa. Evapotranspiration data were measured above the indigenous forest on three visits over a total period of 18 days in 2004. The arrangements employed for measuring were Scintillometer and Eddy Covariance systems on all three data collection trips and a Bowen Ratio system was also employed during the third visit. A model for a 12 month period was developed from the 18 days of data collection. The model produced an estimated 933mm per annum as a rate of evapotranspiration for the Groenkop Forest. The Groenkop forest is situated at the same latitude and altitude as Catchments K50A and K50B but approximately 40 km east of the Knysna Catchments. Everson (2006a) suggested that the total evaporation rates (transpiration and evaporation)[19] of the Groenkop Forest would be similar to that of the indigenous forest in the Knysna Catchments, although he was not specifically familiar with the Knysna Catchments. Everson's suggestion is supported by Leigh (1999c) who showed that many different tropical forests have constant and similar evapotranspiration rates.

Using the Groenkop Forest model's rate of evapotranspiration of 933 mm yr^{-1} the estimated volume of rainfall use for the Knysna Indigenous Forest was calculated by multiplying the model's rate by the area of indigenous forest within the Knysna River drainage (131 207 100 m^2) to obtain a product of 12.2416224×10^7 m^3 yr^{-1}.

The foregoing calculations have produced two estimated volumes for rainfall use by the indigenous forest. The first was the Rainfall minus Runoff method which resulted in an estimate of 10.4568860×10^7 m^3 yr^{-1} rainfall use. The second was the Groenkop Forest model which resulted in an estimate of 12.2416224×10^7 m^3 yr^{-1} rainfall use. The Groenkop Forest model of evapotranspiration produced an estimated rainfall use of 117% of the Rainfall minus Runoff method.

As a further comparison, the evapotranspiration volume of 12.2416224×10^7 m^3 per annum produced by the Groenkop Forest model is 98% of the estimated rainfall over the indigenous forest (12.4646745×10^7 m^3 per annum). The Rainfall minus Runoff method estimated evapotranspiration to be 84% of estimated rainfall over the indigenous forest. If rainfall vs. runoff is compared on a broader scale, Leigh (1999c) reported accumulated data which indicated that in tropical catchments (not selected areas of a catchment such as the indigenous forest of the Knysna Catchments) Rainfall minus Runoff / Rainfall would range from 30% to 80% and in catchments within temperate zones a comparable relationship would range from 38% to 81%.

[19] Total evaporation is evaporation plus transpiration. When referring to total evaporation the terms evaporation and transpiration are usually consolidated to be evapotranspiration. In this thesis evapotranspiration was used to mean rainfall use by the indigenous forest because it is difficult to distinguish between water vapor produced by evaporation and that produced by transpiration.

Because the Rainfall minus Runoff method is an accepted method for determining evapotranspiration and because the lower estimate more closely fits the broader scale at 84% of rainfall the value chosen for use was 10.4568860 x 10^7 m^3 yr^{-1}, as an estimation of evapotranspiration or water use by the indigenous forest.

3.3.8.3 Economic Value of ERF

If water use (evapotranspiration) by the indigenous forest is allocated to the Knysna River, the annual volume of 10.4568860 x 10^7 m^3 would have an equivalent river flow (ERF) of an average 3.3159 m^3 s^{-1}. Therefore the next step in the process is to impute economic value from the sale of timber and recreational activities to ERF.

To impute economic value to the ERF it was necessary to estimate the ecological contribution of the ERF to indigenous forest production. This approach suggests that the contribution of ERF must be identified and quantified in relation to other ecological contributors to forest growth. Rosenzweig (1968) by the linear regression equation adapted here as:

[Log_{10} NAAP = (1.66) Log_{10}AE -1.66] [20]

(hereafter sometimes, Productivity Equation), showed that ERF, alone, was a reliable indicator of forest production. He and Leigh pointed out that other contributors to production are CO_2, sunlight, soil, competition, design, and a myriad of local conditions (Rosenzweig 1968; Leigh 1999a). Of this group, the primary raw materials for productivity are water, sunlight and CO_2. Other biochemical and mineral nutrients integrated into the photosynthesis process are, unless there is a shortage, under the control of the plant organism and for the purposes of this thesis were not considered (Rosenzweig 1968). Only the raw materials sunlight, water use (evapotranspiration) and carbon fixation were considered in estimating the contribution of ERF to forest production. Further, because evapotranspiration and carbon fixation are a reflection of the simultaneous availability of carbon, water and energy (sunlight) and because sunlight was constant for both carbon fixation and evapotranspiration over the Knysna Forest it was concluded that the relation between carbon fixation and evapotranspiration to above ground productivity (dry weight) was appropriate on which to base an estimate of the contribution of ERF to the productivity of the indigenous forest. Because of a lack of local relevant scientific investigation and related data the assumptions and data discussed in other studies were used to

[20] NAAP is the net annual above-ground productivity (dry weight) in grams per square meter. And AE is the annual actual evapotranspiration in millimetres.

make the connection between carbon fixation, evapotranspiration and above ground productivity (dry weight) in the Knysna Forest. This process is explained below.

After converting ERF to 797 mm evapotranspiration it was translated to Log_{10} and applied to the Productivity Equation in substitution of Log_{10} AE to determine an estimate of above ground production (dry weight) of 14.45 t ha^{-1}. To determine carbon fixation it was assumed that the carbon fixation to dry weight relationship would be approximately the same for Massachusetts USA (Mass) at 43^0 54` N as Knysna Forest at $34^0$ 20` S (Leigh 1999a). The Mass forest fixation of carbon was 40.7 t CO_2 to 28 t dry weight[21] vegetable matter. Using the ratio of 40.7 t CO_2 fixation to the 28 t vegetable matter (dry weight) and applying it to 14.45 t of vegetable matter (dry weight) which was predicted by the Productivity Equation it was possible to estimate 21.00 t[22] CO_2 fixation ha^{-1} for the Knysna Indigenous Forest. The 21 t converts to metric t of 19.05, which was rounded to 19.0 t.

The photosynthesis association of sunlight (energy), carbon and water, where energy is the constant in the relationship, produces an equivalent of 797 mm water to 19 t of CO_2 fixation ha^{-1} for above ground productivity (dry weight) (hereafter sometimes, Productivity). This relationship was then integrated with the annual cost of operating and maintaining the forest to determine the portion of the total cost allocated to ERF.

SANParks, Knysna, provided some data for cost of indigenous forest (CIF) for operating and maintaining the indigenous forest. Because of difficulties in merging administrative and accounting procedures and computer systems SANParks was not able to provide total combined cost of producing all revenues related to the 13121 ha of indigenous forest. Specifically, SANParks only provided data related to the sale and cost of indigenous timber and no data related to the recreational activities associated with the indigenous forest areas. With this limitation, the cost and revenues related to timber production were used as total revenue in order

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[21] If the dry weight is the dry weight of total production the estimate used in this thesis is not accurate by the amount of the difference between dry weight of total production and dry weight of above ground production. In this connection see: pg. 128 Leigh (1999_c) where the term 'dry weight of vegetable matter' is apparently used when referring to 'above ground dry production'.

[22] The assumption was that for the purposes of the foregoing calculations the units used were 'US', therefore at this point a conversion will be made to metric units for the Short Ton at .907 x 21 tons = 19.05 metric tons.

to apply the relevant calculations. The lack of cost and revenue data related to recreation reduced the value of the riverflow computed with Young's equation.

Within the limitations stated above the following methods were followed. The allocation between water and carbon can be written as 19.00 t CO_2 ha^{-1} + 797 mm H_20 ha^{-1} = 19.00 t CO_2 ha^{-1}. + 7970 t H_2O ha^{-1}. And can be simplified to 1 ton CO_2 for 419 t H_2O. This relationship equates to a contribution (by weight) to ecological production of the indigenous forest of 0.2% for carbon and 99.8% for water[23].Therefore, an economic cost of forest production would be allocated 99.8% to ERF. ERF was then divided into (CIF x 0.998) to produce a unit price of Rand m^{-3} of ERF. The unit price is equivalent to P_1 in Figure 13 and the ERF is equivalent to (Q_1) in Figure 13. The method for calculating the economic value of ERF by using the demand curve in Figure 13 and Young's equation (Figure 14) will be set out in the following paragraphs.

To impute a share of the total product value (services provided by the indigenous forest) from the economic system to a portion of the ecological system which contributed to those services, in this case the equivalent river flow (Gibbons 1997; King 2002), Young's equation (Figure 14) can be applied to determine the consumer surplus (the value of the water in the river after costs are subtracted (Gibbons 1997). As stated before, this concept is graphically represented by the demand curve in Figure 13 above. In application of Young's equation, unit cost will be 'P_1' , original quantity of ERF will be Q_1, the changed quantity will be Q_2 (in this case 80% of Q_1)[24], the total benefit of the incremental change will be represented by A_i (the incremental area under the demand curve) and price elasticity of demand *E* will be assumed to be inelastic at -.38[25] (Nieuwoudt, Backeberg, & Du Plessis 2004).

A_i (the total benefit of the incremental area under the demand curve represented by Q1 – Q2) = the area bounded by B C Q_1 Q_2. The cost to the consumer of A_i is CQ_1Q_2D = P1 (Q1-Q2). The economic value of the ecological function of the increment is $A_i - CQ_1Q_2D$ = BCD. Common

[23] It is possible to make the ratio between water and carbon using other units such as energy or oxygen as an example. However, because weight was used to calculate productivity it appears consistent to continue to use weight.

[24] The selection of 80% is arbitrary.

[25] This value was assumed for the reasons that demand was perceived to be inelastic because demand for timber and other forest services was growing rapidly and because the SANP was charging cost or less than cost for the services provided by the forest. In Nieuwoudt *et al*. (2004) the price elasticity value of 0.38 was represented as a value for domestic outdoor use of water and as a median short-term value.

angle T allows the calculation of area ACP_1 which is the economic value of the ERF (evapotranspiration) represented by Q_1. The unit value (Rands m^{-3}) of the ecological function is ACP_1 / Q_1. The economic value of the ecological function of Q_1 can be rewritten in terms of R m^{-3} yr^{-1} in order to make a direct comparison between evapotranspiration and riverflow for the year 2000.

