

CHAPTER 1 - INTRODUCTION

1.0 General

Lake Kariba is a multi-use resource with hydro-electric power generation as the principal function. Out of about 1678MW of hydropower generated in Zambia, Kariba North Bank Power Station accounts for 36%. Kariba South Bank Power Station is the only hydropower plant in Zimbabwe worth mentioning and accounts for 37.5% of the total power (Thermal and Hydropower) generated in Zimbabwe (2000MW). Other than hydro-electric power generation, the economy of Lake Kariba area is principally an agricultural one with a number of cash crops such as maize, wheat, cotton and tobacco.

The Lake also supports a thriving large-scale commercial fishing industry. The fishing industry includes inshore (artisanal), pelagic (kapenta), spot and sport fishing. Further, fish breeding is also carried out on Lake Kariba. Tumbare (1997) reported that the annual turn over of the kapenta fish industry on the Lake was in the order of US\$25 million. Besides, Lake Kariba sustains a wide range of water-based recreational activities and provides domestic water to Siavonga and Kariba towns. Significant industries on the catchment of the Lake include tourism, mining and safari hunting.

Up until recently, Lake Kariba has been considered to be oligotrophic or nutrient poor. The Lake is located in an undeveloped area with limited industrial activities and has been free from excessive nutrient loading for a long time. Most of the nutrients entering the Lake are derived from the Zambezi River which provides 77% of the total inflow (Balon & Coche, 1974; Mitchell, 1973). The Lake is now exposed to pollutants from a much larger catchment. Increasing industrialization, urban growth, increasing population and expanding agricultural activities are currently being experienced, thus contributing to increased nutrient loading in the catchment of Lake Kariba. Limited research has been carried out to assess the impact of these activities, and a reliable estimation of nutrient loading into the Lake. Secondary rivers flowing into the Lake bring nutrient-rich water

(Bowmaker, 1973; Coche, 1974) that influences the establishment and proliferation of water hyacinth (Mhlanga, in press).

Thick mats of water hyacinth have serious impact on aquatic ecosystems and cause problems for all aspects of water utilisation. These impacts are socio-economic and environmental in nature. The impacts include a reduction in the quality of drinking water caused by bad odours, taste, colour and turbidity, promotion of the development of waterborne, water based and water related diseases (e.g. malaria, encephalitis and filaraisi), and increase in siltation of rivers and dams. Others are the reduction of useful water surface area for fishing and water transport, deterioration of aquatic biodiversity, clogging of irrigation canals and pumps, and enhancing flood damage to road and rail bridges and hydroelectric power generation schemes (The Specialist Committee of the Intergovernmental Committee for the control of Weeds o Lake Kariba, 1999). Thus the water hyacinth is a threat to the aquatic ecosystems, human health and various economic activities.

The problem under consideration needs a reliable monitoring system that can quantify the spread of water hyacinth to enable management make timely decisions on what interventions to use to deal with this invasive weed. interventions chosen depend on how serious the problem is.

1.1 Statement of the problem

Water hyacinth has been described as the world's worst aquatic weed mainly because of its negative effects on the livelihood of man and domestic animals (Ogwang & Molo, 1999). It is one of the most successful colonisers in he Plant Kingdom (Kannan & Kathiresan, 1999). Rapid growth, vegetative reproduction and ability to re-infest via the seed bank or flood borne plants have resulted in excessive infestations in Africa, Southern Asia and United States of America. It can dou its biomass within two weeks under suitable conditions.

The negative impact of water hyacinth has been felt in many countries in the world. In Africa; Zambia, Zimbabwe, Malawi, Burkina Faso and Kenya are among the countries that have had shares of the problems of water hyacinth. Several aquatic systems are known to be infested with water hyacinth namely Lake Victoria (Uganda, Kenya and Tanzania), Lakes Chivero and Mtirikwe (Zimbabwe), Kafue Flats (Zambia), Lower Shire (Malawi) and Enseleni River (South Africa). Zimbabwe gave the water hyacinth a pest status (Chikwenhere et al., 1999) making it an offence to trade in the weed. In Zambia, the water hyacinth problem in the lower Kafue River was declared a national disaster in 1998 (Kampeshi & Shantima, 1999) calling for concerted efforts to curb the weed.

There are a number of programmes aimed at reducing the spread of the water hyacinth. The integrated control of water hyacinth on Lake Kariba can be described as taking the toolbox to the Lake to fix the problem. In the toolbox are all the tools or control methods (i.e biological, chemical, and mechanical methods, etc.) (Hill, 2002). As the coverage of water hyacinth influences the intervention required, there is need for a reliable procedure for monitoring the coverage of this weed.

Physical observation, mapping using Global Positioning System (GPS) receivers and use of planimeters are the methods which have been used to monitor the coverage of water hyacinth on Lake Kariba (ZRA, 1997 and 1998;). Based on these methods, the water hyacinth coverage on Lake Kariba was estimated at 4000 hectares in 1997 (Murty & Mulendema, 1999) and 3 000 ha in September 1998 (The Specialist Committee of the Intergovernmental Committee for the control of Weeds on Lake Kariba, 1999). It is common knowledge that the real weed coverage could have been over or under estimated since it is not feasible that the entire weed on the Lake was completely mapped. Hill (2001) and Mhlanga (Personal Communication, 2004.) admitted that it is notoriously difficult to estimate the area covered by scattered, fringing mats of the water-weed. Some areas are not accessible by boat while some weed mats are not stationary due the influence of wind and water current. This makes in situ observation and mapping using GPS receivers and use of planimeters difficult.

However, mapping using satellite imagery can provide the solution to these problems. The imagery can capture the view over vast and inaccessible areas of the Lake. The point-in-time location of the weed can be captured using satellite imagery. Satellite imagery can be recorded in various wavelengths and so enables computerised image processing. It is also possible to acquire imagery of the same area regularly making follow up of the varying status of the weed possible (Neuville et al. 1995).

Denconsult (1998) in a pilot project demonstrated the possibility of mapping the water weed on Lake Kariba's Eastern Basin using Spot satellite images. Following this, Murty & Mulendema (1999), in their paper entitled, "In search of a solution to the weed problem" recommended exploring the use of satellite imagery to monitor water hyacinth coverage. Despite the recommendation, there has been very limited research carried out on monitoring the coverage of the weed using satellite images particularly in the Lake Kariba region. Besides, the possibility of classifying near-shore vegetation as weed has not been taken care of. Classifying near shore vegetation as water hyacinth can exaggerate the water weed coverage and cause unnecessary panic. Furthermore, there are still a number of questions unanswered such as "how often and at what time of the year satellite images would be acquired and used".

Thus the problem still remains of having no comprehensive procedure for monitoring the spread of the weed on Lake Kariba using Remote Sensing and GIS.

1.2 Objectives of the study

1.2.1 General objective

The overall objective is to establish a procedure for monitoring the spread of water hyacinth on Lake Kariba using Remote Sensing and GIS.

1.2.2 Specific objectives

The specific objectives are to:

- Identify the factors that promote the growth and proliferation of water hyacinth on the Lake,
- Specify the types of satellite images required to monitor the weed coverage taking into account its extent and distribution pattern,
- Specify the threshold size of weed coverage requiring intervention, how often and at what time of the year satellite images would be acquired and
- Identify the classification technique best suited for monitoring water hyacinth.
- Identify the sequence of steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS

1.2.3 Research questions

The following questions will be answered:

- What factors contribute to the rapid spread of water hyacinth?
- What is the extent and distribution pattern of water hyacinth on the Lake?
- What is the growth pattern of water hyacinth across different seasons in a year?
- What method of classification is best suited for identifying water hyacinth?
- What are the steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS?

The first question is aimed at identifying the factors that promote the growth and proliferation of water hyacinth on the Lake. Key indicators of the possible outbreak and rapid spread of the weed will be isolated. Places on the Lake where these indicators could be found should be target points for the ground truthing exercise. The effect of water level fluctuation on the proliferation of the weed will also be looked into.

The second question will culminate into specifying the threshold size of weed coverage requiring intervention and the types of satellite images required to monitor the weed taking into account its extent and distribution pattern.

The third question will lead to the specification of how often and at what time of the year satellite images would be acquired.

Because many image processing and classification techniques exist, there is need to identify the one that enhances the differentiation of spectral signatures and best suited for monitoring the weed. This will reduce the possibility of classifying near shore vegetation as weed. That is what the fourth question will achieve.

Finally, the fifth question will enable the identification of the sequence of steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS.

Answers to these questions will eventually lead to the development and testing of a procedure for monitoring the coverage of water hyacinth on Lake Kariba using satellite imagery.

1.3 Study area

1.3.1 General Description

Lake Kariba (16° 28' -18° 06' S; 26° 40' - 29° 03'E) is a man-made reservoir which was built on the Zambezi River. Whereas Figure 1.1 shows the map of Lake Kariba, Figure 1.2 depicts its location in Southern Africa on the border between Zambia and Zimbabwe.

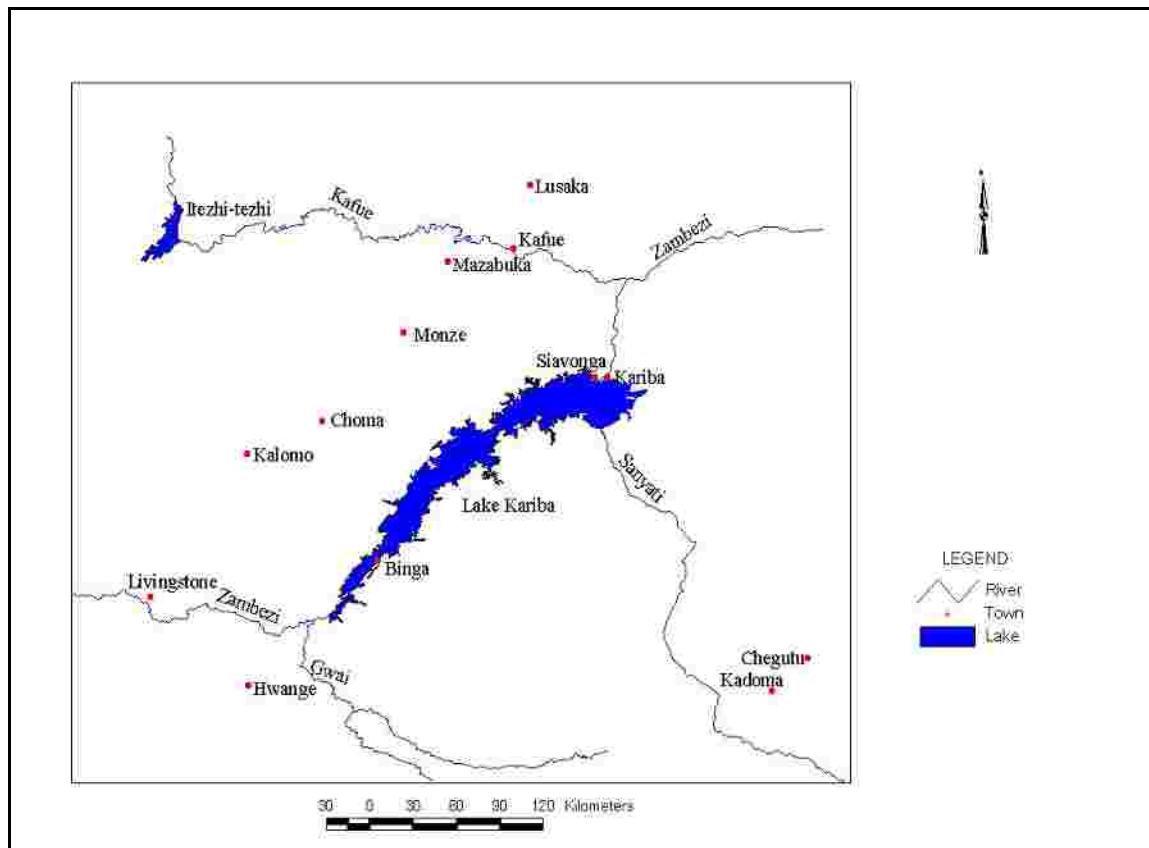


Figure 1.1: Lake Kariba

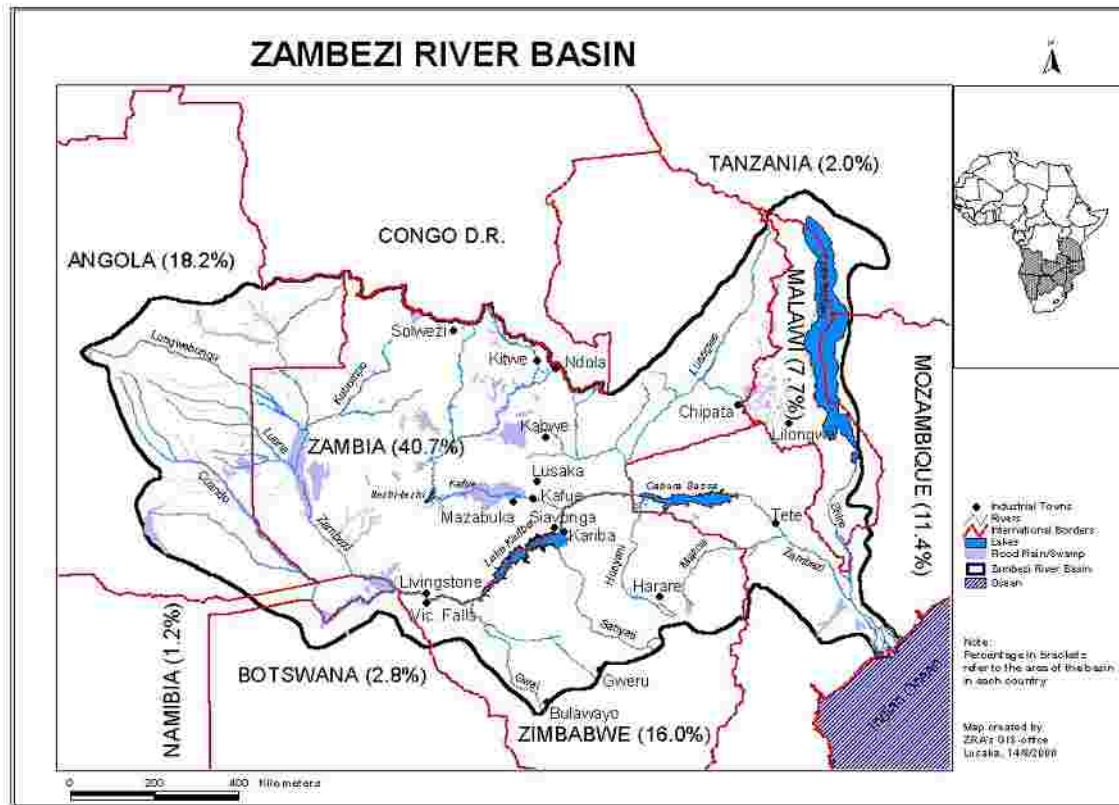


Figure 1.2: The Zambezi River Basin showing the location of Lake Kariba in Southern Africa.

Source ZRA.

Lake Kariba stretches for 280 km in an East-West direction covering a surface area of 5577 km² at the Maximum Retention Level (MRL) with a storage capacity of about 180.6 x 10⁹ m³. The Lake's surface area at the Minimum Operation Level (MOL) is 4354 km² (ZRA, 2000). Lake Kariba is the third largest dam in Africa in terms of surface area, after Lake Volta and Nasser – Nubia (Coche, 1974). The Lake has a maximum width of 32 km at full supply level (FSL). The dam wall is about 128 m high, topped by a wide motor way about 168 m long. It serves not only as a tourist attraction but also an international border crossing between Zambia and Zimbabwe. The dam has a maximum operating level of 488.5 m and a minimum operating level of 475.5 m for power generation purposes.

Over the years, various commercial activities have developed on and around Lake Kariba. Several towns such as Binga, Kariba, Mlibizi, Maamba, Siavonga and Sinazongwe have also developed around the Lake. The Lake is divided into five sub-basins along its long axis (Figure 1.3). This study will concentrate on the whole Lake.

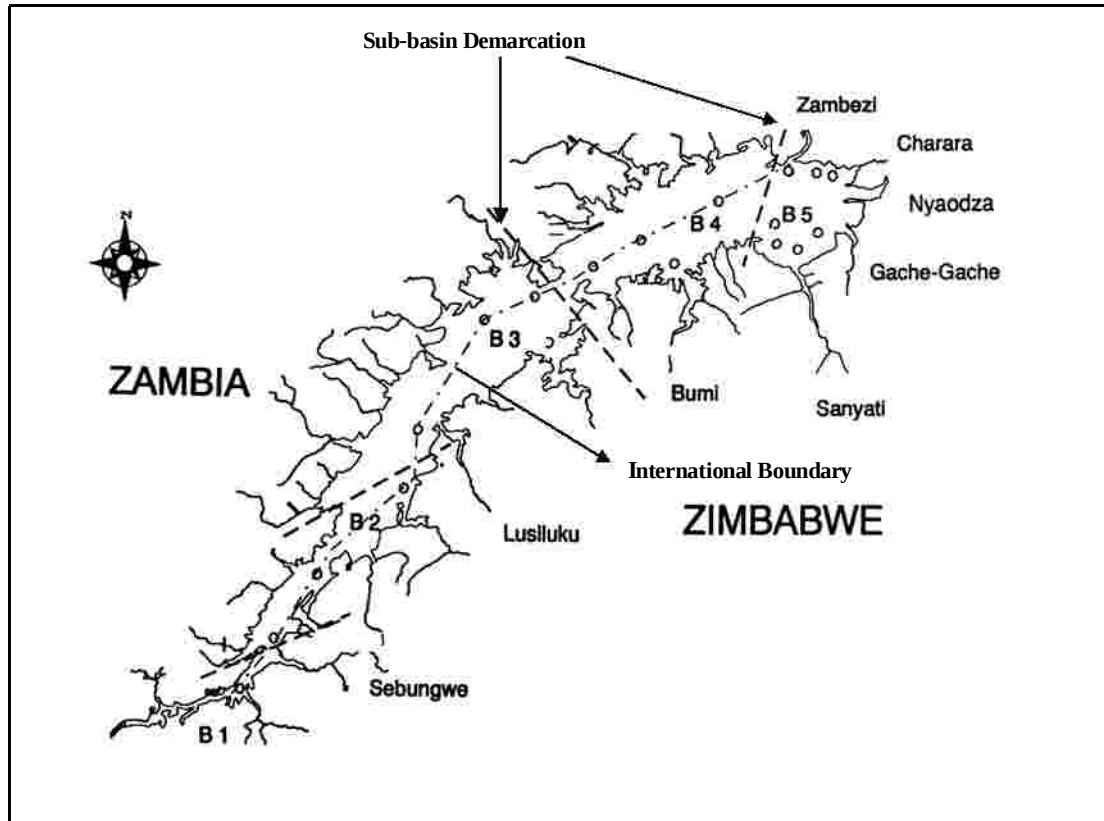


Figure 1.3: Sub-basins of Lake Kariba

Source: ZRA

1.3.2 Climate

Lake Kariba falls in a region whose average rainfall is 650mm and temperature ranges between 24 – 31°C (Pritchard and Munowenyu, 1988). The Lake breezes interact with the north-east monsoon winds (Kariba Town Council, 1987). Nights are influenced by calm north-easterly winds while the day time winds are generally h-westerly. The Lake experiences three distinct seasons namely: hot and dry (August – October), hot and wet (November – April) and cold and dry (May – July) (Chisangano, 1999).

1.3.3 Land use activities

Different land-use/ land-cover types exist around Lake Kariba. Some of the land use types are agriculture, bush/open woodland, grass dominated open land, forest and open land (Figure 1.4).

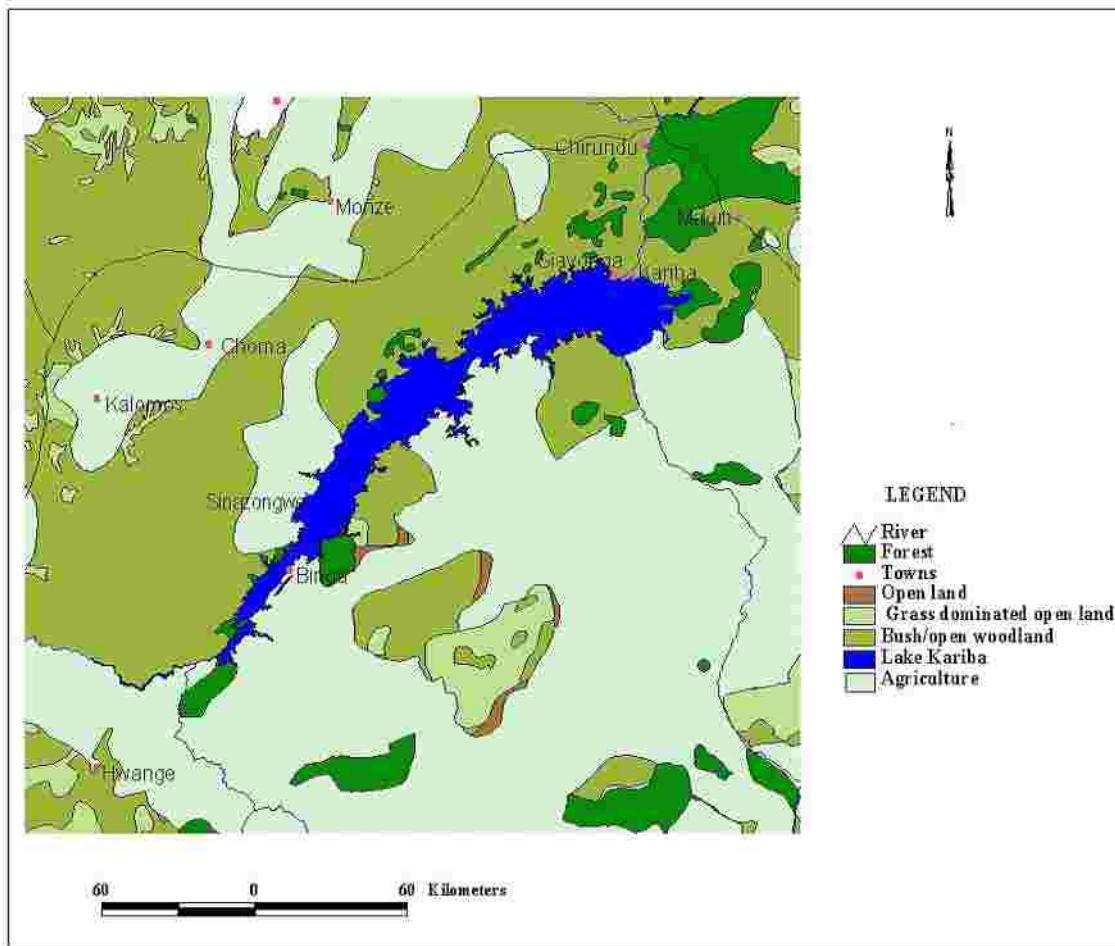


Figure 1.4 Land use/ land-cover types around Lake Kariba

Agriculture: This heading combines all crops and also land that was recently made fallow since it cannot be discriminated from cropland. Bare soils can sometimes be mistaken for crop fields under preparation as shown in Figure 1.5 below.



Figure 1.5: Agriculture in Matebeleland, Zimbabwe. Picture taken in November, 2003

Forest: This heading includes formations bordering the water courses and mainly on alluvial terraces. What is found here is an abundance of *Accacia* spp. in closed thickets as depicted in Figure 1.6 below. Forests also include all areas dominated by evergreen or deciduous trees with a canopy cover of greater than 60% and a height exceeding 2 m. Both broadleaf and needle leaf trees are included.



Figure 1.6: Riverine forest –Gatche Gatche, Picture taken on 11/12/2005

Grass dominated open lands: The flowing landscapes of open areas where grasses are dominant vegetation and where relatively few trees or shrubs grow. Scattered trees dot the open grasslands landscape where small differences in topography, aspect and soils provide moister growing conditions (GCC, 2009). Grasslands, shrub lands and savannah include lands dominated by woody vegetation less than 10 meters tall and with shrub canopy cover greater than 10%. The shrub foliage can be either evergreen or deciduous. This category also includes savannas and grasslands with herbaceous and other understory systems. These lands may have a tree or shrub cover of less than 60% (Loveland, T.R., Reed, B.C., J.F., Brown, J.F., Ohlen, D.O., Zhu, Z., Yang, L. Merchant. J., 2000).

Rock outcrops are also found in Bush/ Open woodland. Rock outcrops refer to the appearance of bedrock or superficial deposits exposed on the surface of the earth (Figure 1.7). In most places the bedrock or superficial deposits are covered by a mantle of soil and vegetation and cannot be seen or examined closely. However, in places where the overlying cover is removed through erosion, the rock may be exposed, or *crop out*.



Figure 1.7: Rock outcrops in Matebeleland, Zimbabwe. Picture taken on 07/11/2003

Bush/ Open woodland: Formations dominated by a wooded and shrubby ligneous layer and with a small herbaceous layer. Several types of formation can be distinguished depending on the floristic composition combined with soil type (BRLi, 2005):

- o Mopane woodland in mono-specific formation on poorly drained clayey soils and on deep alluvial or colluvial soils on which Mopane is dominant but is associated with other species such as *Terminalia spp*;
- o Shrubby-mopane woodland on drained soils and low water on Karoo substrate;
- o Woodland of undifferentiated species on deep alluvial or colluvial soils;
- o Mixed woodland (*Commiphora spp.*, *Pterocarpus spp.*, *Sterculia africana*, *Kirkia accuminata*, *Terminalia spp.*) on rough rocky hills bordering the lake;
- o Miombo woodland (*Brachystegia spp.*, *Julbernardia spp.* and *Colophospermum mopane*) on rocky hills.

Examples of Miombo woodland and shrub land with Mopane occurring in the Zambezi Basin are shown in Figure 1.8 and Figure 1.9 respectively.



Figure 1.8: Miombo woodland in Sinazongwe, Zambia. Picture taken on 09/11/2003



Figure 1.9: Shrub land with Mopane in Mlibizi, Zimbabwe. Picture taken on 12/11/2003

Open land: This is land that generally comprises of open spaces or land tracks. This may be predominantly sandy soil or desert like.

Other land use activities within the proximity of Lake Kariba include mining and municipal infrastructural developments. From these land use activities, only municipal

waste (point source) and run-off from cropland (non-point source) can provide pollution that would affect the proliferation of water hyacinth in the Lake. Rivers like Gatche Gatche (Appendix A) channel some of the run-off into Lake Kariba.

1.4 Report Layout

This report is split into six chapters described as follows:

Chapter 1 contains the background information for this research. It also states the problem and the objectives of this study. It further gives the general description of the study area.

Chapter 2 describes the characteristics of water hyacinth which are to be input to the monitoring procedure. It also explores the distribution and growth pattern of this invasive weed, factors that contribute to its proliferation and its impact on the Lake. Satellite Remote Sensing is introduced in this chapter. The chapter further discusses the use of Remote Sensing and GIS in water resources management. also describes the role of GIS in this study as it relates to the spatial distribution of water hyacinth.

Chapter 3 describes the designed procedure for monitoring water hyacinth. It focuses on the conceptual design that is generic. The activity diagrams designed in this chapter are based on the Unified Modelling Language (UML) version 2.0.

The focus of Chapter 4 is the testing of the conceptual design from the previous chapter. It specifies the data captured for this project and how it was converted to final products. It explains the field expeditions undertaken, the satellite images acquired and how they were processed, classified and analysed in Idrisi 2.0 and ArcView 3.2a respectively.

Finally, Chapter 5 discusses the achievement of the research objectives albeit the obstacles encountered during the course of the study whereas the conclusion and recommendations form the last remarks of this dissertation in Chapter 6.

CHAPTER 2 - CONCEPTUAL BACKGROUND

2.0 Introduction

This Chapter contributes to answering the following research questions;

- What factors contribute to the rapid spread of water hyacinth?
- What is the extent and distribution pattern of water hyacinth on the Lake?
- What is the growth pattern of water hyacinth across different seasons in a year?

Answers to the research questions above would help understand water hyacinth and its characteristics which are to be input to the monitoring procedure. It should be noted, however, that the aim of this study is to develop a procedure for monitoring water hyacinth using Remote Sensing and Geographic Information System (GIS).

2.1 Water hyacinth

Water hyacinth is a perennial, herbaceous, free floating aquatic plant probably originating in and around the Amazon, South America (Center, 1994). Morphological description and biological characteristics of water hyacinth have been reviewed by Harley (1990). Depending on growth conditions it can grow up to a meter in height and forms dense mats of entangled plants. Water hyacinth grows by dual reproduction (sexually and vegetative) and proliferates rapidly forming the dense floating mats that cover water bodies, so reducing light and oxygen, changing the water chemistry, fauna and flora. The leaves are arranged in a rosette and the petioles vary from spongy and bulbous to slender and non-bulbous. The latter are typical of plants in dense infestations whereas the former are typical of open water and spreading infestations.

The weed produces lilac to blue flowers (Figure 2.1) which can set up to 300 seeds per flower. The seeds sink following release from the seed capsule and remain viable for 5-20 years. Water hyacinth can double its mass, in the presence of favorable conditions, within 5-7 days. It is a successful colonizer and can invade both natural and artificial water bodies. Water hyacinth can be used as an accurate indicator of the nutrient status of a water body (i.e. water bodies that are polluted with nitrates and phosphates produce large, healthy water hyacinth plants). Using water hyacinth as a biotic indicator of the nutrient status of the water body is often more accurate than conducting water chemistry analyses of the water infested by the weed (Hill, 2001). This is because the plant is able to rapidly remove nutrients and heavy metals from the water, resulting in an underestimate of the extent of nutrient enrichment of the water.



Figure 2.1: Water hyacinth on Nyaodza bay. Picture taken on 17/1/96

Source: ZRA

2.1.1 Impact of water hyacinth

Water hyacinth is regarded as the world's most damaging aquatic weed. It is (after eutrophication) the largest threat to waterways, lakes and dams in South Africa, Tanzania, Uganda, Zambia, Zimbabwe and other African countries. The weed impairs water quality and quantity, traffic, irrigation, hydro-electricity generation, water use and biodiversity (Chikwenhere et. al., 1999; Hill, 2001).

Lake Kariba is a shared transboundary resource. The invasion of water hyacinth on the Lake causes socio-economic and environmental problems. The invasion of water hyacinth on Lake Kariba has caused problems for fish farming and transportation. It has direct effects on the aquatic habitat and indirect effects on the terrestrial habitat. Aquatic animals seek areas not invaded by the weed while aquatic flora like Kariba weed, water lettuce and the African water lily populations reduced probably due to water hyacinth's competitive ability. Small-scale fishermen became nomadic in search of water hyacinth-free fishing areas and new roads were constructed, as boats could not be anchored where water hyacinth occurred.

Chikwenhere et. al (1999) undertook a study to assess the effect of water hyacinth on the Gache Gache bay on Lake Kariba's Eastern Basin. The study, among other things, found that US\$ 9 611.00 was spent on road construction to a new harbour, US\$ 2 222.00 on boat repairs and US\$ 22 889.00 on controlling water hyacinth. In 1998, ZRA spent over

US\$ 45 000.00 on spraying water hyacinth. To date, ZRA has spent thousands of dollars on activities related to water hyacinth control.

This Lake is an important source of hydroelectric power for both Zambia and Zimbabwe. Water hyacinth threatens this resource through increased evapotranspiration (that decreases the Lake Level). The weed also threatens hydroelectric power generation by blocking intakes (Figure 2.2) and damaging hydroelectric turbines (Center 1994; Epelle and Farri 1993; Jayarath 1987; Wright 1979). Water hyacinth was first observed at the Kariba North Bank (KNBC) Company intakes in 1996. By 1998, the population of the weed had increased to become a sufficient concern for electricity operator. ZRA and KNBC then put resources together and physically removed over 270 tones of weed and disposed them at the latter's rubbish pit (The Special Committee of the Intergovernmental Committee for the control of Weeds on Lake Kariba, 1999).



2.1.2 Distribution of water hyacinth

Water hyacinth was reported on the Gache Gache Bay of the Lake in 199 and emerged as a serious pest in 1991 and 1994 respectively (Chikwenhere 2001). Water hyacinth was first recorded in 1994 in the Masango bay of the Nyaodza River. Water hyacinth has mainly flourished on the Eastern Basin until it was reported from Manchinch Bay

(Zambia) by early 1996. The weed had probably been blown by wind from the Zimbabwean shoreline. It was later reported from the North Bank of the Kariba Dam.

In September 1996, estimated water hyacinth infestation on the Lake's Eastern Basin was 400ha in Charara, 850 ha in Gache Gache Bay, 2 700 ha in Nyaodza and 40 ha in Sanyati. Serious water hyacinth infestations were observed at the Nyaodza area where water hyacinth leaf height averaged 1.25 – 1.40m while root length was between 0.90 – 1.24m long. At all water hyacinth invaded areas, flowering was almost 100% from August to March and over 70% for the rest of the months. The leaves were healthy with no damage except on very old leaves that showed slight disease symptoms (Chikwenhere, 2001).

The weed coverage on the Lake was estimated at 4 000 ha (Murty & Mulendema, 1999) in 1997. In 1998, a survey by the Department of National Parks and Wildlife Management (DNPWM), Kariba, Zimbabwe, estimated the total weed infestation area between the Kariba Dam wall and the Chete Island at 4 510 ha (The Specialist Committee of the Intergovernmental Committee for the control of Weeds on Lake Kariba, 1999). In September, 1998, the estimate made by the spray team was 3 000 ha. A survey made by ZRA in February 1999 reports that the distribution of the weed in the originally sprayed area was now 300 ha, more than 90% reduced compared with the pre – spraying levels. This reduction is attributed to “many other external causes other than the effects of 2,4-dichlorophenoxy acetic acid (2,4-D)” (The Specialist Committee of the Intergovernmental Committee for the control of Weeds o Lake Kariba, 1999; Hill, 2001), and hints that the weed may have been washed out of the river mouths during the peak river flows of the wet season. Areas visited by ZRA staff in February 1999 include Nyaodza, Gache Gache, Spurwing Island through to Sanyati river mouth, Sanyati river up to the first cross line, Tsetse Island and Charara harbour.

In 2001 during his water hyacinth monitoring consultancy to the Zambezi River Authority, Hill (in the company of ZRA staff) surveyed the spread of water hyacinth on Lake Kariba on two missions. During the first mission (Hill, 2001) an aerial survey of the Lake was conducted in an attempt to determine the extent of the water hyacinth

infestations. Although this provided some useful data, it was felt that it was essential to ground-truth the findings of the aerial survey. Therefore, during the second mission (August, 2001), a survey of the entire Lake was conducted by boat to assess the extent of water hyacinth and other aquatic weed infestations. In total 31 sites were visited on Lake Kariba during the second mission in August 2001, 18 along the Zimbabwean shoreline and 13 along the Zambian shoreline. Where water hyacinth was found, a sample of ten plants was taken and several aspects of plant biology and chemical control activity were measured. In addition, an estimate of total area covered by the weed was made. These results are summarized in Table 2.1.