CHAPTER 4

4 CALCULATIONS

4.1 Introduction

The following calculations will be an application of Young's equation (Figure 14) to the Knysna River's contribution to each of the three economic activities examined in this thesis: Municipal Use, Fish Production and Forestry. The manner in which the Knysna River contributed to each economic activity was demonstrated in Chapter 3 on Methods. In summary, it was shown that the river contributed 100% of the Municipal Extractions, 12.45% of the carbon to Fish Production and 99.8% to Indigenous Forestry Production. The following calculations will allocate the relative percent of the cost of obtaining the product to the river in order to obtain the related consumer surplus and thereby the ecological value of the riverflow to the product.

Figures 13 and 14 are the basis for and are used with each calculation. Figure 13 is a stylized representation of the demand curve showing an incremental area under the curve that can be computed by integrating between quantities of riverflow Q_1 and Q_2. In reference to Figure 13, the curve AE will not cross AO. In a non-stylized representation the demand curve and the Y axis will approach at infinity. Because, for this thesis, the portion of the river flow above the ecological reserve is used the assumption is made that the line AO is crossed by AE. An example of this relationship can be seen by referring to Figure 5.

Figure 14 is Young's equation used for integrating between Q_1 and Q_2. Standard assumptions for the use of Young's equation are set out in Figure 14, while specific assumptions relative to specific economic activity are set out in connection with the calculations for such economic activity. In each of the three sets of calculations in addition to specific assumptions there are certain inconsistencies and issues of data quality which will be addressed in the relevant section.

4.2 Calculations – Municipal Use

Knysna Municipality charges municipal users of water for the cost of extracting, treating and delivering water. The municipality makes no charge for the water or for the availability. As mentioned in Chapter 3 there are multiple block levels of charges for increasing usage with the first level being free to all users. The year 2004 was the earliest year for which data was available to calculate an average cost. The average cost for water in 2004 was R 6.25 kL^{-1}. This was the figure used as price P_1 with the consumption for year 2000 to calculate the value of the riverflow. Whether the average cost to the Municipality changed between the years 2000 and 2004 was information not readily available from the Knysna Municipality (McCartney 2007; Nortje 2007). Consumption for the year 2000 was used for the reason that riverflow for Fish Production and Forestry was based on data for 2000.

To adjust for the loss of water resulting from leakage it was possible to determine the estimated losses from the system in year 2000 using information collected and provided by the Knysna Municipality. One of the obvious losses not accounted for was from evaporation at the storage dam. There are different estimates of losses within the system. Young (2005a) estimated losses to municipal systems to average between 40% and 45% whereas a recent estimate for Knysna would indicate approximately 33% loss in the system if losses between the river and the treatment plant of 10% (Perring 2004) are considered (Knysna Catchment Management Forum 2007). After reviewing the production and consumption data provided by the Municipality for year 2000 and using the extraction loss of 10% suggested by Perring (2004) a loss estimate of 31. 44% was applied to Young's equation to determine value of the riverflow.

In applying Young's equation to Municipal extractions two iterations were used. The first was to determine the area under the curve (A_i) for the increment $Q_1 - Q_2$. The A_i will allow the tangent of the common angle C in Figure 13 to be determined and thereby the consumer surplus (CS_{Q3}) related to Q_3, the quantity actually abstracted from the river in order to provide the consumption (Q_1) sold by the Municipality for the year 2000. The unit value of the river flow was then obtained by the equation: $CS_{Q1} \div Q_3 = R\ kL^{-1}\ yr^{-1}$.

Young's equation applied to Municipal Use

$$A_i = \frac{P_1\, Q_1^{X}}{1-X}(Q_2^{1-X} - Q_1^{1-X})$$

Where:

E = elasticity of demand = -.31, and

$X = 1/\,/E/ = 3.2258$

$1 - X = 1 - 3.2258 = -\ 2.2258$

P_1 = R 6.25 kL^{-1} (average cost) = Average cost per kL of water consumed before dilution for leakage at 31.44% for 2000

Q_1 = Water consumed: 1976148 kL yr^{-1} for 2000

Q_2 = Water consumed kL yr^{-1} for 2000 less 20% : 1580918 kL

$Q_1 - Q_2 = 1976148 - 1580918 = 395230$ kL

$Q_1^{X} = 1976148^{\,3.2258} = 2.037297429 \times 10^{\,20}$

$Q_1^{1-X} = 1976148^{-\,2.2258} = 9.699850261 \times 10^{-\,15}$

$Q_2^{1-X} = 1580918^{-\,2.2258} = 1.593923896 \times 10^{-\,14}$

A_i (incremental Area) = Total Benefit for increment $(Q_1 - Q_2)$

$$A_1 = \frac{6.25(2.0372978 \times 10^{20})}{(-\ 2.2258)}(1.5939239 \times 10^{-14} - 9.6998503 \times 10^{-15})$$

= 3569360.

Cost to the consumer for increment $(Q_1 - Q_2) = P_1\,(Q_1 - Q_2) = 6.25\,(395230)$ = R 2470187.

Consumer Surplus for increment $(Q_1 - Q_2)$ $(CS_i) = A_i - (P_1)\,(Q_1 - Q_2)$

$CS_i = 3569360.60 - 2470187.50 = 1099173.$

$$CS_i = \frac{(P_2 - P_1)(Q_1 - Q_2)}{2} = 1099173$$

Therefore $$P_2 = \frac{2(CS_i)}{(Q_1 - Q_2)} + P_1$$

$$P_2 = (2(1099173) \div (395230)) + 6.25 = R11.81$$

To calculate the tangent of the common angle C it is required to know:

$P_2 - P_1$ = R5.56

Tan Common Angle between BCD and ACP_1 (Tan C in Figure 13) = $(P_2 - P_1) \div (Q_1 - Q_2)$

$$\text{Tan C} = 5.56 \div 395230 = .14067 \times 10^{-4}$$

Q_3 = water extracted for 2000 = water consumed ÷ (1.00 – 31.44 % leakage)

$$= 1976148 \div 68.56\% = 2882363.\ \text{kL yr}^{-1}$$

Value of the Knysna River flow which supported the volume extracted by the Knysna Municipality in 2000**:**

$$CS_{Q3} = Q_3 (\text{Tan C} (Q_3)) \div 2$$

$$= Q_3^2(\text{Tan C}) \div 2 = 2882363.00^2 (.14067 \times 10^{-4}) \div 2 = \text{R } 58\,434\,430.$$

For water extracted by Knysna Municipality in 2000, the unit value was:

$$CS_{Q3} = CS_{Q3} \div Q_3 = 58434430. \div 2882363. = \text{R } 20.27\ \text{kL}^{-1}$$

To simplify, the foregoing equation can be stated as:

Ecological value per unit of riverflow diluted for 31.44% leakage

$$= \frac{Q_1^2(\text{Tan C})(.6856)}{(Q_1)(2)} = (.3428)(Q_1)(\text{Tan C})$$

4.3 Calculations – Fish Production

Switzer (2003) determined the DIN contributed from various sources to the Knysna Estuary was 14247 kg for 12 months of 2000–2001. The contribution by the Knysna River was 1774 kg for the period. Using the C:N mass ratio of 6:1 (Iverson 1990), these contributions were converted to carbon equivalents of 85 482 kg C for the estuary and 10 644 kg C or 12.5% contributed by the Knysna River. Although there is no consensus on the contribution of C to the estuary by the Knysna River the range is between 12.5% found by Switzer (2003) and less than 10% (Allanson, Maree, & Grange 2000). Because Switzer's (2003) study was carried over 12 months the 12.5% estimate was chosen as representative of the contribution of C by the Knysna River to the estuary. Further, because of the relation between C and primary production and fish production as demonstrated by Iverson (1990), Nixon (1986) and Houde & Rutherford (1993) in the equation for fish production (Equation 1, Fish Production – Methods) and Table 2 in Houde & Rutherford (1993) (which has not been reproduced herein) 12.5% is also assumed to represent fish production contributed by the Knysna River to the estuary.

Using data and information from Lamberth & Turpie (2003) and (McGrath *et al*. 1997) the following calculations were used to determine the cost of fish catch within the Knysna Estuary and the cost of inshore marine fish catch contributed to by the estuary.

Knysna Estuary falls within the Eastern Cape estuaries which encapsulates a total of 3764 ha and produces fish catch of 78 kg ha^{-1} (Lamberth & Turpie 2003). The Knysna Estuary is 1633 ha and is estimated to produce 127.372 t of fish catch annually. Using another method Lamberth & Turpie (2003) suggested the total catch for the Knysna Estuary could be 250 t but stated this estimate was believed high. The contribution of Knysna Estuary to inshore marine catch was estimated to be 43% (1633 ha in the Knysna Estuary ÷ 3764 total ha in the Eastern Cape estuaries) of the total of 328 estimated t contributed by Eastern Cape estuaries. This resulted in an estimated contribution by the Knysna Estuary to inshore marine catch of 142.32 t annually. The combined fish catch resulting from the Knysna Estuary was therefore estimated to be 270 t.

The cost of producing inshore marine and estuarine fish catch in South Africa (McGrath *et al*. 1997; Lamberth & Turpie 2003) in 1997 Rand was estimated to be R2 167 billion. This value when extrapolated to 2000 Rand was R2 628 billion. The unit cost per ton of fish catch in 2000 Rands was R86170 t^{-1} (total cost of catching estuarine and inshore marine fish catch of R2 628. billion ÷ South African estuarine and inshore marine fish catch of 30501 t).

Therefore, the total cost to produce the fish catch attributable to the Knysna Estuary is: fish catch of 269.692 t x R 86 170 t^{-1} = R 23 239 359. Allocation of 12.5% of total cost to the Knysna River is R2 904 919 And P_1 in Young's equation = R 0.05928 per kL which is average cost per kL of riverflow (R2904919.96 ÷ 4.9 x 10^7 kL yr^{-1}).

The application of Young's equation to determine the value of the riverflow related to the contribution of the Knysna River to the Knysna Estuary fish catch is as follows:

4.3.1 Young's Equation applied to Fish Production

$$A_i = \frac{P_1 Q_1^X}{1-X}(Q_2^{1-X} - Q_1^{1-X})$$

Where:

E = elasticity of demand = -.38 and E not equal to -1.0

X = 1 ÷ /*E*/ = 2.6316

1 – X = 1 – 2.6316 = - 1.6316

P_1 = R 0.05928 per kL (average cost) = Average cost per kL of riverflow

Q_1 = riverflow 4.9×10^7 kL yr^{-1} for 2000

Q_2 = riverflow kL yr^{-1} for 2000 less 20% = 3.92×10^7 kL

$Q_1 - Q_2 = 9.8 \times 10^6$ kL

$Q_1^X = 49000000^{2.6316} = 1.727905568 \times 10^{20}$

$Q_1^{1-X} = 49000000^{-1.6316} = 2.835803119 \times 10^{-13}$

$Q_2^{1-X} = 39200000^{-1.6316} = 4.081261789 \times 10^{-13}$

A_i (incremental Area) = Total Benefit for increment ($Q_1 - Q_2$)

$$A_1 = \frac{(.05928)(1.727905568 \times 10^{20})}{(-1.6316)}(4.081261789 \times 10^{-13} - 2.835803119 \times 10^{-13})$$

= /781887/.