Of the 31 sites visited, 19 had water hyacinth, 15 on the Zimbabwean side of the Lake and 4 on the Zambian side. At many of these sites there were small patches of plants, usually less than 1ha in area. However, fairly severe infestations were recorded in the Charara and Nyaodza rivers (this was expected, as they were located during the aerial survey in April 2001), but also in the Ume and Mlibizi rivers (Table 2.1). This survey reveals the importance of ground truthing. No water hyacinth was recorded in the Mlibizi River during the aerial survey but the weed was found during the ground truthing survey. The total area covered by water hyacinth on Lake Kariba was estimated at less than 1 000ha. The distribution of water hyacinth on the Lake also gives a very good indication of pollution hotspots associated with higher human population densities, for example, around the Sanyati Basin (Nyaodza and Charara Rivers), the Ume River and the Mlibizi River.

Table 2.2 indicates the summary of weed-spread estimates on Lake Kariba between 1992 and 2001. The estimates of the area extent (300ha – 4 510ha) show the possibility of mapping weed spread using Remote Sensing successfully.

Table 2.1: Summary of the 2001 Lake-wide water hyacinth monitoring survey.

No	Site Name	Coordinates	Height	Root length	Area	Comments
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			[cm]	[cm]	[ha]	
1	ULKRS Harbour	16°21'28"/28°50'33"	35.6	41.3	20	
2	Crocodile Farm				50	No Sample
3	Charara River	16°33'07"/28°57'21"	25.6	46.5	100	
4	Nyaodza River	16°35'31"/29°03'20"	40.2	34.8	200	
5	Gatche Gatche River	16.7753°/28.9407°	29.8	58.9	20	
6	Sanyati River				1	No Sample
7	Gordon's Bay	16°45'06"/28°34'18"			1	No Sample
8	Ume River	16°59'02"/28°25'54"	18.8	44.0	300	
9	Sibilobilo River	16°54'27"/28°13'20"	20.7	48.6	10	
10	Sengwa River	17°07'34"/28°01'27"				No WH
11	Mwenda River	17°10'50"/27°51'02"				No WH
12	Luizilukulu River	17°17'06"/27°45'05"				No WH
13	Sengwe River	17°29'50"/27°35'25"	14.5	30.4	1	
14	Masuma River	17°34'35"/27°28'00"	71.8	48.6	1	
15	Lokola River	17°42'22"/27°17'58"	25.3	38.7	1	
16	Jabuwa Island	17°47'16"/27°11'05"			1	No Sample
17	Sebungwe River	17°52'41"/27°10'30"	26.2	28.0	40	
18	Mlibizi River	17°59'06"/27°06'05"	14.8	38.8	150	
19	Atichewe Lagoon	17°55'58"/27°05'24"				No WH
20	Zambezi River	17°55'56"/27°02'29"	29.8	52.4	1	
21	Mwenda River (Zambia)	17°39'48"/27°10'15"				No WH
22	Chimini River	17°35'45"/27°12'20"				No WH
23	Tiger Bay	17°32'40"/27°18'32"				No WH
24	Mazuma River	17°16'12"/27°22'06"	35.4	51.7	10	
25	Sikaputa River	17°07'35"/27°32'39"	29.4	33.5	1	
26	Dungata River	16°47'16"/27°51'40"				No WH
27	Chibuwe River	16°44'20"/27°53'19"				No WH
28	Dundwe River	16°45'14"/27°55'29"				No WH
29	Nangandwe River	16°36'33"/28°08'25"	25.8	40.1	20	
30	Lufua River	16°31'05"/28°16'50"				No WH
31	Munyama					No WH
	Total Water hyacinth Area				928	

N.B All figures of water hyacinth biology are means of 10 plants.

Table 2.2: Summary of weed-spread estimates on Lake Kariba

Year	Estimated extent water hyacinth [ha]	Comment
1992	684	April 1992 Landsat image classified in 1998
1994	1988	December 1994 Landsat image classified in 1998
1996	3990	Charara, Gache gache, Nyaodza and Sanyati
1997	4000	September, 1997
1998	4510	From the Dam wall to Chete Island, DNPWM
1998	3000	Pre-spray survey, September 1998
1999	300	February 1999
2001	928	August 2001

2.1.3 Growth pattern of water hyacinth

Water hyacinth has a tremendous growth and reproductive rate. The plant reproduces by seeds and vegetatively through daughter plants that form on rhizomes and produce dense plant beds. In one study, two plants produced 1,200 daughter plants in four months. By this mechanism, water hyacinth can form impenetrable mats of floating vegetation. Individual plants break off the mat and can be dispersed by wind and water currents. A single plant can produce as many as 5,000 seeds and waterfowl eat and transport seeds to new locations. Seedlings are common on mud banks exposed by low water levels. (<http://www.ecy.wa.gov/programs/wq/plants/weeds/hyacinth.html>)

In regions with a pronounced seasonality, old stem bases initiate growth in spring by producing daughter plants. These plants increase in number and size from the spring until the end of summer when maximum biomass is reached. As the plants become crowded many of the lower leaves die back due to shading. Water hyacinth is in full bloom in late summer and early autumn. Seeds form in the submerged, withered flower. By late autumn, some of the old leaves start dying and in winter most plants have senesced.

The seasonality in Lake Kariba is quite different from temperate conditions because of lower latitude and also because the rainy season (with clouds limiting the irradiance) occurs around the December solstice: the cold season does not coincide with a strongly marked low irradiance, as it does in the northern temperate hemisphere. This means that low daily irradiance and temperature, two of the factors that may contribute to slow growth or senescence, do not occur simultaneously. Flowering may be seen at any season, although some observations indicate a maximum during the warm season (October – December) (Chifamba, personal communication, 2004). Wet sediment in river mouths or flat bays provides sites for the development of young plants, but nothing is known of the upper reaches of the rivers, or about the relative proportion of reproduction by seeds and stems.

Seasonal and inter annual variations of the water level of the lake or its tributaries play a role in the cycle of the water hyacinth. Stranding is a major regulatory environmental

factor of the weed extension during the draw down of the Lake level. As the Lake level increases flooding land that was exposed, fresh germination of water hyacinth can be observed probably from the weed that could have been deposited on the muddy bottom. Weed left stranded but not completely dead (hibernated) on the river banks resuscitate upon accessing water. The weed may be seen to be in full bloom in the rainy season. However, the growth pattern of the weed is not always natural due to the biological control that has taken its toll on some plants as shown in Figure 2.3.



Figure 2.3: Water hyacinth showing leaf damage from biological control agents on Gatche gatche bay.
Picture taken in September 2003
Source: ZRA

The seasonal cycle of the water hyacinth in Lake Kariba is not as clear as that described for the River Kafue, where a correlation of growth with temperature and sunshine was found, with a strong effect of the cold season and a spring development during October and November (ECZ, 2001). In the research done by Chifamba (2004), data was recorded from October 2001 to October 2002 therefore a complete annual cycle of events was documented. A time series trend of the data showed a decrease in root length and plant weight even though the maximum petiole length and the number of leaves per plant remained stable (Figures 2.4 and 2.5 respectively). The area covered by plants decreased as the water receded (Figure 2.5). The amount of reproduction decreased noticeably in both number of ramets (daughter plants) and flowers per plant (Figure 2.6).

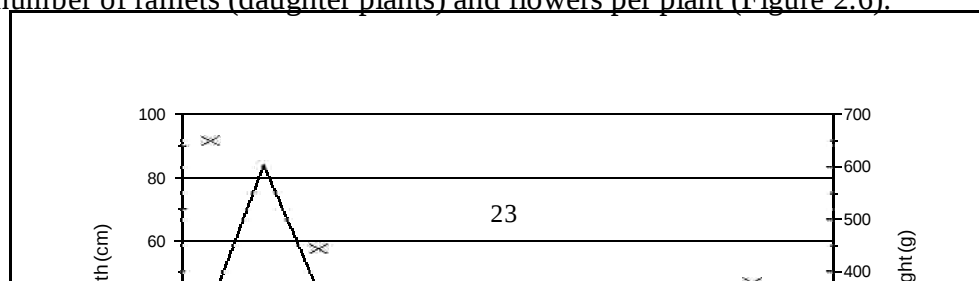


Figure 2.4: The mean maximum petiole length, maximum root length and plant weight.

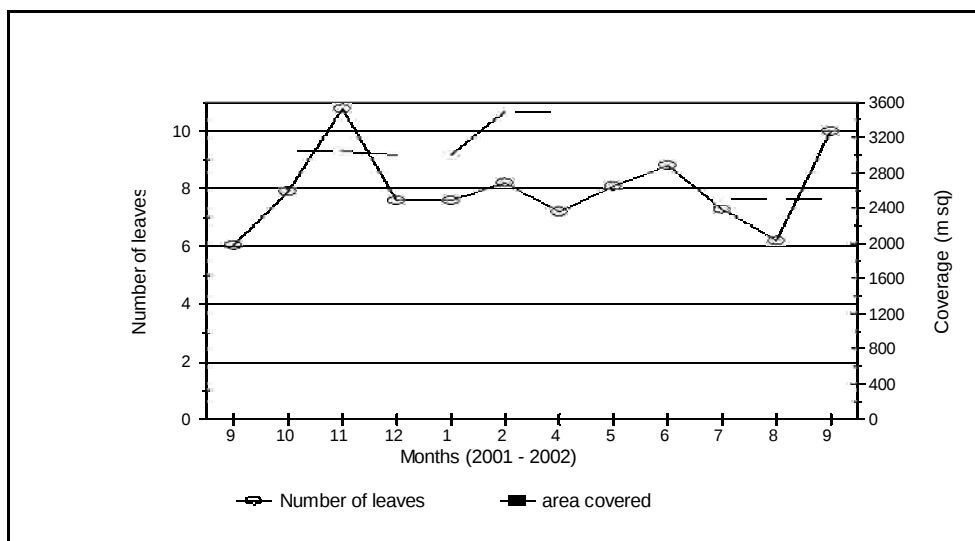


Figure 2.5: The mean number of leaves per plant and the area covered by the water Hyacinth

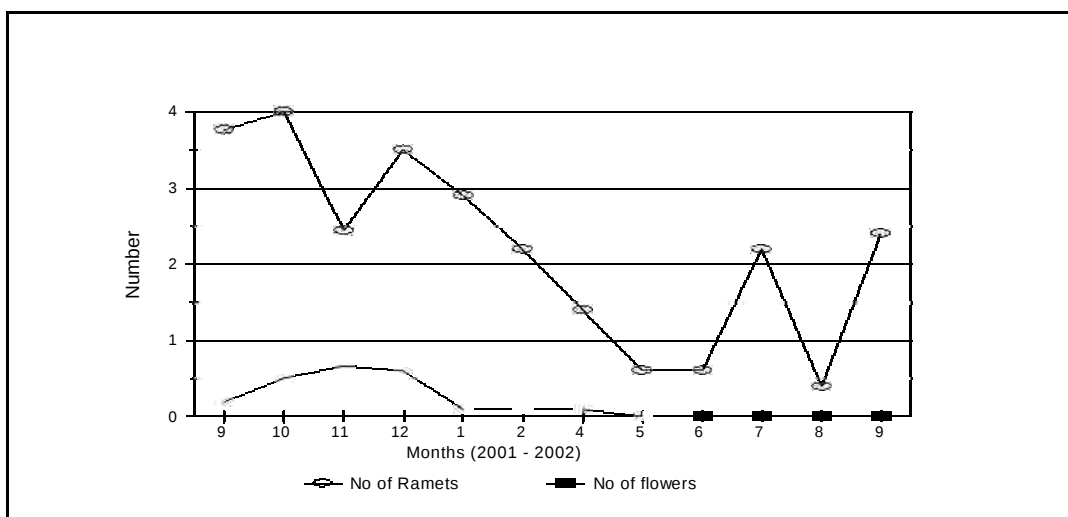


Figure 2.6: Mean number of ramets and flowers on each plant.

All or nearly all water hyacinth plants had larval mines (holes excavated or bored by weevils in the stems of the plants) except from April 2002 to June 2002. The number of

weevil feeding scars remained constant but the mite damage increased from mean 15% to nearly 30%. Through the sampling period the water hyacinth reproduction decreased and the extent of damage to the existing plants increased. It is not possible to separate the effect of the receding water and that of the biological control agents. Alone each process can cause a decline in the plants. Lack of water is likely to stress the plant making it more susceptible to biological control so a dual action is possible. The increase in mite population cannot be discounted.

The weed health in Figures 2.4 to 2.6 (reflected by the area covered, the number of leaves, daughter plants and flowers) imply that the best period to map water hyacinth using Satellite imagery on Lake Kariba is from September to February.

2.1.4 Factors that contribute to the proliferation of water hyacinth

Understanding the factors that contribute to the proliferation of water hyacinth is vital in developing a procedure for monitoring the spread of the weed on Lake Kariba. This knowledge is necessary when selecting water hyacinth hotspots for ground truthing which is an important part of the mapping process using satellite imagery.

2.1.4.1 Water Nutrients

Nitrogen (N) and phosphorous (P) pollution are widely regarded as the main contributing factors to the proliferation of water hyacinth (Gossett & Norris, 1971). As with any other plant species, water hyacinth, and other aquatic weeds, require nitrates and phosphates to grow properly, and the higher the concentrations of these fertilizers, the more the weeds are able to flourish. Therefore, it stands to reason that any management plan for water hyacinth must include aspects of nutrient control (Hill & Olckers, 2000). An understanding of the nutrient status of the aquatic ecosystem and its correlation with water hyacinth growth is vital and will determine the type of control option required, the time taken to achieve control and ultimately the level of control that is likely to be achieved.

Reddy *et al.* (1990) found that concentrations of P above 1.06 mg/l not result in further increases in biomass yields. Similar optimum concentration ranges were found by Balasooriya *et al.* (1984) and by Singh *et al.* (1984): 1-10 mg/l for N, 1-5 mg/l for P and 30 mg/l for Ca. If the concentrations of P fell below 0.1 mg/l, active growth of water hyacinth stops (Haller *et al.* 1971; Haller & Sutton 1973). However, concentrations in excess of this not only allowed growth, but also permitted luxury uptake, i.e. uptake of nutrients by the plant in excess of its immediate requirements but which were stored to maintain growth once concentrations fell. Similar critical concentrations were observed in a range of water bodies in Sri Lanka (Balasooriya *et al.* 1984): 0.4 – 0.6 mg/l P and 0.2 – 9.6 mg/l N and, as above, the lower concentrations limit growth. The doubling time of water hyacinth under these conditions ranged from 6 days (optimal) to 14 days (sub-optimal).

Many of these experiments were conducted in tanks, pools or sewage treatment ponds, where the concentrations of nutrients could easily be manipulated, and were often far higher than could be expected under natural conditions. Doubling times given by Gopal (1987) ranged from 3 to 60 days. Therefore, doubling time depends on the local conditions, including light and temperature.

Of the elements discussed above, it is N and P that are likely to contribute the most to water hyacinth growth. For N and P a wide range is considered optimal as growth can be supported at the lower end of the range provided that there is sufficient input of fresh nutrients to maintain these concentrations (Hill, 2001). In the natural environment, this could be achieved through mineralisation, inflow from rivers and runoff. However, water hyacinth also has a high concentration of Potassium (K) in its tissue, indicating a higher K demand than for many other aquatic plant species. The concentration of K influenced the uptake of N and P as well as growth and productivity (Reddy *et al.* 1991). Reddy *et al.* (1991) found that the optimum concentration of range of K was 12 – 54 mg/l, although at lower concentrations, (2-7 mg/l) productivity was not greatly reduced

until after some 70 days at these concentrations, when, presumably nutrients started to run out and deficiencies set in.

Given sufficient nutrients, a productivity of 20-30 g (dry weight) m⁻² day⁻¹ was attained (Reddy *et al.* 1991). Gopal (1987) quotes a range of figures from 1. to 22.0 g (dry weight) m⁻² day⁻¹, with annual rates ranging from 2.6 to 100 tones (dry weight) ha⁻¹ year⁻¹. The standing crop was from 0.6 to 3.5 kg m⁻² (i.e. 6 to 35 tones ha⁻¹). Reddy & DeBusk (1984) and Singh *et al.* (1984) report similar productivities: 0.26 tones ha⁻¹ day⁻¹, 95-106 tones ha⁻¹ year⁻¹. Even towards the lower end of the range this is a substantial amount of biomass production for any ecosystem, terrestrial, or aquatic. Under the same conditions, other aquatic plants produce less biomass: 72 tones ha⁻¹ year⁻¹ for water lettuce and 41 tones ha⁻¹ year⁻¹ for Hydrocotyle (Reddy & De Busk 1984).

2.1.4.2 Climate

Water hyacinth originates from a typical tropical rain forest climate characterised by high temperatures with a small daily fluctuation; and high rainfall with resultant high atmospheric humidity conditions, which form part of its "hot house" habitat. The biology of water hyacinth is fairly well studied and Gopal, (1984) showed that air temperatures between 30⁰ C and 34⁰ C were required to promote maximum water hyacinth growth while Balasooriya et al. (1984) suggested a range of 26⁰ C to 33⁰ C for luxuriant growth. Cloudiness with resultant heavy showers of rain protects water hyacinth from excessive radiation and/or desiccation. However, the same rain leaches and dilutes nutrients to such an extent that natural enemies of water hyacinth have a better chance to control the latter.

2.1.4.3 Wind and wave action

The wind and water current can also drift the weed in respective directions. Wind is described as a major distributing factor of water hyacinth. The areas receiving the dominant prevailing winds are potential weed depositories (Chisangano, 1999). The wind roses available for 2003 (0800 hrs and 1400 hrs in April, July, October and January) clearly indicate that the wind regime is diurnal, with a South-West sea breeze during the

day and a lighter North East land breeze in the night in Kariba. If this diurnal regime occurs all around the lake, the net movement of the air masses over the lake is small, and the slightly stronger sea breeze would contribute to maintain the weeds along the shores. The main action of the wind on the weed distribution would thus result from the violent storms which sometimes occur on the lake and may induce some dispersion of small weed patches (BRLi/ IRD, 2005).

2.1.4.4 Water level fluctuations

Water level fluctuations can have an important influence on the infestations of water hyacinth and hence the management of the weed. Commenting on what could happen if there was a 5 to 10m change in the water levels of Lake Kariba, Hill (2001) said, “Intuitively I would expect that the water hyacinth would become worse, firstly because there is less surface area of water, secondly because there will be shallower areas which would not be subjected to as much wind and wave action. What we do know is that once the dry areas become re-inundated with water, there will be mass germination of seeds and the weed will undergo rapid vegetative growth”.

Observation by ZRA staff confirm that water hyacinth plants become stranded and die as the water level recedes during the draw-down period in the dry season, leaving the area free for colonisation by germinating seedlings when the water level rises again. In the Gache Gache area on the Lake’s Eastern Basin, water hyacinth was left stranded on dry land as the water level receded only to resuscitate when the water level started rising in November 2003 (Valema, personal communication, 2003).

2.2 Remote Sensing

It is necessary to understand Remote Sensing as it will help to;

- Specify the types of satellite images required to monitor the weed coverage taking into account its extent and distribution pattern,
- Specify the threshold size of weed coverage requiring intervention, how often and at what time of the year satellite images would be acquired and
- Identify the classification technique best suited for monitoring water hyacinth.

Remote Sensing is the art or science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation. Electromagnetic sensors, operated from airborne and space borne platforms capture electromagnetic energy emitted or reflected and this data is analysed to provide information about the resources under investigation (Merka, 2002).

Although remote sensing techniques have been in use for many years, the beginning of the space age greatly stimulated the development of remote sensing technology. The space age is generally acknowledged to have begun with the launch of *Sputnik* by the Soviet Union in October 1957 (Landgrebe, 2003). This event had a fundamental effect on society in general. Among other things, it turned thinking to considerations of how satellites might be useful. The launching of *Sputnik* stimulated the United States Congress to pass a law in 1958 creating the National Aeronautics and Space Administration (NASA) out of the then-existing National Advisory Committee on Aeronautics (NACA). It took the new NASA only until April 1, 1960, to design, build and launch TIROS 1 (a weather satellite designed to primarily provide pictures of the cloud cover over wide areas), the first satellite designed for Earth observational purposes. It is from then on that NOAA, Landsat, Spot and other satellites evolved with the central question being pursued as to whether aerospace technology could be used to better manage the Earth's natural and man-made resources (Landgrebe, 2003).

Images acquired by remote sensing satellites offer a unique perspective of the Earth, its resources, and human impact upon it. In little more than a decade as a commercial industry, satellite remote sensing has proven itself as a cost-effective source of valuable information for numerous applications including land use management, urban planning, water resources management, environmental monitoring, agricultural management, oil exploration, market development, real estate citing and many others.

In many ways, the value of satellite imagery and the information derived from it is obvious. It gives a bird's eye view of objects and features on the Earth's surface and helps understand relationships among those features that might not be as apparent when viewed from ground level. The 'remote' aspect of remote sensing also enhances this value by enabling one to see things halfway around the globe without ever leaving one's office. In addition to these apparent benefits, satellite imagery literally shows more than what meets the eye by revealing hidden details otherwise concealed from human view. Some images, for instance, expose disease in vegetation, minerals in rock outcrops, or pollution in rivers. Furthermore, microwave satellites see through clouds and fog unveiling parts of the Earth's surface.

The practical value and applicability of imagery will continue to grow as advanced new satellites are launched and join those already in orbit. With more satellites on the way, imagery is available in an increasing combination of scene sizes, spectral resolutions, revisit frequencies and spatial details. New space-based sensors make imagery more useful than ever and also present users with greater challenges in choosing the right imagery.

Satellite imagery's accuracy has improved with improved technology. Table 3.1 summarizes the characteristics of some satellite imagery. Spot and Landsat imagery have been used to map vegetation and water hyacinth on Lake Kariba (Surrel, 1987 and Denconsult, 1998). Spot 5 images with a pixel size of 10m x 10m offer a better spatial resolution for monitoring water hyacinth than Landsat. However, Landsat gathers data from eight spectral bands as opposed to four used by Spot and therefore has better vegetation discrimination but its spatial resolution (30m x 30m) is nine times less than that of Spot.

Table 2.3: Summary of the characteristics of some satellite imagery.

Satellite	Pan/Multi/ Superspectral	Resolution (m)	Swath (km)	Revisit (Days)
SPOT 5	Panchromatic	5	60	2 - 3
	Multispectral	10	60	2 - 3

LANDSAT TM	Panchromatic Multispectral	15 30 120 (Band 8)	185 185	16 16
LANDSAT ETM+	Panchromatic Multispectral	15 30 60 (Band 8)	185 185	16 16
IKONOS	Panchromatic Multispectral	1 4	11 11	3.5 - 5 3.5 - 5
Quickbird	Panchromatic Multispectral	0.61 2.4	22	1.5 - 4
RADARSAT	N/A	8 - 100	50 - 500	3 - 35
ERS-1/2	N/A	30 - 50	100- 500	3 - 35
JERS-1	N/A	18 15	75 30	44 4 - 5
MERIS	Superspectral	300	2500	3
MODIS	Superspectral	250-1000	2330	Depends on the bands

Source: Business Image Group and SPOT Image Corporation

2.2.1 Application of satellite imagery

Satellite imagery provides valuable information to thousands of businesses in hundreds of industries around the world. It would not be possible to list all the types of projects and vertical markets in which imagery is utilized, but it is safe to say that nearly all projects involving satellite images involve some variation of one or more of the following common applications (Business Image Group and SPOT Image Corporation, 1998):

Feature Mapping: Satellite images are most commonly used to identify, locate and map objects and features on the ground. The size of the objects mapped depends only on the resolution of the imagery, and images are used to map from geologic structure and highway networks to building locations and bus shelters. Maps can be created from images at a much lower cost in a fraction of the time it would take a survey crew to perform the same task. Feature mapping is used extensively by cartographers, exploration geologists, transportation planners, urban planners and utility engineers.

Land Cover/ Use Classification: This is the type of mapping that multispectral imagery performs extremely well and it can be carried out in a simple image processing system using classification functions. In this process, the is divided into areas of common land cover such as forested, open land, planted fields, water bodies and urban

development. Classification can get very specific, differentiating farm fields by type of crop. Most often, the image is colour coded so that each different land cover class appears as the same colour throughout the image. Land cover mapping is utilized by telecommunications designers, foresters, farmers, natural resource managers, city planners, numerous government agencies, etc.

Change Detection: This is a process that some image processing systems can perform. It requires two satellite images of the same geographic area acquired at different times. After the images are rectified or matched, the system compares the values of corresponding pixels in the two images and determines which values are different, indicating some change in ground features over the intervening period. For visual display, the change image usually has all changed areas highlighted in a bright colour. Manual examinations of the image or field visits are required to determine exactly what the change was. Environmentalists use this technique to track deforestation. Urban planners and developers apply it to locate growth patterns in cities.

Global Positioning System (GPS) Mapping: GPS has become a popular method of surveying, and many surveyors now prefer to plot their GPS points directly on satellite images. This gives a vivid map perspective to what would otherwise be a collection of points. GPS mapping is gaining wide use in farming and civil engineering, especially in applications that require mapping of horizontal and vertical coordinates.

Map Vector Updating: New satellite images are considered ideal maps because they are extremely up-to-date, and they display ground features and their geographic relationships in photographic like perspectives. Image processing and GIS software allow users to overlay a scanned or digitized map on top of a satellite image to find inaccuracies in the maps. For instance, new roads might be visible in the image, and the software allows the user to manually add new vectors or feature icons to the map to reflect these changes. Throughout the cartography industry, this is becoming a much less expensive alternative to sending field crews to update maps.

Three-Dimensional (3D) Modeling: An image can be draped over a digital elevation model to create a 3D view of the landscape. Some software packages have visualization tools that enable the user to choose any vantage point on or above the image and then move through the 3D scene, viewing hills, mountains and other terrain features in a very real perspective. 3D modeling, especially with walk-through or fly-through capabilities requires a high powered computer with a lot of memory. It's used frequently by foresters for harvest planning, military pilots for mission rehearsal, geologists for in-depth structural analysis, civil engineers for construction planning and numerous others.

2.2.1.1 Use of Remote Sensing in Water Resources Management

Remote Sensing offers great opportunities for water resources management and is among the tools that contribute to successful Integrated Water Resources Management (IWRM).

Merka (2000) demonstrated the use of Remote Sensing and GIS in water resources assessment and management in Zimbabwe using the Upper Mupfure River Catchment as a case study. The study showed that Remote Sensing and GIS have a big potential in improving water resources assessment and management in Zimbabwe. Landsat TM data were used to compute actual water-use on farms, detecting where dams are and calculating surface area of dams. A detailed classification of the study area was also made.

On 29th October 2002, Prince Willem Alexander of Netherlands paid a working visit to ITC displaying a special interest in the opportunities afforded by remote sensing in the context of water management (Al-Khaier, 2002). A study whose purpose is to calculate how much water is used for irrigation in the densely populated Nile Delta was presented to him. From this study and through maps, it can be seen throughout the river basin how many kilograms of food can be harvested from a litre of water. In the case of this presentation of rice grown in the Nile Delta, it was concluded that 1000 litres of water are consumed to produce 1kg of rice. Areas of successful farming and adequate water

management can thus be detected from space. In this way successful farming areas and cases of mismanagement are literally put on the map.

Other countries like South Africa, Tanzania, Uganda, Zambia, Zimbabwe, etcetera have benefited from Remote sensing technology (Neuville G. et al., 1995 and Surell, 1987).

2.2.1.2 Mapping water hyacinth using satellite imagery

The chlorophyll in vegetation gives a characteristic spectral signature that enables vegetation to be easily separated from other objects (Jensen 1996). The chlorophyll in healthy green vegetation reflects a strong spectral signal in the near infra red band (NIR), (Jensen, 1996). Everitt et al., (1999) used Remote Sensing and spatial information technologies to study the light reflectance characteristics of water hyacinth, associated plant species and water in water ways in Southern Texas, United States of America. Field reflectance measurements showed that water hyacinth generally had higher NIR reflectance than associated vegetation and water. Some measurements were made on the Rio Grand River near Brownsville, a pond near San Benito and the Atascosa River near Pleasanton. Table 2.4 shows some summary results from the study. As can be seen from the study, water hyacinth generally shows higher NIR reflectance than associated species (Everitt et al., 1999). This strong reflectance facilitates the use of satellite images when monitoring the spread of water hyacinth.

Table 2.4 Mean Light Reflectance of some plant species and water in three wavelengths.

Date	Plant species or water	Reflectance (%) for three wavelengths		
		Green	Red	NIR
July 1998 Rio Grand River, Brownsville	Guinea grass	5.9	3.8	31.8
	Hydrilla (surface)	3.5	2.1	16.2
	Water stargrass	7.3	5.9	20.0
	Water hyacinth	4.9	2.3	43.2
	Deep water (>1.0 m)	2.0	0.8	0.5
	Shallow water (<0.3 m) (Clear)	3.2	1.8	2.3

September 1998 Rio Grand River, Brownsville	Guinea grass	6.1	4.0	30.4
	Hydrilla (surface)	3.0	2.1	17.9
	Water hyacinth	4.0	1.7	40.6
	Deep water (>1.0 m)	1.2	0.6	0.4
	Shallow water (<0.3 m) (Clear)	4.3	3.2	1.5
June 1998 A pond near San Benito	Bermuda grass	5.4	3.2	31.4
	Water hyacinth	5.1	2.4	41.7
	Water (Turbid)	6.4	3.7	2.1
June 1998 Atascosa River, Pleasanton	Bermuda grass	7.7	5.8	31.5
	Black willow	6.2	4.0	43.5
	Water hyacinth	5.5	2.4	47.0
	Water (Turbid)	4.4	2.5	2.8
September 1998 Atascosa River, Pleasanton	Bermuda grass	5.9	4.6	26.6
	Black willow	6.0	3.0	38.3
	Water hyacinth	5.0	2.0	43.1
	Mixed herbaceous species	6.2	3.8	32.7
	Water (Turbid)	6.3	4.9	3.1

Source: J. Aquat. Plant Manage. 37:1999

Surell (1987) mapped shore vegetation types on the Zimbabwean side of Lake Kariba using Landsat MSS Satellite images. Two major vegetation types (*Panicum repens* and *Cyperus-Polygonum*) were distinguished in the satellite images and mapped. Their area extent was also calculated. The rocky shores were too narrow to be distinguished with the resolution used. Where no shore zone was detected, rocky shore with a width of 20m was presumed. The two major vegetation types covered 8 300 hectares. Imagine what panic this would cause if it were classified as weed on the Kariba. In this study, there was no mention of using GPS for ground truthing as well as the method used to assess the accuracy of the results obtained. The resolution of images used, Landsat MSS, is too low for monitoring weed coverage on Lake Kariba. There are also many pixels in the draw down zone between pure water and near shore vegetation that were not classified. Since these pixels appear to have the same signals as those on land, it gives an impression that Surell may not have known how to differentiate vegetation on water from near shore vegetation.

Denconsult (1998) in a pilot project demonstrated the possibility of mapping water hyacinth on Lake Kariba's Eastern Basin using SPOT satellite images.

In search of a lasting solution to the weed problem, ZRA with financial assistance from the Swedish International Development Agency (Sida) contracted Martin Hill (2001) from the Plant Protection Institute who drew up the Integrated Water Hyacinth Management Plan for the Authority. The integrated management plan for water hyacinth monitoring on Lake Kariba requires a Remote sensing/GIS-expert to interpret Satellite images and monitor the coverage of water hyacinth. However, Hill did not delve into the details of how satellite images would be interpreted and used to monitor the coverage of the weed. How often and at what time of the year satellite images would be acquired were not spelt out. Besides, this plan is based on monitoring the status of plant populations through morphological measurements such as the number of leaves, length of petiole, etc. It emphasises monitoring the health of individual plants. His own assessment of the weed coverage was by visual observation. This notwithstanding, Hill was right when he recommended the use of Geographic Information systems and Remote Sensing to monitor the coverage of water hyacinth.

In April, 1995 and with French Technical Assistance, a pilot project was carried out in Uganda where the distribution of water hyacinth on Lake Kyoga was mapped using satellite imagery (Neuville et al., 1995). This pilot project used a four phased methodology as follows: Phase 1 (Satellite imagery acquisition), Phase 2 (Ground truthing survey), Phase 3 (Image pre-processing) and Phase 4 (Final classification). The project used SPOT IMAGE 129/347 from March 1994, which was orthorectified (Level 2B) in order to obtain a map compatible image of the study area. Global positioning system (GPS) receivers were used to accurately position samples on the image. A radiometer was used to measure and discriminate radiometric responses of different objects (Papyrus, hyacinth, etc.) within the 3 wavebands used by the SPOT satellite. To facilitate the visual analysis of the aquatic and neighbouring environment, the basic image was enhanced by elaborating a colour composite with 3 planes, namely: Vegetation Index, Brightness Index and XS2 Band. On the resulting image both clear water and dry land were then masked using numerical and manual methods.

In order to avoid obvious confusion on the image, of the Hyacinth itself with the miscellaneous plants growing on the banks of the lake, the image was subdivided into two parts, using a threshold value within the Brightness Index plane. The two parts the image were then classified separately. One showing the more active aquatic plants in terms of photosynthesis (active papyrus, water hyacinth) while the second shows less active vegetation (old papyrus, mixtures etc.). The final classification is an addition of the two intermediate pre-classifications. From the classification, 1 545 ha were found to be occupied by water hyacinth on Lake Kyoga. Satellite images have therefore proved to be useful tools when monitoring and evaluating the spread of water hyacinth (Neuville et al., 1995; Denconsult, 1998; Everitt et al., 1999).

Satellite images can be used in a variety of ways to help monitor the quality, quantity and geographic distribution of water resources. Satellite images are also widely used in environmental applications.

2.3 Geographic Information System (GIS)

GIS is a system of hardware, software and procedures designed to support the capture, management, manipulation of data for solving complex planning and management problems (Bernhardsen, 1992). GIS comes into this study because of the spatial distribution of water hyacinth on Lake kariba.