Cost to the consumer for increment ($Q_1 - Q_2$) = P_1 ($Q_1 - Q_2$) = 0.05928 (9.8×10^6) = R580944.

Consumer surplus(CS_i) for increment ($Q_1 - Q_2$) = $A_i - (P_1)(Q_1 - Q_2)$

CS_i = 781887 - 580944 = R200943

$$CS_i = \frac{(P_2 - P_1)(Q_1 - Q_2)}{2}$$

Therefore $$P_2 = \frac{2(CS_i)}{(Q_1 - Q_2)} + P_1$$

$P_2 = (2)(200943) \div 9.8 \times 10^6 + 0.05928 = 0.1002$

To calculate the tangent of the common angle 'C' it is required to know:

$P_2 - P_1 = 0.10028 - 0.05928 = 0.0410$

Tangent of the common angle C (tan C in Figure 13)

$$\text{Tan 'C'} = (P_2 - P_1) \div (Q_1 - Q_2) = 0.0410 \div 9.8 \times 10^6 = 0.4 \times 10^{-8}$$

$$\text{Tan 'C'} = .4 \times 10^{-8}$$

Consumer surplus for Q_1**:**

$$(CS_{Q1}) = \underline{Q_1^2 \text{ (Tan C)}} \div 2 = (4.9 \times 10^7)^2 (.4 \times 10^{-8}) \div 2 = \text{R4 802 000.}$$

CS_{Q1} per unit value of river flow:

$$(CS_{Q1}) \div Q_1 = \text{R4 802 000.00} \div 4.9 \times 10^7 \text{ kL} = \text{R0.098 kL}^{-1}$$

4.4 Calculations – Forestry

The Knysna DWAF was merged into SANParks in 2004 and subsequently there was a change in administrative procedures and personnel. Accounting and finance were two administrative areas undergoing change and this resulted in difficulties in obtaining information relating to the cost of operating and managing the indigenous forest. Former DWAF personnel remained in charge of the forest operations and management, however, the accounting system was introduced from SANParks. As a result timber operations cost data were not readily available at SANParks and recreational revenues and cost data for forest operations remained with DWAF.

There are two main divisions of the indigenous forest in the Knysna area and both have furnished some information of cost and revenues related to the sale of timber. There was no information supplied for hiking, camping, picnicking or other recreational activities. Although recreational activities are a formal part of the indigenous forest operation and the information was requested by the person in charge of the finance and budget department for SANParks, the management effort to install the material on the SANParks computer accounting system did not occur. One of the forestry divisions was able to get incomplete information on annual revenues from sale of timber and some of the related cost back as far as 2001. In an effort to develop credible cost information, the sales and cost information, from both divisions of SANParks indigenous forest were plotted (Y axis) against the respective m^3 of wood sold (X axis). This method allowed a liner trend line to be developed with an R^2 value of 0.60. The trend line was projected backward to year 2000 but the result appeared inconsistent with the data in hand and a decision was made not to use the estimate provided by the trend line. Further, the actual revenues and cost when compared both directly and via a trend line showed that all but two sales were made at below cost. As a result, an average of the annual sales was applied for year 2000.

Another aspect of the calculations is that when determining the contribution made to the forest production by the ERF the comparison to carbon was by weight. Because a unit of water is significantly heavier than a unit of carbon the contribution of water appeared to be 99.8%. This striking unequal contribution appears to indicate that another method of comparison may be more appropriate.

4.4.1 Young's Equation applied to Forest Production

$$A_i = \frac{P_1 Q_1^{X}}{1-X}(Q_2^{1-X} - Q_1^{1-X})$$

Where:

E = 'elasticity of demand' = -.38 and E not equal to -1.0

$X = 1 \div /E/ = 2.6316$

$1 - X = 1 - 2.6316 = - 1.6316$

P_1 = R 1394347.64 (average sales per annum @ cost) ÷ 10.4568860×10^{7} kL

$= 1.33 \times 10^{-2}$ = sales per annum @ cost per kL of ERF

Q_1 = ERF = 10.4568860×10^{7} kL yr^{-1} for 2000

Q_2 = ERF = Q_1 kL yr^{-1} for 2000 less 20% = 8.3655088×10^{7} kL yr^{-1} $Q_1 - Q_2$ = 20913772 kL

$Q_1^{X} = (10.4568860 \times 10^{7})^{2.6316} = 1.270162498 \times 10^{21}$

$Q_1^{1-X} = (10.4568860 \times 10^{7})^{-1.6316} = 8.23271512 \times 10^{-14}$

$Q_2^{1-X} = (8.3655088 \times 10^{7})^{-1.6316} = 1.184844794 \times 10^{-13}$

A_i (incremental Area) = Total Benefit for increment ($Q_1 - Q_2$)

$$A_1 = \frac{(1.33 \times 10^{-2})(1.270162498 \times 10^{21})}{(-1.6316)}(1.184844794 \times 10^{-13} - 8.23271512 \times 10^{-14})$$

= / 374363 /

Cost to the consumer for increment $(Q_1 - Q_2) = P_1 (Q_1 - Q_2) = 1.33 \times 10^{-2} \times 20913772$ = R 278153.

Consumer surplus (CS_i) for increment $(Q_1 - Q_2) = A_i - (P_1)(Q_1 - Q_2)$

CS_i = 374363.55 - 278153.17 = R 96210

$$CS_i = \frac{(P_2 - P_1)(Q_1 - Q_2)}{2} = R96210$$

Therefore $$P_2 = \frac{2(CS_i)}{(Q_1 - Q_2)} + P_1 = \frac{(2)(96210.38)}{20913772} + 1.33 \times 10^{-2} = R\ 2.25 \times 10^{-2}$$

To calculate the common angle C it is required to know:

$$P_2 - P_1 = 2.25 \times 10^{-2} - 1.33 \times 10^{-2} = 9.17 \times 10^{-3}$$

Tangent of the common angle between BCD and ACP_1 (Tan C in Figure 13)=$(P_2 - P_1) \div (Q_1 - Q_2)$

$$\text{Tan 'C'} = 9.17 \times 10^{-3} \div 20913772 = 4.386751305 \times 10^{-10}$$

Consumer surplus for Q_1 (CS_{Q1}) = $\underline{Q_1^2 \text{ (Tan C)}} \div 2$

$$=((10.4568860 \times 10^7)^2 (4.386751305 \times 10^{-10})) \div 2$$

CS_{Q1} = R 2398378.

Ecological value of contribution to Forestry by ERF = 99.8 % x 2398378.74 = R2 393 581.

CS_{Q1} per unit value of ERF = $(CS_{Q1}) / Q_1$ = R2398378. $\div 10.4568860 \times 10^7$ kL

= R 2.2935879×10^{-2} kL^{-1}.

CHAPTER 5

5 RESULTS OF METHOD AND CALCULATIONS

5.1 Overview of Results

The methods for producing the calculations of the three ecological values are the results of this project. The ecological values imputed to the river flow of the Knysna River are significant. However, the three ecological values produced here are only small but integral elements of the total ecological value of the river flow which contributes to economic activity within the Knysna Basin. Further, in the context of the economic system of the catchment, riverflow is only one contributing element of the catchment's ecological system. These methods, or iterations of them, for calculating values of the ecological system contributing to economic activities, possibly can lay the predicate for coordinated management of the economic, cultural and ecological activity within the catchment or in the alternative, protection of the catchment's ecological system. The stylistic 'mapping' shows simple linkages between the catchment's ecological system and economic system and provides a framework upon which a dynamic systems model can be structured. It is anticipated that the dynamic systems model will actively demonstrate the contributions of specific ecological function and services to the catchments economic activity and reveal the values of such contributions. The calculations herein are functional, contextual examples of the process required to express methods for knowing the specific contribution of the ecological system to an identified economic activity. The final calculation via Young's equation is to quantify (in economic terms) the flow of ecological functions and services into a valued human product (presumably for human wellbeing).

The following sections of this Chapter will briefly point to significant aspects of the methods leading to the calculations of values for the riverflow's contributions to three economic activities within the Knysna River catchment, i.e. Municipal Use, Fish Production and Forestry. The following Chapter 6 will discuss the limitations and weaknesses of the methods and suggest modifications and other considerations which may enhance the credibility of the approach.

5.2 Mapping and Linkages of the Ecological Contributions to Economic Activities

Identifying and mapping the ecological / economic links was one of the basic results of this study. The linkages between Knysna River flow and the catchment's economic system were represented in a stylistic manner by Figure 9. While Figure 9 was not intended to be a complete network of the connections between the Knysna River and related economic activity within the catchment, the network does clearly show the multiple-connectivity of the river and catchment's economy. The links suggest the possibility of revealing the contribution(s) of the Knysna River to any of the connected economic activities. Valuation of the contribution to the economic activity (contribution is represented by the links) requires an understanding of the biotic and abiotic factors in the contributing ecological system.

The value of the contribution represented by a specific link is not assessed in economic terms but as a proportionate part of the ecological contributions to the economic product.

In the three economic activities used in this study the contribution of the Knysna River ranged from relatively simple to complex, that is to say, the extractions by the Knysna Municipality are contributed 100% by the river, whereas the riverflow contribution to fish production in the estuary was 12% when compared to the contribution of carbon by other elements within the estuary (assuming all other contributors to fish production, other than carbon, were constant) and the contribution of the equivalent riverflow (ERF) to indigenous forest production was 99.8% by weight when compared to the contribution of carbon fixed by the forest (assuming the contribution of energy, sunlight, to be constant). As will be mentioned in Chapter 6 (Discussion and Conclusions) the science for assessing ecological contribution to an economic activity is not uncomplicated but research is being conducted which allows the linkages to be ascertained.