There are five generic questions a GIS can answer. The first of these questions seeks to find out what exists at a particular location (what is at...?). The second question (where is it?) is a converse of the first, requiring spatial analysis to answer, seeks to find for example a location where certain conditions are satisfied. The third is a question of trend analysis (what has changed since...?) while the fourth deals with spatial patterns (what spatial patterns exist?). One might ask the latter question to determine whether malaria is the major cause of death of workers in lodges near water hyacinth infestations. The fifth question concerns modelling scenarios (what if...?) (ESRI, 1990). Data quality and integration, however, pose great challenges for any GIS.

Many scientists feel that the real utility of both GIS and remote sensing can best be achieved if the technologies are integrated (Jensen, 1989; Dobson, 1993). In the long term, the real utility of remotely sensed data is intimately related to whether it can be

associated with other spatial information, usually stored in a GIS format (Hutchinson, 1982; Davis and Simonett, 1991). It is not a unidirectional relationship, however. Information derived from remotely sensed data can be used to correct, update, and maintain cartographic databases and geographic information systems (e.g., Nellis et. al., 1990; Erkhhardt et. al., 1990; Ehlers et. al., 1991).

GIS can be applied in many practical ways; water resources management, flood, search and rescue management inclusive. As part of the National Flood Insurance Program (NFIP), the Federal Emergency Management Agency (FEMA) manages and updates an estimated 100,000 flood insurance rate maps (FIRMs), most of which are more than five years old and do not reflect recent developments in flood plains. FEMA also supervises the more than 19,000 communities that currently participate in the NFIP and responds to participant's inquiries and letters requesting changes to FIRMs. To improve this process, PBS&J (a company was contracted to manage, develop and expand FEMA's flood map data) and FEMA implemented a comprehensive, accessible GIS that would not only allow analysts to more efficiently respond to the growing number of customer requests but also make flood data more accessible to those inside and outside FEMA (Smith and Price, 2002).

On March 2, 2002, members of a South African Rescue Organization were participating in a simulated sea recovery drill in Table Bay, an area northwest of Cape Town, when fog suddenly rolled in, enveloping the three teenagers who had volunteered to act as survivors of an airplane crash. When rescuers were unable to quickly locate the trio, the drill quickly became a real-life emergency. Just short of 90 minutes later, the three survivors were pulled from the icy Atlantic waters. The incident not only demonstrated the value of a newly developed GIS-based sea search and rescue application but also helped refine its functionality. As part of the exercise-turned-emergency, personnel used RescueView, an ArcView 3.2 application, to identify the last known location of the survivors, track rescue craft, and explain the event to the media (Pratt, 2002).

The combination of GIS and Remote sensing to monitor water hyacinth coverage on Lake Kariba is an economic measure that can contribute to mitigating the impacts of the water hyacinth on this water resource. This falls in line with the third area of the IWRM toolbox: water resources assessment, demand management, public information and education, conflict resolution, regulatory devices, economic measures, information and communication (GWP, 2002).

The role of GIS in this study was to map GPS data from the ground truthing surveys, visualize, analyze and display the results of weed monitoring. It was also used as a database management system.

CHAPTER 3 – DESIGN OF MONITORING PROCEDURE

3.0 Introduction

Physical observation, mapping using Global Positioning System (GPS) receivers and use of planimeters are the methods which have been used to monitor the spread of water hyacinth on Lake Kariba. Based on these methods, the water hyacinth coverage was estimated in hectares at various times. The results obtained were limited since some areas are not accessible by boat while weed mats are not always stationary due to the influence of wind and water current. Aerial surveys were undertaken in isolated cases while mapping using satellite imagery was done on pilot basis.

This study has designed a formal procedure that can easily be implemented to monitor the spread of water hyacinth on Lake Kariba using Remote Sensing and GIS. The conceptual model designed is generic and can be adapted by any implementor depending on the software available. The software used are Idrisi 2.0 for Remote Sensing and ArcView GIS 3.2a as set out in the project proposal.

3.1 The Conceptual model procedure

The designed procedure is a four step process that aims at coordinated water hyacinth monitoring. This would involve data acquisition, processing, satellite image classification and analysis. The output of the previous step will be the input of the next one. The results would then be produced as a map layout showing weed occurrence and spread in both soft and hard copy format. Figure 3.1 below is an activity diagram of the model procedure for monitoring the distribution of water hyacinth. The purpose of an activity diagram is to model the procedural flow of actions (Be 1, 2003) that form the monitoring procedure. The activity diagrams in this study are based on the Unified Modelling Language (UML) Version 2.0. The UML is the standard language for specifying, visualizing, constructing and documenting all artifacts of a software system (Quatrani, 2003). UML is a standard design language in software and business process engineering.

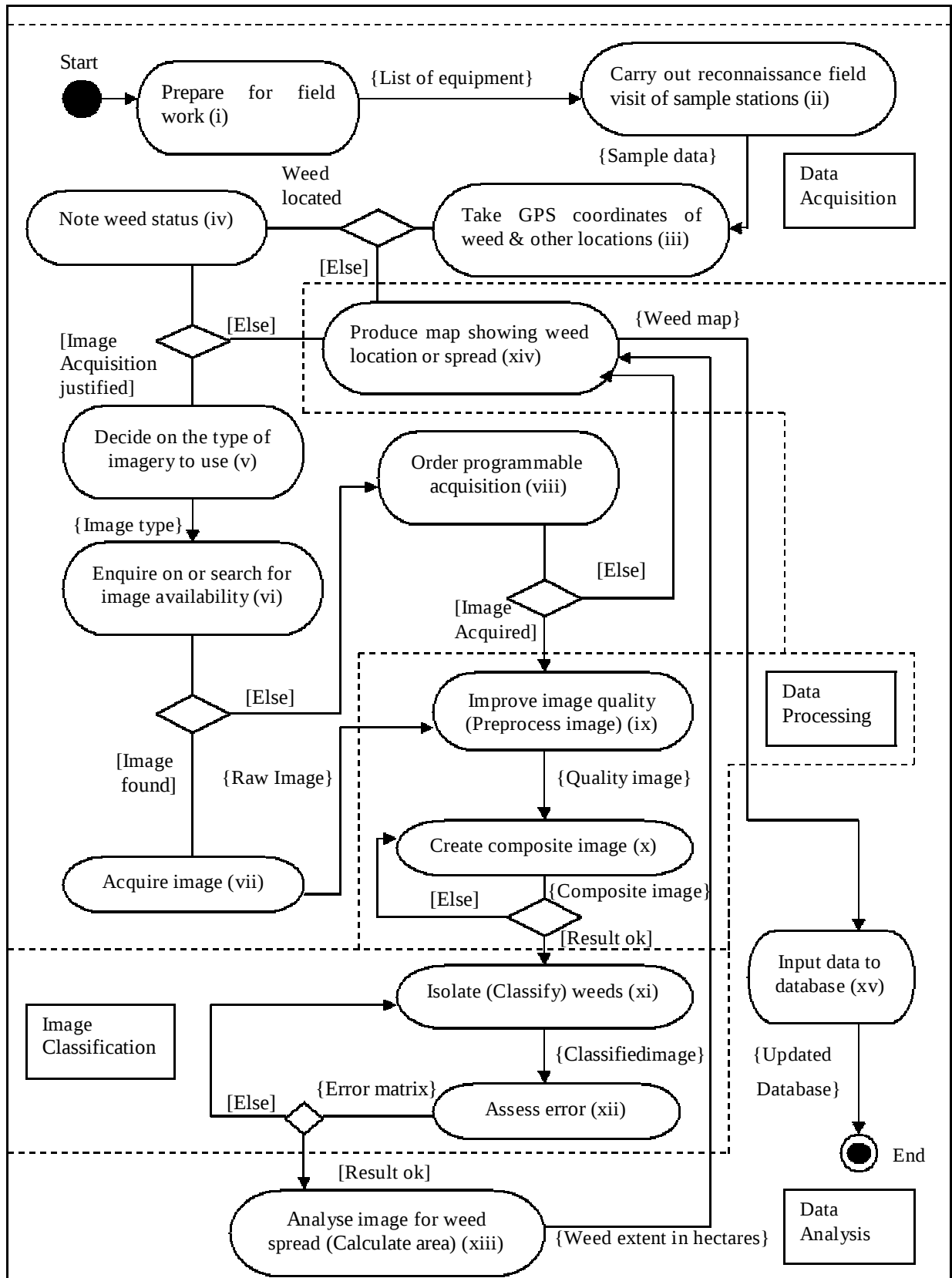


Figure 3.1: Activity diagram for the monitoring procedure

3.1.1 Data acquisition

(i) Prepare for fieldwork

Fieldwork should consist of reconnaissance surveys (by road and boat) and interviewing stakeholders. Prior to fieldwork activities, thorough preparation should be done. The issues to consider during preparation are as follows:

(a) Constitute Field Crew

The Field Crew should first be constituted to enable preparation and actual fieldwork to be undertaken successfully. The team could comprise of at least four people as detailed in Table 3.1 below.

Table 3.1: Field Crew Composition

Title	Responsibility	Number
Team Leader	Overall responsibility	One
Assistant	To carry out work as delegated by the Team Leader	One
Coxswain (Boat Captain)	Responsibility over the House and Speed Boats. This is required for some sites to be visited during reconnaissance surveys that are easily accessible by boat.	One
Boat attendant	To assist the Coxswain.	One

It is worth noting that all crew members should have valid passports and at least one of them having a valid Southern African Development Cooperation (SADC) Driving license.

(b) Undertake background research

Background research to assess water quality data and information on previous water hyacinth occurrence is necessary. This will enable proper planning and choosing of areas where field visits would be done. An assessment of cloud cover and weather forecast should also be considered. This is necessary when selecting

actual dates for surveys because storms can cause havoc during boat or aerial surveys.

(c) Decide on sites to visit

This decision should be taken before setting out for field work. It would determine the type of equipment required (e.g. whether both the Houseboat and speed boat would be needed or either).

(d) Forecast weather

Stormy times can be hazardous on Lake Kariba. Cloudy can also affect the capture of satellite images by optical sensors. Forecasting the weather can help in scheduling field work for days of bearable conditions. The weather forecast information can be obtained from the Zambian and Zimbabwean Meteorological Departments.

(e) Schedule ground truthing

The GPS receivers will be used to accurately position weed and other locations as a way of ground truthing. Ground truthing should be scheduled to coincide with image acquisition by checking the image acquisition calendar for the respective satellite. This is necessary when programmable acquisition of satellite imagery is under consideration.

The Landsat acquisition calendar can be accessed via the internet ([http://landsat.usgs.gov/technical_details /data_acquisition](http://landsat.usgs.gov/technical_details/data_acquisition)). For Spot, enquiries can be sent to sales@Spotimage.com.

(f) Secure equipment

The team should also secure the necessary equipment required for field work in time. Table 3.2 gives the list of necessary equipment.

Table 3.2: List of field equipment

Type	Number
Water hyacinth monitoring form	One for each site
Lake Kariba charts (Scale 1:100 000)	Three
Maps of Lake Kariba (for sketching weed spread)	One for each site
Binoculars	One
Rule	One
Scale	One
Boat accessories	Lot
Life saving Jackets	Atleast four
Sun screen (Sun burn prevention cream)	Lot
Digital camera	One
Pencils	Atleast two
GPS Receivers	Atleast two

(g) Schedule stakeholders' interviews

It is also necessary to contact stakeholders to schedule interviews in advance. The interviews need to be brief and centered on the occurrence and proliferation of water hyacinth on the Lake as the subject matter.

The following are among the stakeholders relevant to weed monitoring:

- National Parks and Wildlife Authorities, Kariba
- University Lake Kariba Research Station (ULKRS)
- Department of Fisheries, Zambia
- Environmental Council of Zambia
- Crocodile Farm, Kariba
- Mulibizi Hotel
- Landela Lodge,
- Hotel and Lodge Operators
- Kariba Municipality

- Binga Municipality
- Siavonga District Council
- Sinazongwe District Council
- Fishermen

The list above would have to be updated as and when necessary. There is also need for a memorandum of understanding with all the stakeholders to facilitate easy exchange of data.

(h) Secure cross-border permission

Since Lake Kariba lies on the border area, permission for boat access to cross-border areas should be secured in advance from the relevant Immigration Authorities. For sites where ground truthing has to be undertaken by road, other immigration formalities such as temporal export of vehicle permit and clearance of the same by International Police (Interpol) should be prepared for in advance. Authority to temporarily export the field equipment should be sought at boarder crossing. This implies that all the serial numbers of the field equipment should have been taken prior to the field work exercise.

Figure 3.2 summarizes the preparation required prior to reconnaissance survey using the Unified Modeling Language (UML) 2.0.

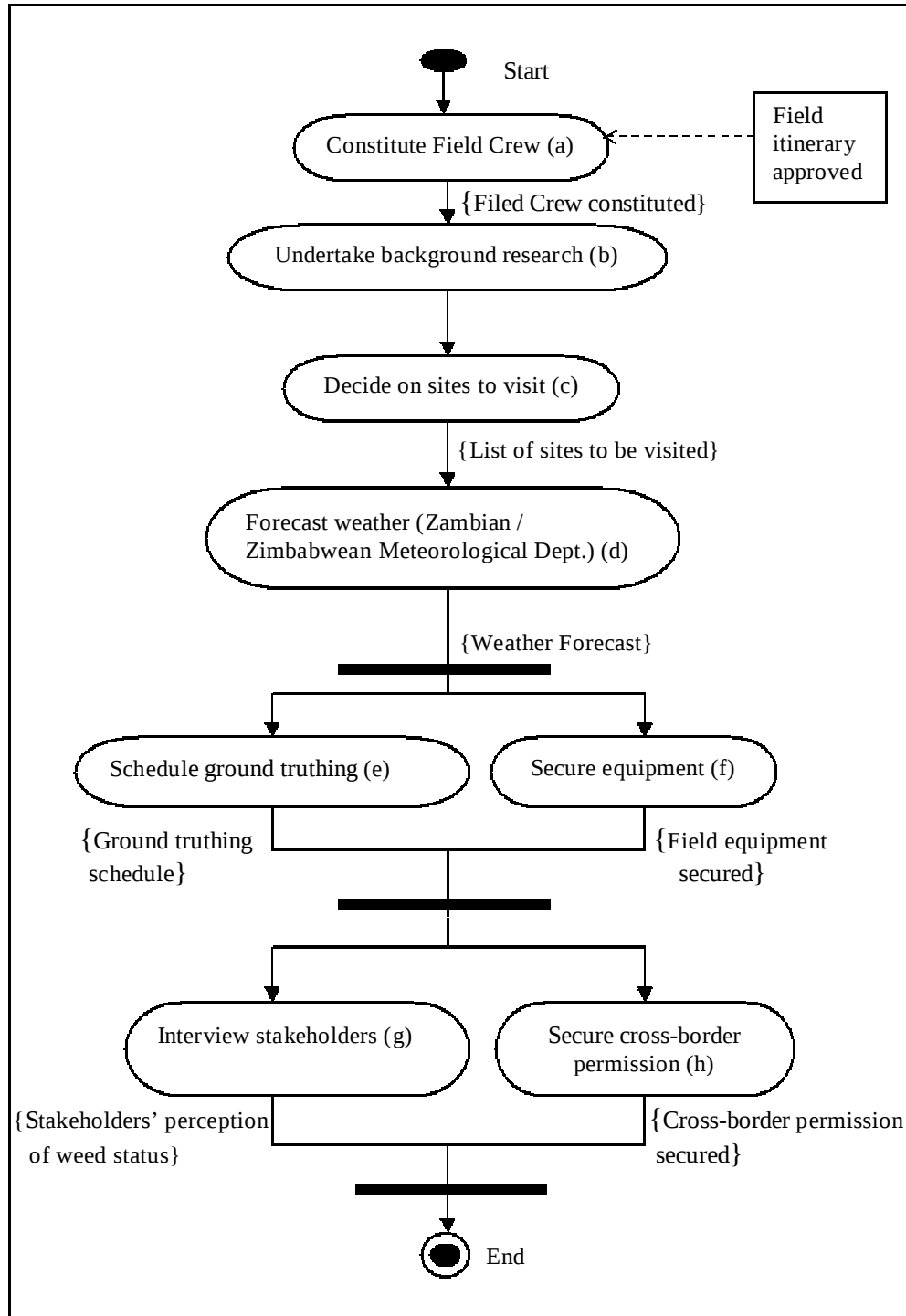


Figure 3.2: Pre- reconnaissance survey preparation activity diagram

(ii) Carry out reconnaissance field visit of sample stations

This survey is required for site familiarization. It would enable the field crew to understand what obtains at the site before taking GPS coordinates and measuring weed parameters.

(iii) Take GPS coordinates of weed and other locations

The GPS coordinates of weed and other locations are required for future reference. They are also needed for ground truthing satellite images. These coordinates should be recorded on the monitoring form for each site (Table 3.3). The coordinates can also be saved on the GPS receiver and downloaded on a computer. This would be applicable where the user has knowledge of the software to be used. The coordinates can be taken using any GPS by the field crew. The Garmin GPS 28 model is sufficient although the E-trex series would be preferable for this purpose as it indicates the accuracy with which any coordinate is taken.

(iv) Note weed status

The status of the weed on site should be noted on the water hyacinth monitoring form. Table 3.3 is a sample of the water hyacinth monitoring form that must be completed during fieldwork. The form consists of enumerator, site description, weed description, weed location and provision for logging photographs taken in the field. The physical parameters to be measured are meant to monitor the growth pattern of the weed.

Table 3.3: Sample water hyacinth monitoring form

ENUMERATOR					
Collection date (mm/dd/yyyy)					
Observer's name					
Observer's contact information		Address:			
		City:		Country:	Post code:
		Phone:			
		Email:			
Source of the data		Organization name:			
SITE DESCRIPTION					
Site name				Site ID:	
Province					
Country					
Land use type		? Ag ? Rangeland Rural Res. ? Urban ? Indust/Comm. ? Other			
Invaded vegetation type		? Forest ? Woodland ? Shrub ? Grass			
WEED DESCRIPTION					
Weed genus and species					
Presence or Absence		Present ? Absent (Not sighted)			
Infested area		Area: m ² acres ha			
Canopy Cover		Choose one: ? <1% ? 1-5% ? 5-25% ? 25-50% ? 50-75% ? 75-95% ? 95-100%			
Appearance/ phenology		? Germinating/ early growth ? New growth ? Flowering ? Seeding ? Senescence ? Dead			
Distribution pattern Circle any:		? Thick mats ? Free floating patches ? Fringe along the shore line			
Weed Status		Maximum root length (cm):		Maximum petiole length (cm):	
		Wet weight (g):		No. of ramets:	
		No. of flowers:		No. of Leaves:	
WEED LOCATION					
Geo Feature type		Circle one: Point Polygon Line			
Geographic location		GPS waypoint or feature no:			
		Coordinates. (if point): X:		Y:	
Coordinate system		? UTM Zone 35s ? Lat/Long decimal degrees ? Other (specify):			
Datum		? WGS 84 ? Other (specify):			
Location data accuracy		? <1m ? 1-5m ? 5-15m ? 15-100m ? 100m-1km ? 1km-10km ? >10km			
PHOTO LOG					
Photo No.	GPS waypoint or feature no.	X Coordinate	Y Coordinate	Site ID	Comment
NOTES					

The water hyacinth monitoring form should be attached to a hand-drawn map with the date, observer's name, and the site and feature numbers written thereon for easy cross-referencing.

(v) Decide on the type of imagery to acquire

The focus is now on high resolution satellite imagery, for example Spot and Landsat, that have been tested on Lake Kariba. Landsat has been more consistent in capturing Lake Kariba than Spot. All image data acquired by the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) (http://landsat.usgs.gov/technical_details) from July 14, 2003 to present (excluding a two-week interval from 9/3/03 to 9/17/03) have been collected in Scan Line Corrector (SLC)-off mode. The total loss of image data has been estimated to be approximately 22 percent over any given scene. The maximum width of the data gaps along the edge of the image (or duplicated data, in the case of Level 0 Reformatted (L0Rp) and Level 1 Radiometrically Corrected (L1R)) would be equivalent to one full scan line, or approximately 390 to 450 meters. The precise location of the missing scan lines will vary from scene to scene.

The primary difference between an SLC-off Landsat 7 product compared to data collected prior to the anomaly will be the presence of duplicated data in the SLC-off image for L0Rp and L1R data. In the case of a L1G product, the United States Geological Survey (USGS) processing systems use a variety of methods to replace the duplicated image data. This disadvantages it when acquiring new images for features that can change position like water hyacinth. Hence Landsat could be given attention when considering images archived before May 2003. Further, other imagery like ASAR, Radarsat, etc should be tested as resources become available.

(a) Satellite sensors

Satellite sensors could either be passive or active imaging systems (Business Image Group and SPOT Image Corporation, 1998). Passive imaging systems produce

panchromatic, multispectral or hyperspectral imagery. Panchromatic imagery is acquired by a digital sensor that measures energy reflectance in one wide portion of the electromagnetic spectrum. Panchromatic data is represented as black and white imagery. Multispectral imagery is acquired by a digital sensor that measures reflectance in many bands. These multiple reflectance values are combined to create color images. Current multispectral remote sensing satellites measure reflectance in three to fifteen different bands at once. Hyperspectral imagery is acquired by a spectral sensor that measures reflectance in many individual bands, often hundreds.

Synthetic Aperture Radar (SAR) sensors are active imaging systems. SAR imagery conveys feature information that is different in some ways from the spatial and spectral details of electro-optical imagery. Because SAR is active and operates in longer wavelengths than electro-optical systems, it can acquire images through clouds, fog, haze and darkness. SAR imagery is used in some of the same applications as electro-optical sensors but has several specific uses in which it excels.

Both Landsat and Spot satellites fall in the category of passive imaging systems. They are only able to capture panchromatic and multispectral imagery. Multispectral imagery offers better visualisation capabilities for weed monitoring than panchromatic images. However, radar images have to be explored as one would almost be guaranteed availability during the cloudy weather in rain season.

(b) Spatial resolution

The spatial resolution of satellite imagery has improved with advancement in technology. The spatial resolution to use would depend on the accuracy level required to monitor the spread of water hyacinth.

Landsat 7 has the following spatial resolution (http://landsat.usgs.gov/technical_details);

- 15m panchromatic band
- 30m multispectral bands one to five and seven and
- 60m thermal band (six)

Spot 5 has the following spatial resolution (<http://www.spotimage.com>);

- 5m panchromatic band
- 2 panchromatic (5m) combined to generate a 2.5m product
- 10m multispectral (bands one to three) and
- 20m shortwave infrared (band four)

Spot 4 has the following spatial resolution;

- 10m panchromatic band
- 20m multispectral (bands one to three) and
- 20m shortwave infrared (SWIR) (band four)

If the weed spread justifies the use of Landsat, then the 30m multispectral bands should be used for easy discrimination spectral signatures. For Spot, the 10m multispectral bands of Spot 5 or 20m multispectral bands of Spot 4 should be the relevant choices.

(c) Spectral bands

Reflectance measurements in various wavelengths reveal specific information about ground features (http://landsat.usgs.gov/resources/remote_sensing). It should be noted that single bands are seldom used alone but typically three-band combinations. The Landsat Enhanced Thematic Mapper Plus (ETM+) captures data in eight spectral bands, including a pan and thermal band (http://landsat.usgs.gov/resources/remote_sensing):

- Band 1 Visible (0.45 – 0.52 μ m) 30m
- Band 2 Visible (0.52 – 0.60 μ m) 30m
- Band 3 Visible (0.63 – 0.69 μ m) 30m
- Band 4 Near Infrared (NIR) (0.76 – 0.90 μ m) 30m
- Band 5 NIR (1.55 – 1.75 μ m) 30m
- Band 6 Thermal (10.40 – 12.50 μ m) 60 m Low Gain / High Gain
- Band 7 Mid IR (2.08 – 2.35 μ m) 30m

- Band 8 Panchromatic (PAN) (0.52 - 0.90 μ m) 15m

Landsat scientists (http://landsat.usgs.gov/resources/remote_sensing) confirm that most of the information required for vegetation mapping is captured in the spectral range using bands 3, 4 and 5. As can be seen from Figure 3.3 most of the information required to monitor green vegetation is captured between 0.6 μ m to 1.75 μ m both wavelengths inclusive.

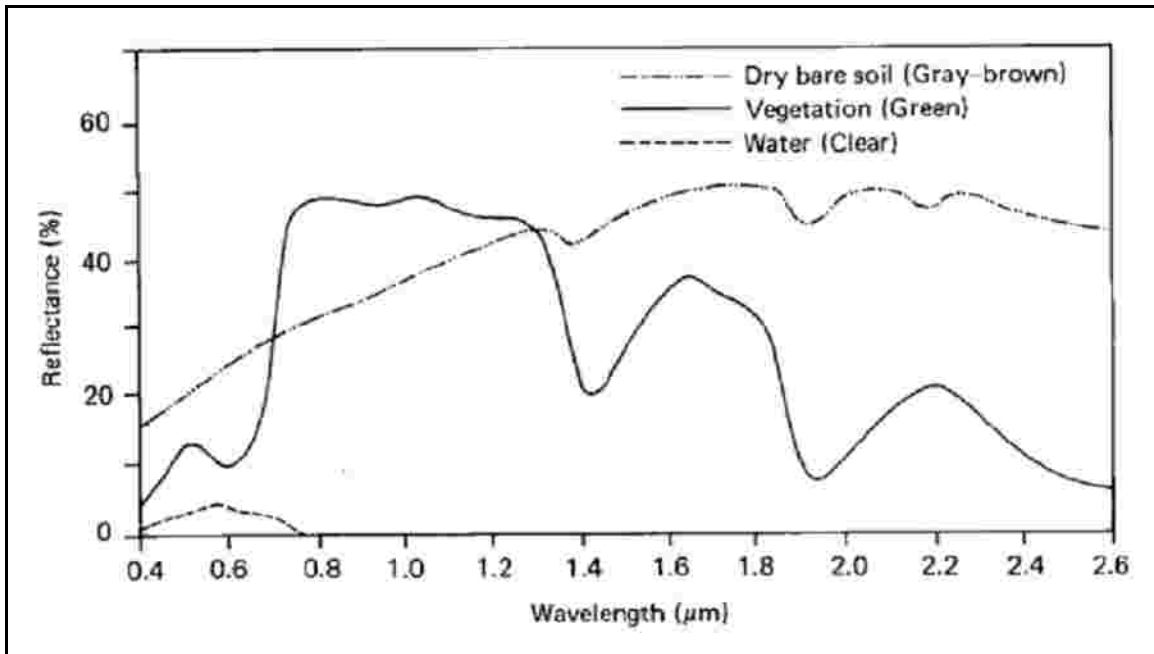


Figure3.3: Generalised spectral signatures of soil, vegetation and water

Source: http://geog.hkbu.edu.hk/virtuallabs/rs/env_backgr_refl.htm

Spot 5 captures data in five spectral bands (www.spotimage.com).

- Panchromatic Band (0.48 – 0.71 μ m)
- Band 1 (green) (0.50 – 0.59 μ m)
- Band 2 (red) (0.61 – 0.68 μ m)
- Band 3 NIR (0.78 – 0.89 μ m)
- Band 4 SWIR (1.58 – 1.75 μ m)

Spot 4 captures data in five spectral bands (<http://www.spotimage.com>).

- Panchromatic Band (0.61 – 0.68 μ m)
- Band 1 (Visible green) (0.50 – 0.59 μ m)
- Band 2 (Visible red) (0.61 – 0.68 μ m)
- Band 3 NIR (0.78 – 0.89 μ m)
- Band 4 SWIR (1.58 – 1.75 μ m)

Bands 1, 2 and 3 are to be used for Spot unless band 4 is available in which case different band combinations can be tried. It must also be noted that the spatial resolution for band 4 is 20m and the effect it can have on the colour composite when used with other bands of different and higher resolution needs to be examined.

(d) Choosing between Archived and New Imagery

Old satellite images also have significant value and are applied extensively in change detection studies (Business Image Group and SPOT Image Corporation, 1998). This is where the old images are compared with newer ones to detect that have changed over time. This is also applicable to weed monitoring when conducting trend analysis (change in weed spread over time).

(e) Sizes

Landsat images only have the size 185 km x 185km. Depending on the surface of the area to be studied. Spot scenes are available in the following sizes:

- § **Full scenes:** 60 km long x 60 to 80 km wide, according to the view le.
- § **Scene extracts** (2.5 m and 5 m in black and white and 10 m in colour):

Scene extracts cover a floating area within a Spot scene and the size depends on the viewing angle (<http://www.spotimage.com>).

§ A 1/2 scene covers an area of 40 km x 40 km

§ A 1/4 scene covers an area of 30 km x 30 km

§ A 1/8 scene covers an area of 20 km x 20 km

One full Spot image is required to cover the Eastern Basin whereas six images the whole Lake. Landsat captures the Eastern Basin and the whole Lake on one and three images respectively.

(f) Pricing

Landsat images available in black and white and colour are currently free although the cost was US\$450 per scene as at February, 2008. An image that had already been purchased by another client could still be purchased at US\$45 per scene in the same year. Spot scenes are also available in black and white (B&W) and colour. The current prices of archived and programmed products are reflected in Tables 3.4 and 3.5 respectively.

Table 3.4: Prices of archived Spot products

	Standard images - Levels 1A and 2A (2005 – to date)				Full scene old archive 1986-2004 inclusive
	Full scene	½ Scene	¼ Scene	1/8 Scene	
20 m colour	€1,900	-	-	-	€1,200
10 m B&W					
10 m colour	€2,700	€2,025	€1,350	€1,020	-
5 m B&W					
5 m colour	€5,400	-	-		-
2.5 m B&W					
2.5 m colour	€8,100	-	-	-	-

Source: <http://www.spotimage.com>

Table 3.5: Prices of Spot Programming Service

	Standard Programming Service - Levels 1A and 2A (2005 – to date)				Priority programming service (subject to feasibility)
	Full scene	½ Scene	¼ Scene	1/8 Scene	
20 m colour	€2,700	-	-	-	↑ + €3,100 ↓
10 m B&W					
10 m colour	€3,500	€2,825	€2,150	€1,820	
5 m B&W					
5 m colour	€6,200	-	-		
2.5 m B&W					
2.5 m colour	€8,900	-	-	-	

Source: <http://www.spotimage.com>**(g) Formats**

Two formats exist for Spot images;

- The **DIMAP format**, which stands for Digital Image Map, is the Spot product data format introduced in mid-2002 for the launch of the new Spot 5 satellite. DIMAP was developed in partnership with Centre National d'Etudes Spatiales (CNES), the French space agency (<http://www.spotimage.com>).
- The **CAP format**
Spot Scene products derived from Spot 1 to 4 can be supplied on request in the CAP format, CEOS standard compliant.

The DIMAP format is a public format for describing geographic data. Although it was specially designed for raster (image) data, it can also handle vector data. Spot products in DIMAP format now consist of two parts, one for the image and the other for a description of the image (metadata).

Image: By default it is described in GeoTIFF format consisting of:

- A **TIFF part**, as TIFF is the most widely used image format in the world, recognized by all software on the market and easily integrated.
- A **Geo part**, recognized by all geographic information processing software. It adds georeferencing information for the image file (coordinates in the upper left-hand corner of the image and pixel size) to the basic TIFF file and may also describe the map projection used and its corresponding geographic system.

Metadata: This is written in Extensible Markup Language (XML). XML, similar to Hypertext Markup Language (HTML), is more highly structured and allows users to create their own keywords with their corresponding values.

Landsat images (http://landsat.usgs.gov/resources/remote_sensing) are delivered in three output formats. The options are [GeoTiff Format](#), Fast L7A and [Hierarchical Data Format](#)

- The [GeoTiff Format](#) (GEO)

GeoTiff defines a set of public domain ([TIFF](#)) tags that describe all cartographic and geodetic information associated with geographic TIFF imagery. GeoTiff is a means for tying a raster image to a known model space or map projection and for describing those projections. A metadata format provides geographic information to associate with the image data, but the TIFF file structure allows both the metadata and the image data to be encoded into the same file. The GeoTiff file is grayscale, scanline, uncompressed, and 8-bit unsigned integers (TM, ETM+ and ETM+ SLC-Off only).

- The **FastL7A format** (FSTL7)

Geometrically and radiometrically corrected ETM+ products are provided in the FastL7A format, which has each band self contained in its own file (i.e. external element style). The delivered Landsat data will consist of binary (8-bit, unsigned

integer, unblocked) image files in band sequential (BSQ) format, along with three separate image header files, each containing three records (administrative, radiometric, and geometric). Sensor specific information is placed in the administrative record, gains and biases can be found in the radiometric record and projection information and image coordinates are stored in the geometric record (ETM+ and ETM+ SLC-Off only).

- The [Hierarchical Data Format](#) (HDF)

HDF is a library and multi-object file format for the transfer of graphical and numerical data between machines. The HDF software is developed and supported by the National Center for Supercomputing Applications (NCSA). 4.1r4 is the HDF version currently used for Landsat products (ETM+ ETM+ SLC-Off only).

The purchaser should specify the format of imagery required depending on the capabilities of the processing software to be used.

(h) Media:

Satellite imagery is sold either as digital image files or in hardcopy formats. Spot images are supplied on CD-ROM, DVD or by File Transfer Protocol (FTP). The same is applicable to Landsat. It would be recommendable to purchase the images on CD- ROM or DVD to avoid the internet problems that would be encountered when downloading via FTP.

(vi) Enquire on or search for image availability

Enquiries on the availability of satellite imagery can be made by either contacting the dealer directly (through e-mail, fax or telephone) or searching the image archives. Many satellite operators now have archives that are searchable via the Internet. Search parameters can be limited by geographic area (Specify top left and bottom right coordinates of area of interest - Table 3.6), date range and cloud cover content.

Table 3.6: Coordinate list for Lake Kariba

Area		Latitude (South)	Longitude (East)
Eastern Basin	Top left corner	16° 30'	28° 40'
	Bottom right corner	16° 50'	29° 05'
Whole Lake	Top left corner	16° 30'	28° 40'
	Bottom right corner	18° 00'	29° 05'

Many search engines allow previewing on screen a sub-sampled image of the scene before it is bought. Orders can be placed online if one likes the image. While in developed countries one may be able to pay for and download a full image over the Internet, many developing countries are yet to benefit from this technological advancement as resources become available. However, the scenario is changing in cases where fast internet connections and download accelerator programmes are available. The Landsat archive is accessible through the clickable map on the internet (<http://landsat.org>) or inquiries can be sent direct to custserv@usgs.gov. For Spot, the Sirius online catalogue can be accessed through the site <http://www.csir.co.za> or inquiries can be sent direct to sales@Spotimage.com.

(vii) Acquire image

The image acquisition procedure as summarized in Figure 3.4 below could be followed.