5.3 Calculations

To arrive at the final value for the ecological contribution using Young's equation it was necessary to quantify the volume of riverflow contributing to the specific economic activity and to determine the cost of that portion of the economic activity to which the riverflow contributed. As a result of acquiring the two foregoing values it was possible to apply them to the demand curve represented by Figure 13 and Young's equation (Figure 14) which allowed the calculation of consumer surplus at the quantity of riverflow and the related cost of the product. The result is that the consumer surplus related to the cost paid to obtain that proportionate part of the economic product produced by the riverflow is the value of the riverflow which contributed to the economic product. The following subsections will describe the three methods used for calculating the economic value of the ecological contribution of the riverflow for each of the three economic activities, i.e. Municipal Use, Fish Production and Forestry.

5.3.1 Municipal Use

The ecological value of the annual contribution of riverflow to municipal water production was R58.4 m. The allocation of the ecological contribution by riverflow was 100%. The process for computing the foregoing values is described in the following paragraphs.

Municipal use of the riverflow is a straight forward extraction of the water required and sold to the municipality's customers at cost of extraction, treatment and delivery (cost of production). All of the water extracted from the river is utilized by the municipality without contribution by another part of the ecological system. Therefore, the total quantity of water extracted and the related cost of production per unit can be applied to Young's equation (Young 2005c) as described in Figure 14. Young's equation requires four data items (Young 2005c), to wit:

- A price in effect for the period under consideration. In this case the price was average cost of R6.25 kL^{-1} determined from the records of the municipality.
- The total water (Q_1) deliveries for the period. Deliveries for the year 2000 were determined from the records of the municipality.
- A hypothetical change in quantity of water (Q_2) to be delivered. In this study the change was 20% less than the actual quantity delivered for the period.
- The assumed price elasticity of demand. The price elasticity of demand was assumed to be (-.31).

An extension to Young's equation was called for because of 31.44% loss of water within the system. The loss of water required that 31.44% more water (Q_3) be extracted than was sold. The increase in extractions is represented graphically by Figure 18. The values for P_1 and Q_1 and the slope of the Demand Curve are assumed to be the same in Figures 13 and 18. By referring back to Figure 13 it can be seen that it is possible to determine the tangent of the common angle of BCD and ACP_1. Under the assumption stated above, the tangent for Figure 13 is the same as for the intersection of P_1S_2 and the demand curve (D_1D_1') in Figure 18. It was therefore possible to compute the consumer surplus of the price – quantity at P_3 and Q_3. Q_3 is calculated by $Q_1 \div$ 68.56% (percent water delivered).

It is helpful to note that the actual paid value of water at Q_1 and Q_3 is the same.

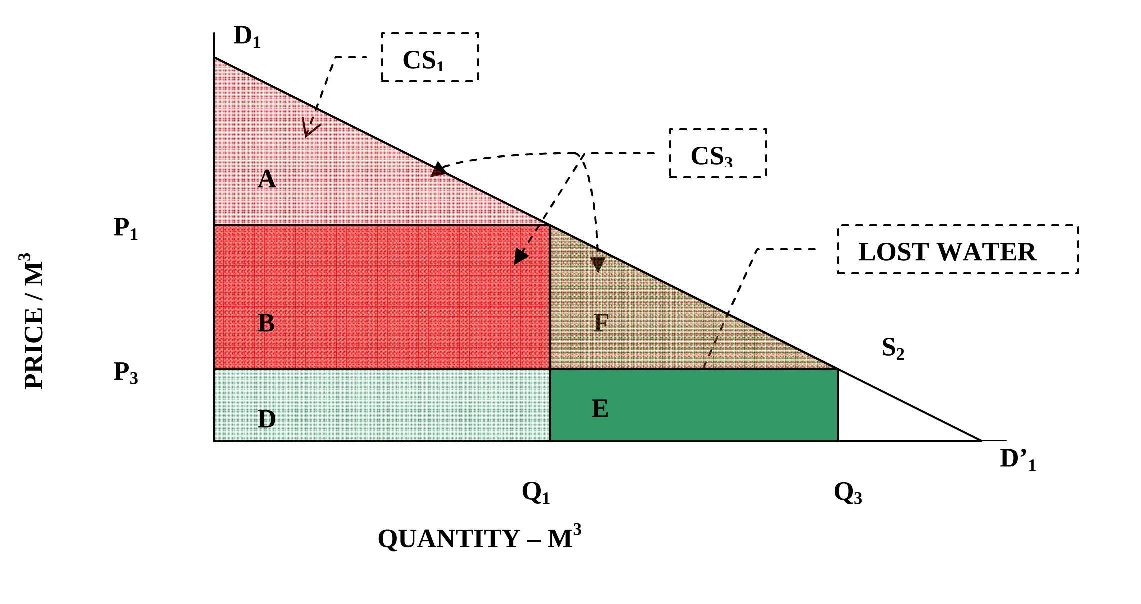


FIGURE 18. Graphic depiction of loss of value due to leakage in the municipal water system. Q3 – Q1 (Area E) represents water lost to leakage in the municipal system. CS1 (Area A) is the consumer surplus relative to Q1. CS3 (Area A + B + F) is the consumer surplus relative to Q3.

The result of the inordinately large consumer surplus (ecological value) at price point P_3Q_3 reflects the leakage of water from the delivery system and the loss of value to the consumer. These results (losses of value) are demonstrated in Figure 18 by areas B, E and F. Area B is the actual additional price paid (P_1) for Q_1 where no additional benefit is received for the same amount of water at price P_1 (represented by Area D). Area F represents the loss of consumer value without benefit to the consumer as a result of having to produce the additional increment

Q_1 Q_3.[26] Area E is the value of the water leaked from the system which has only negative consequences because not only was it removed from the ecological system the river water was of no benefit to the consumer. The slope represented by D_1D_1' can produce a combination of losses represented by areas B, E and F which in total is larger than the consumer surplus represented by area A for price point P_1Q_1. The economic implications of the river water remaining in the ecological system and not leaking from the Municipal delivery system will be commented on in Chapter 6.

5.3.2 Fish Production

The ecological value of the annual contribution of riverflow to fish production was R4. 8 m. The allocation of the ecological contribution of riverflow to carbon content of estuarine fish production was 12.5%. The process of arriving at the foregoing values revealed a lack of local data sufficient to support an equation for computing fish production in the Knysna Estuary. Further the process revealed that there was very little economic data relevant to cost of fish production available in connection with the estuary.

Fish Production is an in-stream use of the Knysna River. The riverflow along with other inputs (both biotic and abiotic) makes a contribution to the production of fish in the estuary which production also contributes to the inshore marine fisheries of the South coast of South Africa. In an effort to find a simple method for determining the Knysna River's input to the estuary's fish production several different researchers' expertise were drawn upon (Iverson 1990; Whitfield 1993; Houde & Rutherford 1993; Adams *et al*. 2002; Peterson 2003; Mbande, Froneman, & Whitfield 2004; Allanson 2005b; Allanson 2005a; Whitfield 2005c). The result of this part of the study was that carbon in the form of primary production appeared to provide the most consistent connection between fish production and the estuary. A review of Switzer's (2003) doctorial thesis provided information that the Knysna River provided 12.5% of the DIN to the estuary. Using the C:N mass ratio of 6:1 (Iverson 1990; Allanson 2005b) it was possible to estimate carbon production in grams per m^2. However, it was not possible to use the equations proposed by Houde & Rutherford (1993)[27] because the production of carbon was insufficient in the estuary as well as the river to overcome the Y axis intercept of -3.08. The failure of the applicability of the Houde & Rutherford (1993) equations required that an estimate of quantities of fish catch be

[26] This loss is sometimes referred to as a 'dead weight' loss.

[27] Refer to equations 1 & 2 in the chapter on Materials and Methods (Chapter 3).

made by using general data from studies of Eastern Cape estuaries and their related inshore marine fisheries (Lamberth & Turpie 2003).Using the general data on fish catch a portion thereof was allocated to the Knysna Estuary based on a ratio of the area of the Knysna Estuary to the total area of the Eastern Cape estuaries (National Parks Board 1994). In this manner the estimated fish catch (for estuarine and inshore marine fisheries) produced by the Knysna Estuary was calculated.

The cost of fish catch for the Knysna Estuary and the related inshore marine fisheries was also determined by using an estimation of cost[28] of South African line fishery (McGrath *et al*. 1997) allocated as a proportion of total cost over the Knysna Estuary. Twelve and one half percent of the estuary's fish cost was apportioned to the Knysna River and divided by the annual riverflow (Q_1) for year 2000 to obtain the resulting unit value per cubic meter of riverflow (P_1) which is the requirement to implement Young's equation and determine the related ecological value (consumer surplus) provided by the riverflow.

The foregoing was not a testable method for valuing the ecological contribution of riverflow to the estuary's fish production. It was, however, the result of experimenting with several procedures and choosing the one that reflected available local data. After reviewing the studies underlying the Houde & Rutherford (1993) equations it would seem that similar equations might be developed for South African estuaries and thereby provide additional insights into valuation methods and modeling of the ecological and economic systems of catchments.

5.3.3 Forestry

In 2000 the ecological value of the annual contribution of riverflow to indigenous forest production was R2. 4 m. The allocation of the ecological contribution by weight was 99.8% to water and 0.2% to carbon with energy assumed to have a constant and equal bearing on both water and carbon. Some of the effects of developing the process for computing the foregoing values are explained in the following paragraphs.

To determine the contribution of riverflow to indigenous forest production it was assumed that the water used by the forest was captured from rainfall prior to entering the river. That part of the annual rainfall which was used by the forest as evapotranspiration is referred to as equivalent

[28] This cost was assumed to be average (as opposed to marginal) full cost pricing (without producers surplus) (Young 2005c).

river flow (ERF). It was also assumed that 100 % of the water captured by the forest would have entered the river at some point. This is not an accurate assumption because, in any event, some of the water would have evaporated and / or participated in evapotranspiration in concert with the existing ground cover, whether or not the ground cover was forest. In order to determine the proportion of the ecological contribution played by ERF and impute an economic value to that portion it was necessary to find a commonality among the ecological inputs. Specific investigation into this aspect of the process was not found after a review of the literature.

After reviewing several studies it was found there are many contributing inputs in forest production, however, within a catchment most inputs remain constant. Soil makeup and mineral content are two examples of constant inputs which are regulated by the forest growth, assuming the soil and minerals are present in sufficient quantities. Water, energy (sunlight) and carbon fixation fluctuate depending on external influences. As previously described in Chapter 3 the allocation was between ERF and carbon fixation because sunlight was an equal and constant influence on both. The commonality between ERF and carbon fixation was weight, e.g. the ratio for allocation was weight of the annual evapotranspiration divided by the total weight of the annual carbon fixation plus annual evapotranspiration.