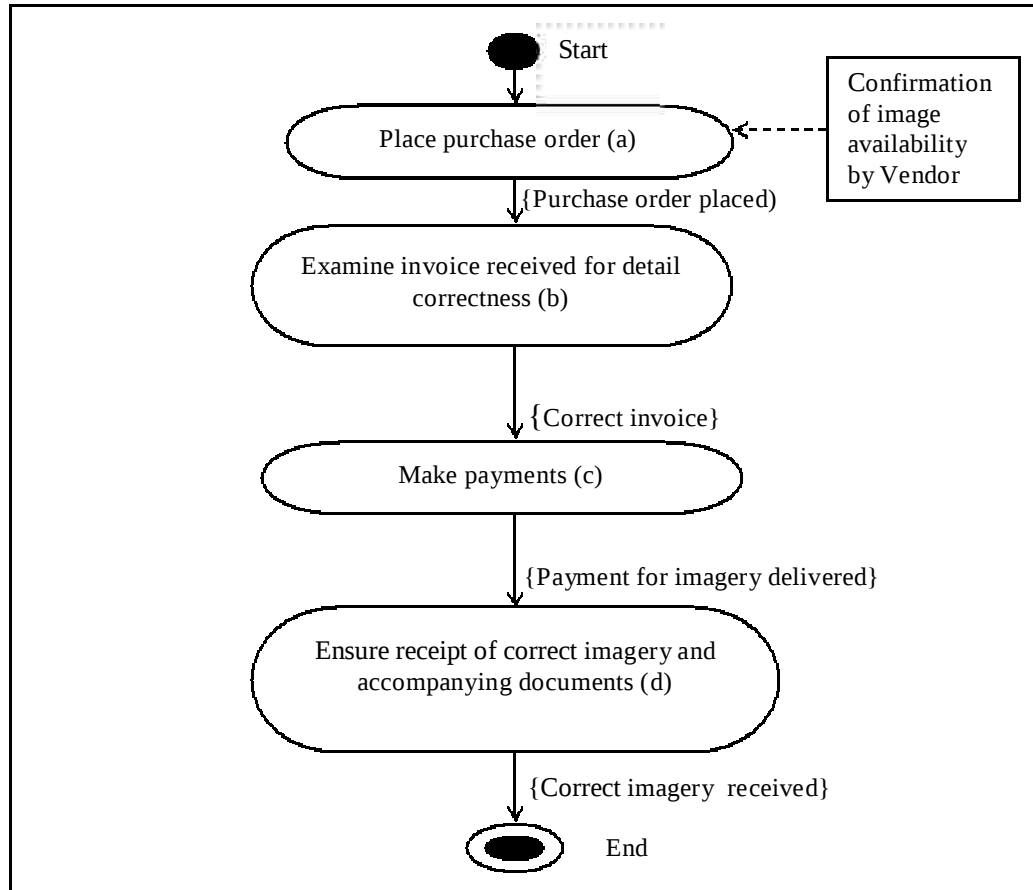


Figure 3.4: Image acquisition activity diagram

(a) Place purchase order

When image availability is confirmed by the Vendor, a purchase order can then be placed. The purchase order should specify the type of image, preprocessing level, spatial resolution, spectral resolution (sensor type), size, format and media required.

(b) Examine invoice received for detail correctness

Ensure invoice received is according to order placed or else corrections should be made before effecting payments.

(c) Make payments

The mode of payment required as well as Bank details of the Supplier are specified on the invoice. Payment can be through Bank transfer or draft.

(d) Ensure receipt of right imagery and accompanying documents

Ensure receipt of right imagery and check accompanying documents for necessary information. The information required is as follows:

- image format
- number of bands
- size of the header file
- number of columns
- number of rows,
- bits per pixel per band
- minimum X coordinate,
- maximum X coordinate,
- minimum Y coordinate,
- maximum Y coordinate,
- reference system (utm 35s for Lake Kariba),
- reference units (meters).

(viii) Order programmable acquisition

Where a satellite image required can not be found in the archive, a programmable acquisition can be ordered. It has to be noted here that programmable acquisition is available with Spot (<http://www.spotimage.com>) and not Landsat. The customer can request a Programming Request Form and duly complete it before sending back to the dealer. After analysing the Programming Request parameters, Spot Image will send a Programming Proposal to the Customer. Once the parameters defined in the proposal are approved, the customer is contractually bound to purchase the products corresponding to all requested scenes successfully acquired by the satellite.

The following are the parameters required when applying for programmable acquisition:

(a) Programming service

- **Standard programming service**

This option allows for requesting specific image acquisitions if the image needed cannot be found in the catalogue. It is particularly suited to applications that do not require images to be acquired within specific time windows or at extreme viewing angles.

- **Priority programming service**

This option guarantees high-priority image acquisition after analysis of available satellite capacity and previous commitments. Spot Image then commits the necessary satellite programming resources. This option is particularly suited to applications that are subject to urgent time constraints or require full coverage of an area under specific conditions.

Refer to the Spot Products & Services price list for the price of standard and priority programming services

(b) Thematic requirements

The exact thematic requirements must be specified to enable Spot Image make an accurate assessment of the Programming Request. Among the choices given, indicate under the “**Other**” Category that the area of application is Mapping and Monitoring the spread of Water Hyacinth.

(c) Survey Period

The survey period could be Single Period Survey or Multi-Date Survey.

For the Single Survey Period, the starting and ending (Day/Month/Year) of the survey must be stated. This type of survey also has an option for multiple surveys within the single survey period. Within the single observation period, the number of times the area should be covered and if necessary, the interval (number of days) between two cloud-free scenes acquired (dead period) ought to be indicated.

The Multi-Date Survey consists of two or more survey periods for example; First Period, Second Period, Third Period, etc. The starting and ending dates of each survey period must be stated.

(d) Resolution and Spectral Mode

The resolution options available are 2.5m, 5m, 10m and 20m. Black and White, Colour 3-band and Colour 4-band are the spectral modes available. The 2.5-m and 5-m colour products are available in 3 bands only and concern SPOTView products exclusively.

(e) Survey Method

Near-vertical ($\pm 12^\circ$), Unspecified oblique viewing ($\pm 31^\circ$) and Cross-track (acquisition) stereopairs are the available options. The Near-vertical option is sufficient for weed mapping purposes.

(f) Survey Area

The Survey area must be described in terms of geographical name (Country and Place Name) and Geographical coordinates (Latitude and Longitude as Degrees, Minutes and Seconds) of vertices of the Polygon that forms the boundary.

(g) Cloud Cover

Two options are available for the cloud cover: Less than 10% and Cloud free warranty. If the option preferred is not specified, Spot Image will end satellite programming as soon as the required scenes have been acquired with less than 10% cloud cover.

For imagery that is completely free of cloud, fog, haze, dust clouds and sandstorms, choose the “cloud-free warranty” option. This service is offered after a feasibility study, and is subject to the programming of the images with priority service.

For purposes of weed monitoring, it is important to specify that the area of interest (Lake Surface) should be cloud free so that weed can be clearly seen.

(h) Additional Information and Contact

Any other additional information could be provided in space provided in the Programming Request Form. Spot Image must also be given the contact (delivery) and billing addresses. The Customer Reference Number should also be

included. The completed Programming Request Form should be sent to the local distributor (where applicable) or to Spot Image – Customer Service.

3.1.2 Data processing

(ix) Improve image quality

Preprocessing of satellite imagery improves visual appearance and geometric accuracy.

(a) Landsat preprocessing levels

Landsat 7 data can be delivered to customers in three products depending on the level of processing performed on the data: Level 0 Reformatted (L0R), Level 1 Radiometrically Corrected (L1R), and Level 1 Geometrically Corrected (L1G) (http://landsat.usgs.gov/resources/remote_sensing).

Level 0 Reformatted (L0R) : The Level 0R product is reformatted, raw data. Reformatting includes shifting pixels by integer amounts to account for 1) the alternating forward-reverse scanning pattern of the Enhanced Thematic Mapper Plus (ETM+) sensor, 2) the odd-even detector arrangement within each band, and 3) the detector offsets inherent to the focal plan array engineering design. Pixels are neither resampled nor are they geometrically corrected or registered, i.e. the pixels are NOT aligned per scan line.

Level 1 Radiometrically Corrected (L1R): The Level 1R product is a radiometrically corrected L0R product. This product (i) corrects detector artifacts such as coherent noise, (ii) improves cosmetic artifacts such as banding, striping, and dropped lines or pixels, and (iii) is calibrated to radiance units, i.e. color corrected, as integer values. Radiometric corrections are not reversible. Pixels are neither resampled nor are they geometrically corrected or registered, i.e. the pixels are NOT aligned per scan line.

Level 1 Geometrically Corrected (L1G): The L1G product is radiometrically and geometrically corrected (systematic) to the user-specified parameters including output map projection, image orientation, pixel grid-cell size, and resampling kernel. The correction algorithms model the spacecraft and sensor data generated by onboard computers during imaging. Sensor, focal plane, and detector alignment information provided by the Image Assessment System (IAS) in the Calibration Parameter File (CPF) is also used to improve the overall geometric fidelity. The resulting product is free from distortions related to the sensor (e.g., jitter, view angle effect), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature). Residual error in the systematic L1G product is less than 250 meters (1 sigma) in flat areas at sea level. The systematic L1G correction process does not employ ground control or relief models to attain absolute geodetic accuracy. This product is the most correct product offered geometrically and geodetically. This level of preprocessing is sufficient for weed monitoring.

(b) Spot preprocessing levels

Spot images come with different levels of preprocessing, divided into 2 product lines. These are **SPOT Scenes** consisting of levels 1A, 1B and 2A and **SPOTView** levels 2B and 3 (<http://www.spotimage.com>).

Level 1A: This imagery is corrected by normalizing CCD response to compensate for radiometric variations due to detector sensitivity. No geometric corrections are performed. Level 1A preprocessing thus leaves data in almost raw form.

Level 1A products are for experienced users working with image processing software. They are designed primarily for mapping applications and are used for geometric processing – to orthorectify images and generate digital elevation (DEMs). They are also used for precise radiometric processing.

Level 1B: This applies the same radiometric processing as Level 1A. Geometric corrections compensate for systematic effects including panoramic distortion, the Earth's rotation and curvature, and variations in the satellite's orbital altitude. Internal distortions of the image are corrected for measuring distances, angles and surface areas.

Level 1B products are for users who require basic geometric corrections. They are well suited for geometric measurements (distances, angles and areas), photo-interpretation and thematic studies. Thematic analysis may be visual, computer assisted or fully digital.

Level 2A: Radiometric correction identical to that of level 1A. Level 2A scenes are fully rectified to match a standard cartographic map projection (UTM WGS 84), without using ground control points. Level 2A is the entry-level map product. For Spot 1 through Spot 4, the mean rectification level is constant across the scene. For Spot 5, a global DEM with a post spacing of one kilometre is used. Geometric corrections use a resampling model that compensates for systematic distortion effects and performs transformations needed to project the image in a standard map projection (UTM WGS 84). This model is based on known viewing parameters (satellite ephemeris data and attitude, etc.) and does not use external measurements. Other map projections or mean rectification elevations are available on request.

Level 2A products are for users who want to combine different kinds of geographic information, from different sources, and apply their own colour processing in order to extract specific information. While allowing for location error, level 2A images register directly with other layers of geographic information – vector data, raster maps or other satellite images – in the same map projection.

Level 2B (Precision): This product comes in a map projection with ground control points taken on maps or from GPS type measurements taken in the field. The image is corrected for a mean elevation in a projection and a standard map frame. This product is used when deformations due to relief are not that important (flat ground, etc.).

Level 3 (Ortho): This imagery is also georeferenced like Level 2B. Level 3 products also called ortho images, are preprocessed using a digital elevation model (DEM) to correct residual parallax errors due to relief. Geometric corrections consist in orthorectifying imagery using a resampling model that compensates for distortion effects and performs transformations needed to project the image in a specified map projection (Lambert conformal, UTM, polar stereographic, polyconic, etc). Corrections are based on a model of the satellite's flight dynamics, GCPs and a DEM.

Level 3 products are satellite image maps, in full-scene or standard mapsheet formats (30' x 30', 15' x 15', 7'30 x 7'30). They are ideal for mapping relief. Such a sophisticated level of preprocessing is designed to offer maximum accuracy for producing and updating maps. It also allows images to be registered with other geographic data.

For weed monitoring purposes, Spot scenes processed to level 2A are sufficient.

(x) Create composite image

To facilitate the visual analysis of the aquatic and neighboring environment, appropriate image enhancement techniques need to be used. Image enhancement refers to the alteration of the appearance of an image in such a way that information contained in that image is more readily interpreted by the viewer in terms of the viewer's particular needs. In this case, the concentration is on improving the visual interpretability of an image by altering its contrast (Contrast Enhancement). Linear stretch, Histogram equalisation and Gaussian stretch are the standard techniques of contrast enhancement (Mather, 1987). These are normally included in Remote Sensing image processing software packages.

The creation of a false colour composite further aids visual analysis. A false colour composite should be created using linear contrast stretching.

3.1.3 Satellite image classification

(xi) Isolate (classify) weeds

There are two general approaches to image classification: *supervised* and *unsupervised*. They differ in how the classification is performed (Jensen, 1989). In the case of supervised classification, the software system delineates specific land cover types based on statistical characterization data drawn from known samples in the image (known as training sites). With unsupervised classification, however, clustering software is used to uncover the commonly occurring land cover types, with analyst providing interpretations of those cover types at a later stage.

Hard classifiers, soft classifiers and hyperspectral classifiers constitute the supervised classification approach. Hard classifiers make a definitive decision about the land cover class to which any pixel belongs. Contrary to hard classifiers, soft classifiers do not make a definitive decision about the land cover class to which each pixel belongs. Rather, they develop statements of the degree to which each pixel belongs to each of the land cover classes being considered. It should suffice to say that what is of interest in weed monitoring is not to what degree a pixel is classified as water or weed but whether the pixel really falls under the class of weed or not. It then appears that the decision by hard classifiers is sufficient for this kind of monitoring. Hyperspectral classification is still in infant and developmental stages.

Isoclust is an iterative self-organizing unsupervised classifier based on a concept to the well-known Isodata routine of Ball and Hall (1965) and cluster routines such as the H-means and K-means procedures. Being a hybrid classification, Isoclust bridges the supervised and unsupervised classification approaches. Hybrid classification method best isolates water hyacinth and is recommended for weed monitoring purposes.

(xii) Assess error

A common means for quantifying the accuracy of a classification (error assessment) is to use the Error Matrix (sometimes called Confusion or Accuracy Matrix). It is most particularly used in the post-classification assessment of land cover classifications derived from remotely sensed data. Errors of omission and commission, an overall error measure, confidence intervals, and a Kappa Index of Agreement (KIA) are key outputs of the error assessment exercise (Landgrebe, 2003). However, in cases where the wind and wave action greatly affect the weed movement (Fig. 3.5), it is difficult and not feasible to use an error matrix for post classification accuracy unless image acquisition is done at the same time as ground truthing. In such instances, the photo-interpretation skill of the one classifying the images has to be relied on.

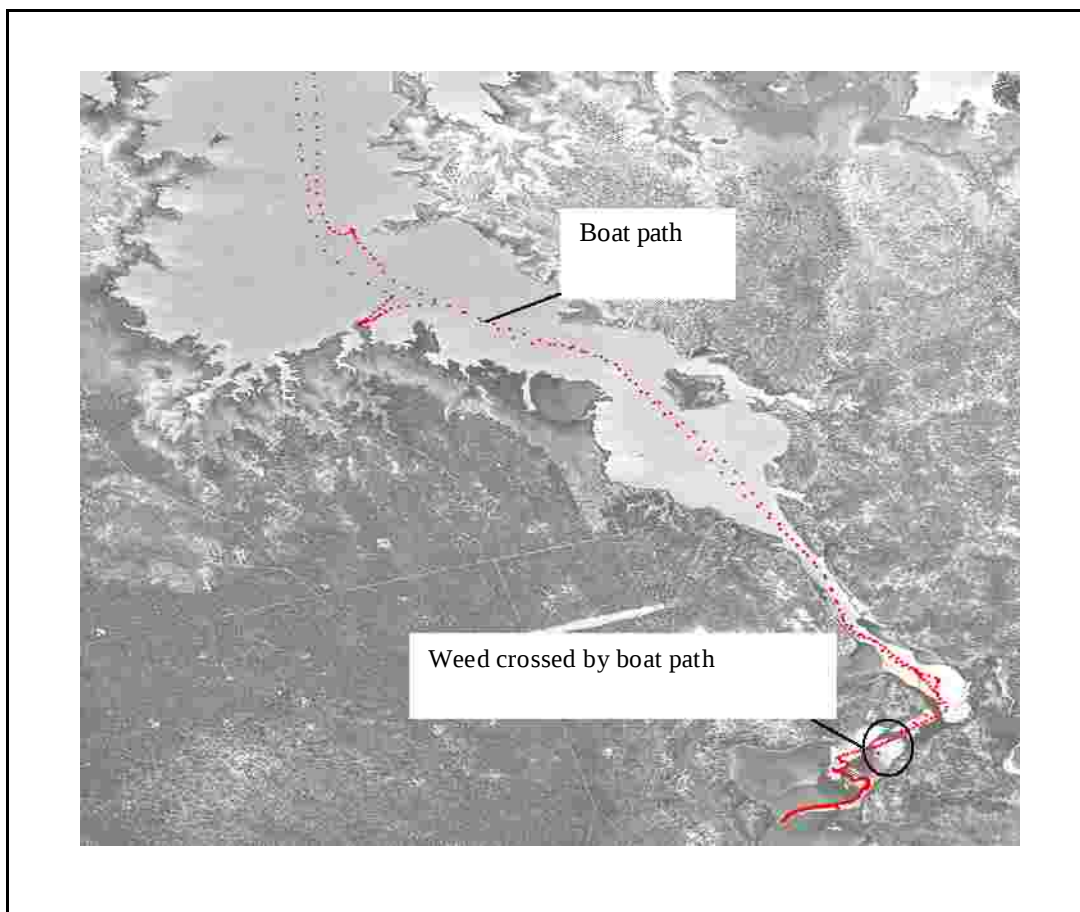


Figure 3.5: A 2003 Spot 5 image showing change of weed position in relation to boat path.