To produce the comparison between ERF and carbon fixation it was necessary to determine rainfall, runoff and then evapotranspiration for the indigenous portion of the Knysna Forest. Thereafter, a determination was made of the annual rate of carbon fixation for the indigenous forest using equations based on data from the East coast of the United States.
No precedent was located to support the view of limiting the comparison of ecological inputs to evapotranspiration and carbon fixation. And clearly, there are other inputs to forest production. There are also suggestions for commonalities other than weight. Energy was one possibility. However, weight was a more simple approach and within the reach of the data available to make the allocation of ecological contributions.

To determine P_1 for the application of Young's equation the SANParks provided cost and sales information relative to indigenous timber. SANParks was not able to provide cost information related to recreation, non-timber forest products, or other uses of the indigenous forest. Therefore, the full cost average price related to production is deficient. SANParks advised that the sale of timber and cost related thereto was many times greater than other cost or income generated by the indigenous forest (Baard 2006). The financial information furnished by

SANParks showed that average sales were below cost. Therefore P_1 was calculated by dividing sales of indigenous timber x 99.8% (contribution by ERF) by the annual ERF in kL for year 2000. Q_1 was equivalent to ERF by volume (kL) not weight. The ecological value of the ERF was computed by applying the values P_1 and Q_1 to Young's equation.

The consequence of the foregoing process is that the pattern or some iteration thereof has potential to provide an imputed economic value of ecological inputs into the forest production. In this case, the data upon which the calculations were based are weak.

CHAPTER 6

6 DISCUSSION AND CONCLUSIONS

6.1 Overview of Discussion and Conclusions

"It is impossible to create something from nothing; all economic production requires a flow of natural resources generated by a stock of natural capital. … In other words, production requires inputs of ecosystem structure. Ecosystem structure generates ecosystem function which in turn provides services. All economic production thus has an impact on ecosystem services, and because this impact is unavoidable, it is completely internal to the economic process" (Daly & Farley 2004d). In this context there are three conceptual features of this thesis:

a) The catchment is assumed to be a separated ecological and economic system. The word 'separated' does not mean a catchment is isolated. There will be economic and ecological influences (negatives and positives) which originate from outside and move into the catchment. Also, there will be ecological and economic impacts (negatives and positives) which originate within the catchment and leave the catchment.

b) The ecological contributions to a specific economic activity within the catchment will be viewed as a production input to the economic activity. The allocation of the ecological contribution to the cost of production is relative to the ecological system and not the economic system. Therefore, the ecological function or service being valued will be first viewed as a proportion of the total ecological input into the specific economic activity, thereafter, the percentage of the ecological contribution will be applied to the full cost pricing of acquiring the product.

c) The third feature is that the economic value of the ecological contribution will be imputed from the economic activity to which the ecological contribution is made by the means of Young's equation (Young 2005c). The pricing unit (P_1 in Young's equation) is based on full cost pricing of acquiring the product, without producer surplus.

Bringing together the foregoing requires an understanding of the links between the ecological goods and services and the economic activity to which they contribute. Using the concepts also requires an application of the linkages in the context of stock-flow and fund-service resources. The methods for revealing the ecological value of the contribution of the Knysna River to the three economic activities depends on the resource relationship of the river to the economic use. River water which transforms into municipal drinking water is a stock-flow resource. Essentially the river water is converted to drinking water; it can be used up and it can be stockpiled for future use. The river water that contributes to fish production in the estuary is a fund-service resource. This function (river) provides a service and is not used up it is not converted into fish[29]; and it cannot be stockpiled for future use in fish production. The use of rainwater as equivalent river flow (ERF) in forestry (production of indigenous forest) is potentially a contribution of a stock-flow resource and a fund-service resource. In one sense the ERF is a fund-service resource which contributes to the production of trees but is not used up or converted into trees. Conversely, the ERF has the characteristic of a stock-flow resource because a portion of the ERF is stockpiled in the soil for use when the forest requires it and that stockpile can be used up if a drought occurs. In each of the three economic activities considered herein the river water is material converted directly to a product for economic use (municipal drinking water) or is a contributor to an ecologically produced good (fish or indigenous forest). In the sense that the economic product is also an ecological product it is straightforward to determine the ecological value of the inputs. If, however, the economic product was a manmade product the process for determining value of the ecological contributions to such a product, while one or more steps removed, is essentially the same.

An example of a manmade product would be a wooden gadget or device (hereinafter, sometimes, widget) manufactured in the Knysna catchment. To obtain the value of the ecological contributions to production of the widget it would be necessary to remove the value of the producer surplus from the production inputs in order to obtain a price P_1 (a price point value for use in Young’s equation) based on full cost pricing (Daly & Farley 2004e; Young 2005c). After obtaining a full cost price for P_1 the contribution of the individual ecological inputs could be obtained.

[29] Except to the extent fish are composed of water.

Extension of the foregoing example of a manmade product (and many ecological economic products) reveals the potentially complex issue of determining economic value for that portion of the ecological system which must absorb the waste produced with a manufactured product. Briefly, each manmade product produces two waste streams. The first is the waste arising from the production process. The second waste stream is that which arises when the product is no longer useful. The production of a useful product and its related waste stream(s) is sometimes referred to as joint production (Baumgartner *et al*. 2001). Valuing the combined cost of product and waste creates a greater risk of negative value being the result of the production process (Baumgartner *et al*. 2001). Although economic valuation of the contributions by ecological systems to manufactured products (including that of waste absorption) is useful in order to understand the costs of production, it is not within the scope of this paper.

Discussion of certain assumptions which underlie the suggested method developed here is called for as part of the overview. First, the demand curve represented in Figure 13 as the basis for applying Young's equation is stylized and real data will likely not produce a straight line demand curve with a constant slope. The justification for using a demand curve with a constant slope was based on Young's suggestion (Young 2005c) and on the creation of an area of use of riverflow between the thresholds of flooding and the ecological reserve as shown in Figure 5. It appears that Figure 13 is an appropriate example for Municipal Use. However, the image of Figure 5 may not apply to fish production (for two reasons) or forestry. Fish production is benefited by nutrient contribution from the Knysna River most of which is brought to the estuary during times of flood (Whitfield 2005b; Allanson 2005a). Although the contribution of nutrients is based on average flow for a 12 month period (Switzer 2003) and fish catch and value are based on a similar 12 month period it appears that a demand curve with a constant slope with value P_1 over quantity Q_1 would not result in placing the ecological value in an accurate setting. Further, the straight line demand curve will not be a sufficient representation of fish production if the riverflow is reduced below the ecological reserve. The slope of the demand curve in Figure 13 will also not fit well for the calculation of value of ERF in indigenous forest production. ERF is entirely related to rainfall which is not spread evenly throughout the year (Switzer 2003; Joubert 2005b). It appears that a curvilinear function for the demand curve would produce a more accurate calculation of the value for forestry and fish production. In this thesis there was not sufficient data or time to develop a more accurate demand curve.

Second, price elasticity of demand was estimated to be -.31 for municipal use and -.38 for both fish production and forestry. Each choice reflects an inelastic demand. There were several suggestions that contributed to the selection of the specific values. Studies by Espey *et al*. (1997) Nieuwoudt *et al*. (2004) and King (2002) contributed to the selection of the elasticity values. Additionally, over a period of seven years, observations of the mix of people using the three economic products considered in this thesis provided some basis for concluding that the persons using the goods and services would not increase or decrease the quantity of use by a reasonable change in price.

Several specific circumstances were considered when estimating elasticity but only three will be mentioned. First, Knysna has a base population of approximately 50 000–60 000. The town has a tourist based economy and the population swells to double the base population in the tourist season. The tourists and working and retired Knysna residents have considerable discretionary income which protects them from price increases which may be related to municipal water service, fish production and forestry. The poor will not be deprived by pricing of municipal water services because there is provision for free water in excess of basic needs and because pricing is structured so that the higher levels of consumption are most expensive. Second, fish production is the one area where the poor possibly could be impacted by price increase on equipment. Subsistence fishing and fishing by the poor for commercial purposes will not be impacted by cost increase relevant to sports fishing within the estuary or inshore commercial and sports fishing. The poor arrange for their own bait (Hodgson, Allanson, & Cretchley 2000; Turpie & Joubert 2003) and by and large obtain used equipment. In the event the poor were required to purchase bait or if because of an increase in bait prices the opportunity cost of using the bait for fishing was more than selling the bait the fishing poor would be impacted. The last two scenarios do not appear likely. And third, elasticity will be inelastic in fish production and indigenous forest production because the market for fish from the estuary and indigenous forest is with individual with large amounts of discretionary money such as tourists, upper income residents, commercial fisheries and customers of rare wood furniture manufacturers respectively. It would, therefore, appear that the three economic activities under consideration in this paper will not be responsive to reasonable price increases.

This is not to suggest that if the cost of obtaining any of the products was increased dramatically, such as may occur in the event of a severe prolonged drought, the municipal charges for water could be increased for discretionary uses[30] and demand may become elastic.

Third, in Figure 13 the increment under the demand curve between Q_1 and Q_2 is 20% of Q_1. Under most conditions where a curvilinear demand curve is represented a 20% decrease in quantity as an increment would not provide a constant slope unlike the straight line demand curve in Figure 13. Also, when a straight line demand curve is represented elasticity will vary from zero on the quantity axis to infinity on the price axis. Further, with a curvilinear demand curve, except for the special case of a constant elasticity demand function, the elasticity will vary along the demand curve (Lipsey, Courant, & Ragan 1999b; Young 2005c). The purpose of using a 20% increment was to demonstrate the process and ease in calculating the tangent of the angle between the demand curve and the price point line. Also, the large increment would create a larger difference in P_1 and P_2 for comparison purposes. In a true application, the increment $Q_1 – Q_2$ would necessarily have to be small enough to provide a reasonably accurate estimate of slope provided by the tangent to the demand curve at the price-quantity point in question.

Fourth, whether Young's equation (Young 2005c) is the appropriate method for imputing economic value to the ecological contributors is as yet to be tested. The literature reviewed thus far has revealed no confirmation of the use of the equation for the purposes addressed here. Young (2005a) specifically used the method to integrate an increment under the demand curve to find value of water flowing in-stream so that that there could be a comparison of values between municipal and agriculture uses. Young's purpose was to obtain an average price of the consumer surplus per quantity of flow. The price P_1 was the full cost pricing of water delivered by the municipality without producer surplus. The result, as he interpreted it, was the value of the in-stream flow. The value of the in-stream flow is the ecological value identified as consumer surplus in Howarth and Farber (2002). The method appears adaptable to other goods and services of the ecological system which can be identified as contributors (or inputs) to economic production. A further review of the literature suggests that a proper test for the applicability of Young's equation would be a dynamic systems model which would allow for accumulation of a

[30] Knysna currently uses a block pricing structure which is intended to reduce discretionary consumption. Block pricing does not appear to have been successful and the municipality imposed use restrictions in 2004 which were only relaxed in 2007.

number of ecological contributions to a single economic activity occurring within a catchment (Ruth & Hannon 1997; Costanza & Voinov 2004). The simple stylistic approach adopted here suggests that limitations on the model which present themselves may be overcome by a flexible, but more complicated production function (Daly & Farley 2004e).

6.2 Comparison of Methods

It may be helpful to provide a brief comparison between the applications and outcomes of the valuation method suggested in the thesis and the conventional valuation methods referred to in Chapter 2. For the purpose of viewing a conventional valuation technique an example is where there is change in environmental quality of a Habitat. Figure 3 shows that conventional valuation techniques provide at least four methods for valuing change in environmental quality of Habitat. None of the four conventional valuation techniques methods look at the value of the Habitat ecosystem; instead they value the goods or services or the change in goods or services provided to humans by the Habitat. The value to humans of the goods or services delivered can be viewed as the connecting link between the environment and humans. This view is an 'anthropological view' of the use of the ecology and is of course not the only correct view because humans are not separate from the environment and, as mentioned before, some economists view the economic system as embedded in the ecosystem. In taking an anthropological approach the conventional valuation techniques looks at Opportunity Cost, Replacement Cost, Hedonic Prices and Contingent Valuation methods. The primary focus of each one of these valuation techniques is what the consumer is willing to pay (WTP) for the change in goods or services. In the thesis method, cost of accessing[31] the ecological contribution is considered and not WTP. This is one of the differences between the methods of application. The thesis method is also focused on the functioning of the ecosystem and the value thereof relative to the cost of accessing the ecosystem's contribution. By focusing on the ecosystem attributable to the specific economic product and the cost of access thereof the thesis method suggests that the contribution of the Habitat ecosystem can be valued. For the purposes of this comparison assume the Habitat's ecological function is similar to the water in the Knysna River in that the Habitat may make more than one contribution to economic goods or services. As an

[31] Access cost is the economic cost required to connect the ecosystem and the economic system. The economic value of the relevant ecosystem is imputed from this cost via 'Young's Equation.

example, one contribution by Habitat may be to tourism occurring within the catchment[32]. The cost of accessing the ecosystem contribution, i.e. the cost of making the Habitat available, can be defined on a per unit basis. In the case of tourists' utilization of the Habitat the per unit basis would conceivably be a per day use and therefore a per day unit value. In an extension of this example, it can be seen that whatever contribution the Habitat may make to another economic activity within the catchment may be valued in the same manner. The total economic value of the Habitat contribution within a particular catchment will be the sum of the values (imputed from access cost) of all contributions by the Habitat to specific economic goods or services.

The premise for this thesis is that rather than the conventional valuation techniques discussed in Chapter 2 a simpler, more easily implemented method for estimating ecosystem service values is needed. The method suggested herein faces challenges in obtaining data to apply and test the method. These challenges require a response to the question: Whether the thesis method is more useful or applicable than conventional valuation techniques? If in fact the suggested method cannot realistically be made operational with confidence then multiple methods for valuation may be necessary to obtain credible values and even these values may change as social preferences shift.

The examples used in the thesis were all ecosystems produced economic products, i.e. water extracted from the Knysna River, fish from the Knysna Estuary and indigenous forest in the Knysna Catchment. The economic products could just as well have been manufactured goods or services but the methods for describing the ecological contribution and the cost of accessing the ecosystem would have been more complex than necessary to demonstrate the underlying idea. The emphasis in this comparison is on collection and application of data.

There are two types of data to be collected using the thesis method. One data type is scientific information which describes the contribution of the ecosystem to a specific economic good or service. The second data type is the cost of accessing the ecological contribution to the economic good or service[33]. Both data types are available to be assembled. However, in many

[32] This is not to suggest that the Habitat will not have an economic as well as an ecological contribution in other catchments.

[33] As mentioned above, access cost is the economic cost required to connect the ecosystem and the economic system.

instances, the data (specifically the scientific data) does not currently exist in a format required by the thesis method. As a functional aspect this creates a shortage in readily available data but not in the sense that data is not obtainable.

The data collected in applying conventional valuation techniques does not have the same scientific focus as the data of the thesis method. Also, as with the thesis method, the conventional valuation techniques have their own data shortage problems; each method for different reasons. The conventional valuation methods, as previously mentioned in Chapter 2, also have deficiencies other than data collection. An example using the Hedonic method will be sufficient to demonstrate one type of data shortage and two deficiencies of the Hedonic technique[34]. A common problem when using the Hedonic method is data shortage in connection with expressing buyer preference. The primary data collected for Hedonic valuation is property sales[35] and in any urban area the sales information is a matter of record. However, if willingness to pay is to be correctly identified there must be sufficient data to assess the incomes and preferences of buyers (Leiman & van Zyl 2004). In many instances data on buyers' incomes and preferences is not readily available because the estate agents conducting sales in a specific urban area are not inclined to obtain or maintain such information in a usable format. Nonetheless, if some of the buyers' preferences and incomes information can be obtained from interviews with estate agents, the sample size must be limited to small areas in order to acquire buyer data with similar preferences and incomes. The small area sample reveals two analytical concerns arising from the use of the Hedonic method. One is that the results are in most instances not transferable from one development to another in the same urban area. The second concern is that if part of the focus of the study is to determine the value of an environmental amenity e.g. a habitat or open space, within a development the result does not address the value of the amenity but the marginal price of a unit of distance away from the amenity. The marginal price of a unit of distance will allow one to understand the impact, if any, of an amenity on housing value, i.e. an indicator of impact of distance on market prices, but not the value of the amenity.

This limited comparison of the thesis method with conventional valuation methods indicates that the primary restriction on the thesis method is a requirement to refocus the applicable scientific data into a usable format. It is also clear that the conventional valuation techniques have deficits

[34] The Hedonic Pricing Method is referred to in Figure 3.

[35] Hedonic Valuation is not always used for housing valuation but it is the predominate use.

in obtaining reliable data. Furthermore, when Hedonic data relating to buyer preferences is available through interviews with broker agents the results are not usually transferable and the results do not describe the value of the ecological contribution (the pricing would describe the value of the distance of the house from the open space) There is no indication that appropriate data bases for the thesis method do not exist and / or cannot be refocused in a credible manner to reflect the relevant contribution of the ecosystem to a specific economic product. Such data, when obtained, can be transferred within the catchment and the results will reflect the value of the ecological contribution. The suggested conclusion is that reformatting applicable scientific data to fit the thesis method would over the long term provide a less complex, less time consuming, less expensive, transferable and more credible valuation technique than the conventional valuation methods.

6.3 Imputing Value to Riverflow

The following sections address the methods and implications of imputing value to one function of the ecological system (riverflow) which supports ecological products having an immediate commercial application. The scope of this thesis does not include imputing value to riverflow from ecological contributions which have no immediate market value. This limitation on scope is not to suggest that it is impossible to impute value from the economy to ecological contributions which have no market value. To the contrary, valuation of ecological non-market contributions appears quite possible using the methods developed here or some iteration of them. The underlying principles for valuation of non-market ecological contributions arise from the following notions: "All economic production … has an impact on ecosystem services…." (Baumgartner *et al*. 2001) and because the economic system is embedded in the ecological system they are interdependent (Ropke 2005a) . Addressing non-market valuation requires as a primary facility the capability to accurately link an explicit economic activity with an impact on or contribution by specific ecological functions (Perrings 1999; Barabasi 2003; Cowling 2005b).

6.4 Municipal Use

The calculation of the ecological value of riverflow used for municipal purposes was R58.4 m. This value was based on 1 976 148 kL of water delivered to consumers who paid R12.4 m. The R58.4 m value, without explanation, would appear to be excessive. However, in addition to the delivered water there was leakage from the system of 905 215 kL equal to 31.44 % of the total extracted. The wasted water had an economic and ecological cost. This cost can be seen in graphic form as Figure 18. The economic cost of the additional water extracted because of leakage was recovered by the municipality from the consumers who received no benefit for the extra payment. The value of the leakage for which payment was made is represented by area B of Figure 18. Area B also represents an ecological value of the water associated with area D for which the consumers paid and therefore is a partial verification of the ecological value of the riverflow represented by Q_3. Further, the consumers lost, without compensation, the ecological value of the water represented by the leakage, i.e. area F in Figure 18. In some circumstances area F would be referred to as the dead weight loss. The loss of water to both the ecological system and consumers as leakage was not recovered and is represented by $Q_3 – Q_1$. The value of the lost water at price P_3 is represented by area E in Figure 18. The amount calculated for ecological value of riverflow at Q_3 appears to be confirmed for the reason that the losses represented by areas B, F, and E are larger than the ecological value represented by areas B, F and A. In this case the area A is to area E as quantity Q_1 is to quantity Q_3 thereby representing a greater value for A than E. This relationship may not exist for other slopes or losses of water in the system.

Figure 18 can be viewed from another perspective. If the water represented by $Q_3 – Q_1$ had remained in the river instead of leaking from the delivery system and the consumers had paid for the water represented by Q_1 at the price P_1 (R6.25 kL^{-1}), areas B, F and E could be seen to represent values intentionally given up by consumers in order for the ecological system to retain the flow represented by $Q_3 – Q_1$. This would further indicate confirmation of the ecological value and be solid evidence of the consumer’s willingness to pay.

The data used for calculating the ecological values related to municipal use of riverflow were obtained from several sources, including DWAF, SAWS, SANParks and the Engineering Department of Knysna Municipality and certain of their consultants. In each case in which data were obtained and used there was no representation on the part of the agency or their consultants that the data were sufficient for the purposes of this thesis. The data were checked for systemic errors, that is, whether the data recorded by the municipality were within the general pattern of similar data. Specifically, as an example, the data were visually reviewed for water consumption in January over a period of ten years and plotted using an Excel database to verify that January consumption for year 2000 (the year of focus for the economic activity) fell within the normal pattern of the linear trend line for ten years of January consumption.

6.5 Fish Production

Using Young's equation the calculated ecological value of the Knysna River's contribution to Fish Production in the Knysna Estuary was R4.8 m while the total cost of Fish Production allocated to the Knysna River was estimated to be R2.9 m The total for catch in the Knysna Estuary was estimated to be 269.69 t and the allocation to the Knysna River was 12.5% or 33.7 t. It may be helpful to discuss some of the underlying considerations and assumptions used in calculating the value of the river's contribution to fish production.

As mentioned earlier the cost of production (P_1) as applied in Young's equation is full cost pricing, that is, without producer surplus being an element of the cost. The cost used in the fish production calculations was obtained from McGrath *et al*. (1997) and extrapolated to the year 2000. McGrath *et al*. (1997) (hereafter, sometimes McGrath) studied the cost related to commercial and recreational fishing via skiboat and recreational fishing for shore anglers. McGrath determined cost by surveying fisherman to obtain values for cost per day, travel cost and days fished. There was no specific mention of either including or excluding producer surplus from the cost values. On making a superficial comparison of the cost values used by Young (Young 2005c) and those used by McGrath, it appears that the end user had no producer surplus in the cost of acquiring the end product in either Young or McGrath, i.e. water in the case of the Young, and fish in the case of McGrath. Clearly there would be up stream cost containing producer surplus, e.g. the purchase of fishing tackle in the survey by McGrath and the purchase of extraction and delivery equipment in the municipal water study by Young. The conclusion drawn was that the cost figures were compatible in the sense they were full cost when applied by the end user.

Allocation of 12.5% of total fish production to the river was the same ratio as nutrient input into the estuary by the river is to total nutrient input to the estuary by all sources (Switzer 2003). The relationship of nutrient contribution to fish production is based on the assumption that nutrients contribute to primary production which contributes to carbon, which in turn can be converted to estimated fish production and estimated sustainable fish catch. For this thesis these conversions were suggested by three papers (Nixon 1988; Iverson 1990; Houde & Rutherford 1993). Combined studies by the aforementioned persons resulted in suggested equations for estimating fish production and estimating sustainable fish catch. The basis for these equations was primary production stated in grams of carbon. The equation for fish production (presented earlier in the Methods section of this thesis) is:

$$\text{Fish Production} = (0.083P_0 - 3.08) \times E_2^n \times C_2$$

This equation was developed from data obtained from a wide range of sources. The data for new primary production (annual) fit the regressed mean well with $r^2 = .92$ (Iverson 1990). For the equation to produce a positive number the Primary Production (P_0) must be greater than 37.1 $gCm^{-2}yr^{-1}$ because of the intercept of the regressed data (-3.08). Primary production in the Knysna Estuary was 5.24 $gCm^{-2}yr^{-1}$ assuming the estuary's area to be 1633 ha at mean sea level (National Parks Board 1994). The effect of such low primary productivity in the Knysna Estuary renders the Iverson (1990) equation inapplicable.

Because of the apparently low primary productivity indicated by 5.24 $gCm^{-2}yr^{-1}$ it would seem the fish catch would be low. And by using the sustainable fish catch equation developed by Iverson (1990) a proposed catch of 1.5 kg ha^{-1} was calculated. This was compared to Lamberth and Turpie's (2003) estuarine catch of 78kg ha^{-1}. A difference of about 76 kg ha^{-1} suggests that the Iverson (1990) equations for fish production and sustainable fish catch are inappropriate in their present configuration for South African fisheries or that Knysna Estuary may be dramatically over fished. That there is insufficient data to predict fish production and sustainable fish catch in South African estuarine and inshore fisheries is supported by well respected authorities (Whitfield 2005a; Allanson 2005b). From this study and the material reviewed it would appear that an increased focus on data supporting analysis of fish production and sustainable fish catch would be well received.

The calculations for Fish Production have not been tested and because of the use of low confidence secondary data and because of the failure of Iverson's (1990) equations to confirm either fish production or sustainable fish catch, the calculations would not appear to be robust enough to be reliable. However, the methods appear valid for allocating contribution to the Knysna River and calculating value of catch and quantity of fish production and sustainable fish catch if used with equations adjusted for local primary production.

6.6 Forestry

Applying Young's equation to the ERF contribution to indigenous forest production was calculated to be R2.4 m. As earlier mentioned ERF is the rainfall within the Knysna River catchment falling over the indigenous forest which is converted into evapotranspiration - an ecological function. ERF along with other ecological functions contributes to indigenous forest production which is a stock-flow resource. ERF, or a part of it, would run into the river if it were not extracted by the forest before it reached the river. Although ERF is similar to the extraction process exercises by the Knysna Municipality there are several differences. One difference is that the ERF as evapotranspiration helps to create its own rainfall and thereby replenish the river and ERF. This benefit of ERF has both ecological and economic value but was not considered in this thesis.

This cyclical aspect of the ecological structure and functions which produce evapotranspiration allows the question to be raised as to how to quantify the allocation of ecological contributions to indigenous forest production (Daly & Farley 2004d). Daly and Farley (2004a) suggest that the allocation is not possible, but others suggest that if some elements (such as mineral content in the soil) can be assumed to be equally available it may be possible to see forest production as comprised of three functions – carbon production, water (evapotranspiration) and energy (sunlight). The calculation of carbon was based on an equation used by Rosenzweig (1968) to determine the dry weight of above ground annual productivity and certain data obtained from the East coast of the United States (Mass.) which had latitude in the Northern Hemisphere approximately the same as Knysna in the Southern Hemisphere. At this point there are two aspects of the process which require attention. The first is that the USA data used had not been tested for appropriateness in the Knysna catchment. The second and more important aspect is that only above ground production was used in calculating carbon fixation. Annual underground production was not considered. The root system may have had a great influence on the total quantity of carbon produced annually and consequently the weight when compared to evapotranspiration. If after testing, this method proves acceptable it will be necessary to consider annual underground forest growth for a more accurate allocation of contribution between water and carbon.

The following comments on the data used in determining rainfall, evapotranspiration and pricing may give perspective on data availability. Rainfall estimation is difficult in the mountainous part of the Knysna catchment. As mentioned earlier there are very few collection stations in the mountains. The stations which do exist are in areas difficult to access and read regularly. Also, because of the steep and rugged terrain which rises rapidly from the sea and because of the prevailing winds which are from the sea, the rainfall is inconsistent between minor catchments.

The inconsistent rainfall patterns and lack of data collecting facilities required the use of data which was more than ten years old and based on regression equations and extrapolations which had not been updated since the original calculations, (Grogens & Hughes 1982; Hughes 1982). The primary difficulty with the 80 year old rainfall data used was that within the Knysna Basin weather patterns appear to have produced less rainfall (Table 2) and development patterns appear to have reduced forest and ground cover within the last 10 years (Joubert 2005a).

In the context of rainfall, estimation was made of rainfall minus runoff to determine water use or evapotranspiration. In this case both the estimation of rainfall and the estimation of runoff were secondary data. The reliability of the runoff data was discussed in the section on Methods. It would appear that estimation of runoff may improve now that DWAF has installed a flow meter where the river enters the estuary and, under the NWA (Republic of South Africa 1998b), the municipality and local farmers are required to maintain records of their extractions. Also, it seems increased management capacity of the indigenous forest in the Knysna catchment through the combined efforts of DWAF and SANParks will result in enhanced rainfall data collection.

The final element to be discussed regarding valuation of ERF contribution to Indigenous Forest Production in the Knysna catchment is full cost pricing required for application of Young's equation. The difficulties in obtaining cost data for management and maintenance of the forest has been addressed in the section on Methods. It appears that the cost data for recreation and timber sales in connection with the forest, which will be prepared in the future, will be full cost pricing in the same sense that Young used the term when calculating the value of riverflow used by municipalities (Young 2005c).

In the context of full cost pricing it can be noticed that by adding the cost of recreation to the timber sales a higher price (P_1) will be used in applying Young's equation. If it can be assumed that the demand function, elasticity and ERF remain the same the ecological value attributable to ERF will be reduced. The long term implication of this reduction in ecological value of ERF is that proper management of the forest will require that increased revenues at cost not be allowed to decimate the ecological and economic value of the forest.

CHAPTER 7

7 SUMMARY AND SYNTHESIS

7.1 Literature Review

The literature review was focused on developing a premise for presenting a more efficient and credible method for evaluating non-market contributions to economic activity at a microeconomic level. The literature reviewed suggested two views in justification of such a method. The first was that many times certain of the valuation methods were not used because they lacked credibility or they were overly difficult, awkward or too costly to apply and therefore were not applied or were ineptly applied. The second view, supported by a great number of reputable scientists and economists (Turner 2001), was that passive use or non-use functions and services of the ecological system have intrinsic value but not necessarily monetary value (Daly & Farley 2004b). The point here was not to attempt to reconcile or answer directly either of the two perspectives. Rather, it was important to acknowledge that non-market ecological contributions to the economy are not efficiently or effectively valued, although it is clear that such ecological contributions do have economic value. Until we are able to assess, in monetary terms, the entire inputs of the ecological system into the economy with reasonable credibility and expense we have not addressed one of the basic requirements of any system of economics we may choose to apply. It seems apparent from the literature that the methods of valuation discussed are not sufficient in that in most instances the valuation techniques are both inefficient to implement and do not provide information of sufficient credibility. The literature review laid the predicate for further investigation and the method for valuation suggested in the thesis.

7.2 Materials and Methods

As mentioned above the concentration of the thesis is to investigate a method for valuation of non-market ecological contributions to specific economic products. As a result of such emphasis, in order to correctly place descriptions of the relative methods these appear in two sections. The first is on Material and Methods and the second is the on Calculations, which set out the back ground and logic for arriving at the use of the calculations. In the section on Calculations the description of methods is related to application of the series of calculations and the nuances associated therewith.

To simplify the valuation methods investigation, three economic activities dependent on the flow of the Knysna River were selected and three separate models for valuation were developed. The first model addressed the water supply for the Knysna Municipality. The second addressed fish production within the Knysna Estuary and the third addressed indigenous forest production within the Knysna Basin. To properly join the ecological and economic systems to produce the valuation models it was necessary to make three assumptions:

1) The catchment is assumed to be a separate ecological and economic system;
2) The ecological contributions to a specific economic activity within a catchment will be viewed as a production input to the economic activity; and
3) The economic value of the ecological contribution will be imputed from the economic activity to which the ecological contribution is made by the means of Young's equation (Young 2005b).

The foregoing assumptions required an understanding of the links between the ecological functions and the economic activity to which they contribute. In the sense that the economic product is also an ecological product it is straightforward to determine the ecological value of the inputs. Determination of the economic value of ecological contribution to a manmade product can be more complex. The simple stylistic approach adopted in this thesis suggested that limitations on the model which present themselves may be overcome by a flexible but more complicated production function (Daly & Farley 2004e). Addressing non-market valuations requires as a primary facility the capability to accurately link an explicit economic activity with an impact on, or a contribution by, specific ecological goods or services to an economic activity (Perrings 1999; Barabasi 2003; Cowling 2005b).

There are three critical aspects of each of the three valuation models. The first is that the ecological contributions are from within the catchment. This is not to say that either the economic activity or the ecological activity within the catchment is not influenced by out of catchment activities because they are in almost every case. It was necessary to adjust for the out of catchment influence. The second is that the pricing unit (P_1 in Young's equation) is based on average full cost pricing (without producer surplus). The third aspect is that the allocation of the ecological contribution to the cost of production is relative to the ecological system and not the economic system.

Each of these economic uses requires a different method of analysis to determine the relative contribution of river flow to the ecological system which produces the end product, i.e., direct municipal use, fish or forest. In looking at the ecological system to determine the contributing components it became clear that there was a great deal of science related to municipal water supply, to fish production and to forest production. There was, however, very little investigation into the relative contribution of each of the elements of the ecological production system for each economic product. It was clear that each of the products was demanded; therefore, a demand curve should reflect a cost of access at the margin and consumer surplus would reflect the additional value to the consumer in terms of total ecological contribution. This is the essence of Young's equation.

If the slope of the demand curve can be known and the science of the ecological system is sufficiently understood to know the contribution of the ecological inputs, it would appear this method can be used to obtain the economic value of the ecological input related to any economic activity. There will be modifications to the calculations because of the need to assess the contribution of ecological input into the economic product and because of inefficiencies within the economic system. However, once the specific contribution of the ecological service or function is determined, Young's equation can be applied using the appropriate assumptions.

Two additional points should be made regarding methods. The first is that in applying Young's equation -0.31 and -0.38 were used as the price elasticity of demand. The adoption of these highly inelastic values for demand was based on Espey (1997) as well as personal observations that the trend in Knysna was toward wealthy tourists and residents and that higher prices appeared to have no noticeable effect on the increasing number of tourist or residents. Increasing prices have had a dramatic effect in many areas of the lives of lower income persons in the

Knysna Basin. However, in the specific economic activities reviewed here, it appears that lower income persons are shielded from higher prices in each of the three activities used in this project. As an example, Knysna Municipality delivers free water to all residents at the lowest volume of use and prices higher volumes of domestic water in block rates sufficient to recover cost only. In regard to the other two economic activities, lower income persons generally catch their own fish (at a lesser cost); they do not participate in the fee paying recreational activities associated with the indigenous forest nor do they purchase timber grown in the indigenous forest.

The second point is that the application of Young's equation (2005a) requires that cost be used as the Y axis component of the estimated demand curve and the X axis is the quantity of the product. In each of the three economic activities observed, cost was estimated and averaged. As an example, in the application of the equation to the municipality's extraction of water it was assumed that all water was supplied at the same average cost.

7.3 Calculations

The calculations produced three separate values contributed by the Knysna River to the economy of Knysna. In list form they are:

- Municipality Use…...…………R58.4 m
- Fish Production.………………..R4.8 m
- Forestry…………..…………….R2.4 m
- Total……………..……………R65.6 m

The foregoing values were based on secondary data which in all instances were incomplete data sets. Also, from another perspective, in Fish Production the data on primary production were out of line with the actual fish catch for the estuary. The failure of the primary production data to reflect a closer relation to the actual fish catch data may be a simple reflection that the current fish catch is not sustainable or it may indicate the data collection for nutrients in the estuary is more complex than appears or it may reflect that the fish catch data are inaccurate. The large value associated with Municipal Use appears to be an indication of an inefficient system. Regarding indigenous forest production, data were difficult to obtain because of the accounting gaps between DWAF and SANParks. Accurate rainfall data were difficult to obtain because of the lack of measuring stations in the mountains. Of the two sets of data obtained, a sensitivity analysis was not conducted in an effort to compare influence of either set.

7.4 Results, Discussion and Conclusions

Each one of the economic activities required a different approach in order to determine the contribution of the ecological input into the economic product. The following are summarizing comments about specific issues relating to the valuation technique through which economic value was imputed to riverflow.

7.4.1 Municipal Use

The calculation of the ecological value of riverflow used for Municipal purposes was R58.4 m. This value appears to be inordinately large. Viewed from a different perspective, if the water represented by $Q_3 – Q_1$ had remained in the river instead of leaking from the delivery system and the consumers had paid for the water represented by Q_1 at the price P_1, the areas B, F and E (Figure 18) could be seen to represent values intentionally given up by consumers in order for the ecological system to retain the leaked flow.

7.4.2 Fish Production

For the year 2000 the economic value of the Knysna River's contribution to fish production in the Knysna Estuary was R4.8 m while the paid cost of fish production allocated to the Knysna River was estimated to be R2.9 m. There appear to be several reasons for the lower than expected value of the ecological contribution. The most compelling suggestion is that there are insufficient data to obtain an accurate estimate of primary production in the estuary. This lower than expected value indicates that an increased focus on data supporting analysis of fish production and sustainable fish catch would be well received. Notwithstanding the lack of viable data the method for valuing the ecological contribution to fish production set out in this thesis appears valid. The equations of Houde and Rutherford (1993) also appear valid for estimating fish production and sustainable fish catch if used with data adjusted for local primary production.

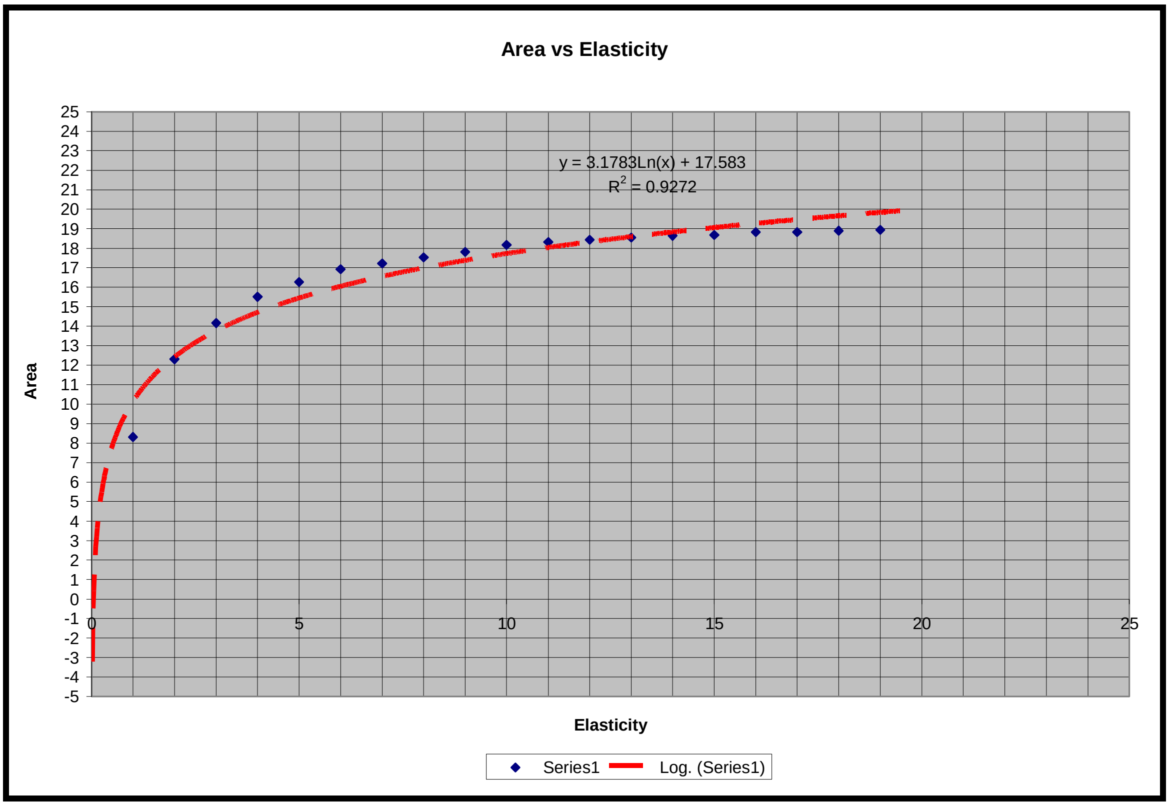
7.4.3 Forestry

The ERF contribution to indigenous forest production was estimated to be R2.5 m. Determination of ERF's ecological contribution to forest production was the most complex part of the valuation processes reviewed in this thesis. The deficiencies in rainfall, runoff and cost data produced a less than credible and lower than expected value for the ERF contribution. Another question raised but not addressed was whether a proper balance between evapotranspiration and carbon fixation was reached. If the allocations between ecological contributions to forest production were not satisfactory the imputation of value via Young's equation would also be inadequate. Notwithstanding the foregoing deficiencies and questions the overall method used for valuation of ERF's contribution to forest production appears to justify further investigation.

The calculations in each valuation model can be criticized for various deficiencies. However, the method suggested does lay a predicate for valuing the non market ecological contributions to the catchment's economy.

This method for valuing the ecological contribution to an economic product has not been tested and an extensive literature review has not disclosed an application of the suggested method for valuation. Ideas and concepts have been taken from other studies and brought together to develop the valuation technique suggested in this thesis. The authors of the studies or parts thereof that have been used herein are not responsible for any misapplication of their data or theories. Finally, as a minimum, this thesis suggests a method for valuing ecological input into economic activity which input has value sometimes not identified by the market but accessible nonetheless.

8 APPENDIX A



Impact on Area by a change in Elasticity

elasticity	Area
0.1	8.309
0.2	12.312
0.3	14.159
0.4	15.502
0.5	16.265
0.6	16.917
0.7	17.22
0.8	17.529
0.9	17.81
1.1	18.171
1.2	18.315
1.3	18.428
1.4	18.543
1.5	18.639
1.6	18.678
1.7	18.823
1.8	18.819
1.9	18.899
2	18.933

9 REFERENCES

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