Source: BRLi/IRD

3.1.4 Data analysis

(xiii) Analyse image for weed spread

Calculation of the area covered by water hyacinth per bay should be done and compared with previous occurrences using GIS. This trend analysis across different years would enable visualisation of whether the weed is spreading or not. It would also enable management to review their weed control measures accordingly.

(xiv) Produce map of water hyacinth spread

This is the key output of the weed monitoring procedure. It would enable visualisation of the weed occurrence on Lake Kariba. Further, it would contribute to efficient reporting on the weed situation through inclusion of maps in written reports.

(xv) Input data into database

Data from weed monitoring need to be stored in a database for easy storage, management and future reference. Data on hard copies should also be well kept. Both the soft and hard copies of the data must be backed up and well secured.

CHAPTER 4 – TESTING THE MONITORING PROCEDURE

4.0 Introduction

This Chapter focuses on the testing of the conceptual from the previous chapter. Easy to follow step by step instructions are set out. Further, data capture and processing procedures carried out in this project are outlined. Results of the field expeditions undertaken are explained. Only Spot (September 1995 and August 1999) and Landsat (November 2004, March 2005, June 2005 and November 2005) imagery covering the eastern basin of Lake Kariba were used as test data for this study due to financial limitations. These images were processed, classified and analysed in Idrisi 2.0 and ArcView 3.2a respectively. Idrisi 2.0 and ArcView 3.2a were used for testing specific parts of the monitoring procedure that required the use of software basically because they were the ones available and approved in the proposal for this study.

4.1 Testing the designed procedure

The testing of the designed procedure was in four phases involving data acquisition, data processing, satellite image classification and data analysis.

4.1.1 Data acquisition

(i) Preparation for fieldwork

Fieldwork consisted of reconnaissance surveys (by road and boat) and interviewing stakeholders. When preparing for fieldwork, the following were some of the activities done:

(g) Constituting Field Crew;

Among others, the field Crew was made up of the Team Leader, Assistant, Boat Captain and Boat attendant.

(h) Background research

Reference was made to past activities concerning water quality data and information on previous water hyacinth occurrence for proper planning and choosing of areas where field visits were done.

(i) Deciding on sites to visit

Site visits to both the Eastern Basin of Lake Kariba and the whole Lake (Lakewide field surveys) were done. using Houseboats and speed boats.

(j) Weather forecasting

Weather forecasts by the Meteorological Departments in Zambia and Zimbabwe were also taken into consideration.

(k) Scheduling ground truthing

The GPS receivers were used to accurately position the weed and other locations as a way of ground truthing. When programmable acquisition of satellite imagery is under consideration, ground truthing should be scheduled to coincide with image acquisition by checking the image acquisition calendar for the respective satellite. For example, the Landsat acquisition calendar can be accessed via the internet (http://landsat.usgs.gov/technical_details/data_acquisition) while for Spot, enquiries can be sent to sales@Spotimage.com. Programmable image acquisition was not undertaken in this study and therefore did not influence scheduling of ground truthing.

(l) Securing equipment

The necessary equipment required for field work (Table 3.2) were secured with few adjustments. The sample water hyacinth monitoring form (Table 3.3) was still under design and so the weed parameters were recorded similar tables (Table 4.1).

(g) Stakeholders' interviews

The following stakeholders were consulted on the occurrence and proliferation of water hyacinth in the areas of concern on the Lake.

- Crocodile Farm, Kariba
- Landela Lodge staff,
- Fishermen, both on the Zambian and Zimbabwean side of Lake Kariba.
- Mlibizi Hotel

(h) Securing cross-border permission

Lake Kariba lies on the border area between Zambia and Zimbabwe. The boats used during the field surveys are registered with Lake Navigation in Zimbabwe. Permission for the boats to access or cross into the Zambian Territory was secured from the Zambian Immigration Authorities. International Police (Interpol) clearance and authority to temporarily export the field equipment was also secured at boarder crossing.

(v) Reconnaissance field visit s

The reconnaissance surveys were undertaken at the same time of taking GPS coordinates and measuring weed parameters.

(vi) GPS coordinates of weed and other locations

GPS coordinates of weed and other locations were taken using both the Garmin GPS 28 and Etrex receivers. These coordinates were recorded manually in readiness for being processed using ArcView 3.2a. Since the GPS coordinates taken during this study were few, they were done and even entered into the computer to be used by 3.2a software manually. However, where many coordinates are to be taken, it would be advisable to record them in the GPS receiver as way points and eventually downloaded direct into the computer.

(a) Create an ArcView Shapefile from Garmin GPS Data

This section describes the process of converting data from a recreation-grade GPS receiver into a shapefile format that can be used in an ArcView GIS setting. This section is adapted from information found in the California Weed Mapping Handbook (DiPietro, 2002). The first steps described below help to use Waypoints Plus to download GPS data from a Garmin unit. If one is using a different brand of recreation-grade GPS unit, download the data using the download tool associated with the unit, and skip to Step 6. Waypoint Plus can be found at <http://www.tapr.org/~kh2z/Waypoint/>. Searching the internet using a search engine like Google can trace a site where the software can be downloaded free even if the website address changes.

Step 1: Turn off the GPS unit and connect it to the computer's serial port (probably COM1) using the PC interface cable.

If the GPS coordinates were not recorded or entered into the receiver but just written on the weed monitoring form, convert them to decimal degrees = Degrees + (minutes/60) + (seconds/3600)) and enter them into an excel spread sheet. Then go strait to step 5.

Step 2: Launch Waypoints Plus and go to FILE-CONFIGURATION-MODES. Set the coordinates to Decimal Degrees and the units to meters. Go to the FILE-DATUM menu and select WGS 84. (One can choose a different datum if required—Waypoints Plus takes the data out of the GPS unit and it into the designated datum. ArcView’s default set-up is “Geographic,” which is Decimal Degrees)

Step 3: Go to GPS-PORT and make sure it is set to the port being used (generally COM1).

Step 4: Select WAYPOINTS-DOWNLOAD or GPS-DOWNLOAD from GPS-Waypoints to download the waypoints (or tracks or routes). Save the waypoints as “comma delimited text file” (File-Save- Waypoint). Make sure to note where the data is saved.

Step 5: Open Microsoft Excel. Be sure to select DELIMITED instead of FIXED WIDTH, and use a comma as the delimiter. Don't import any columns not needed. Once it is in Excel, get rid of any extra rows. Bringing it into Excel mostly allows for surety that it is in a format that ArcView will read. Save the table in .txt format again (tab delimited is fine).

If the receiver is not a Garmin GPS and have succeeded in getting the GPS unit to download the waypoints into a text file, one may find that the coordinates use N and W instead of + and -, and that there is a bunch of header information that keeps the data from looking like a neat arrangement of rows and columns. Delete the header information. Use SEARCH-REPLACE to replace the N and W directional information with just the numbers. For example if the latitude longitude for a location is N38 W121 then do one replace (Find N3, Replace with 3) for the latitude coordinate; one for the longitude coordinate (Find W1 , Replace with -1). If both the tracks and waypoints are in one file; out the track points and put them into a separate text file. Save all files. Tab delimited text is fine.

Step 6: Open ArcView. Make the tables active and add your .txt file. Then in a VIEW and under the VIEW menu select ADD EVENT THEME. Select the .txt table, and make the longitude field the **x field** and the latitude field the **y field**. Click OK. The points should now be seen in the VIEW.

Step 7: Convert this to a shapefile. With the VIEW open, make the text THEME active by clicking on its legend (it will look like a ☐ button). Go to THEME-CONVERT TO SHAPEFILE, and save it into the chosen data folder (working directory). At this point one will need to do whatever projection and datum conversions that may be needed to get the shapefile into the required system.

(vii) Note weed status

The status of the weed on visited sites was recorded in Table form. The physical parameters were also measured for the purpose of monitoring the growth pattern of the weed. Pictures of the weed were also taken.

(v) Deciding on the type of imagery to acquire

Spot and Landsat imagery were chosen for test purposes in this study.

(vi) Enquiring on or searching for satellite image availability

Enquiries on the availability of satellite imagery were done by both contacting the dealer directly (through e-mail) for Spot and searching the image archives via the Internet (Landsat). The Landsat and Spot catalogues were searched via the ☐ to preview available images. The Sales support staff for Spot in France was also contacted by e-mail. It was discovered that not all images desired could be found in the catalogues. No Spot images for Lake Kariba for 2004 were available in the archives. The Sirius online catalogue was also searched but yielded unprofitable results on the whole. Enquiries for

Radarsat imagery from the distributor only yielded very few and undesired results (Appendix B) while no imagery over the eastern basin of Lake Kariba were found.

The Landsat archive was accessed through the clickable map on the internet (<http://landsat.org>). The 2004 and 2005 Landsat images were purchased online and delivered in soft copy HDF format on DVDs.

The effect of cloud cover on some available Landsat images was more than could be tolerated ($>10\%$). A preview of the Landsat ETM+ image of the southern part of Lake Kariba (Figure 4.1) shows the effect of cloud cover. In some instances, the whole satellite image was spoiled by cloud cover.

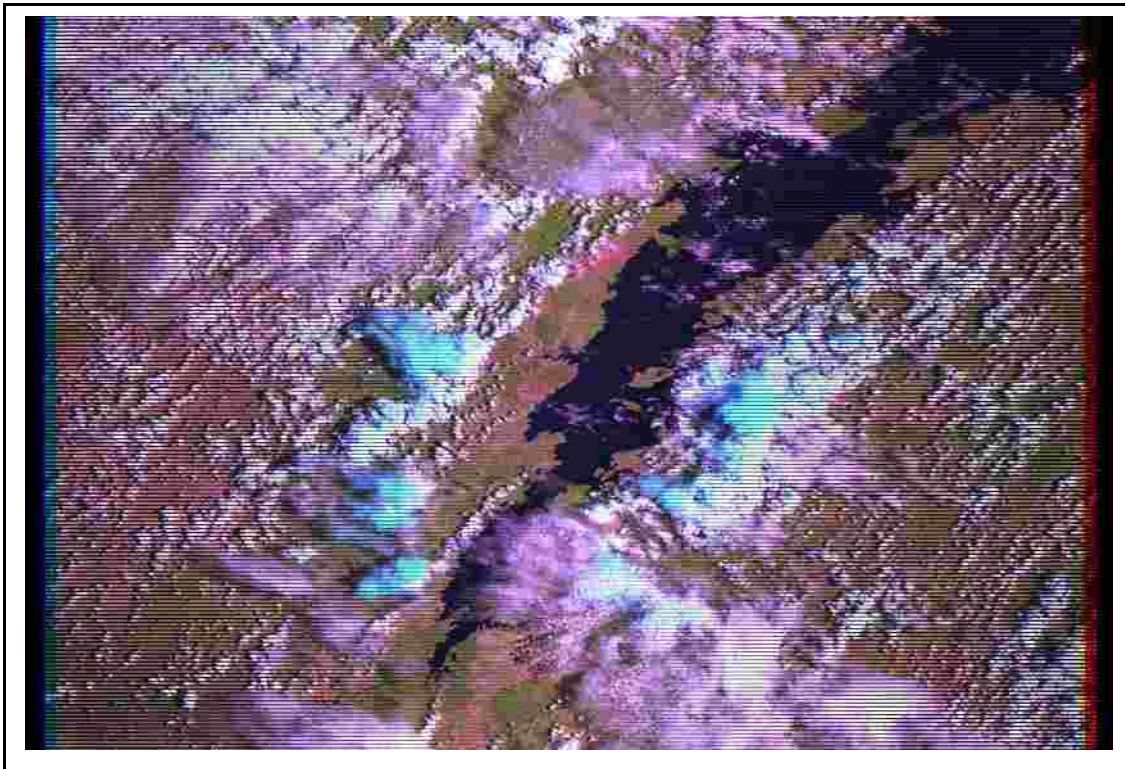


Figure 4.1: Effect of cloud cover on Landsat ETM+ image. Preview for January 2005.

Source: Landsat Archives (<http://landsat.org>)

(vii) Acquiring satellite images

Spot images for 1995 and 1999 and the 2001 Landsat image were already available while other archived images for Landsat 2004 -2005 were later purchased and used in this study (Courtesy of Zambezi River Authority). Searching the archive for Spot imagery for the desired period yielded no results.

4.1.1.2 Acquired data

Four boat surveys were carried out to monitor the spread of water hyacinth on Lake Kariba, three to the hotspot sites and one Lake wide. visits to the hotspot sites (eastern basin and Mlibizi) took place in December 2004, January 2005 (eastern basin only) and December 2005. The trip round the Lake was done in April 2005. The Lake wide field visit was supposed to include the eastern basin as well. However, this did not happen because the House boat (Batoka) developed a fault in one of its engines. During the field visits coordinates depicting the location of weeds were taken using a GPS receiver (Garmin GPS 28). The status of the weed was also noted by counting the number of leaves, measuring root and petiole length and assessing the impact of biological agents (weevils and mites) on the plants. Photographs of the weed were also taken using cameras (analogue and digital) while a video camera was also used in some instances.

The types of weed spread on the lake were observed as fringe along the shore line (Figure 4.2), free floating patches (Figure 4.3) and thick mats (Figure 4.4).



Figure 4.2: Fringe of water hyacinth in Mlibizi Bay. Picture taken on 04/12/04



Figure 4.3: Free floating patches of water hyacinth on Gatche gatche Bay. Picture taken on 02/12/04



Figure 4.4: Thick floating mats of water hyacinth on Gatche Gatche Bay. Picture taken on 02/12/04

Water weeds were observed drifting under the influence of wind and wave action (Figures 4.5 and 4.6)



Figure 4.5: Wind and wave action drifting water hyacinth on Sany y. Picture taken on 01/12/04.



Figure 4.6: Wind and wave action drifting water weeds on Gatche gatche Bay. Picture taken on 2/12/04.

The fluctuation in the daily Lake levels for selected years is reflected in Figure 4.7.

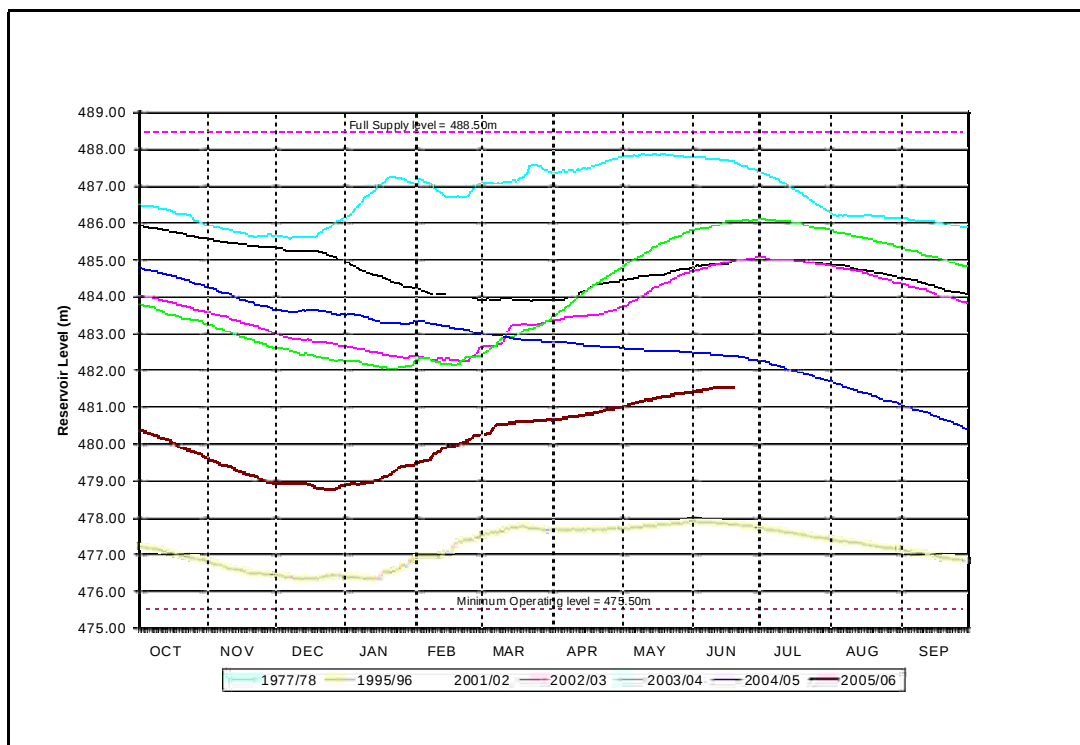


Figure 4.7: Comparison of daily Lake water levels for selected years
Source: ZRA

The end-of-month variation of the water level for the Lake since time the Dam was built to April 2006 is reflected in Figure 4.8.

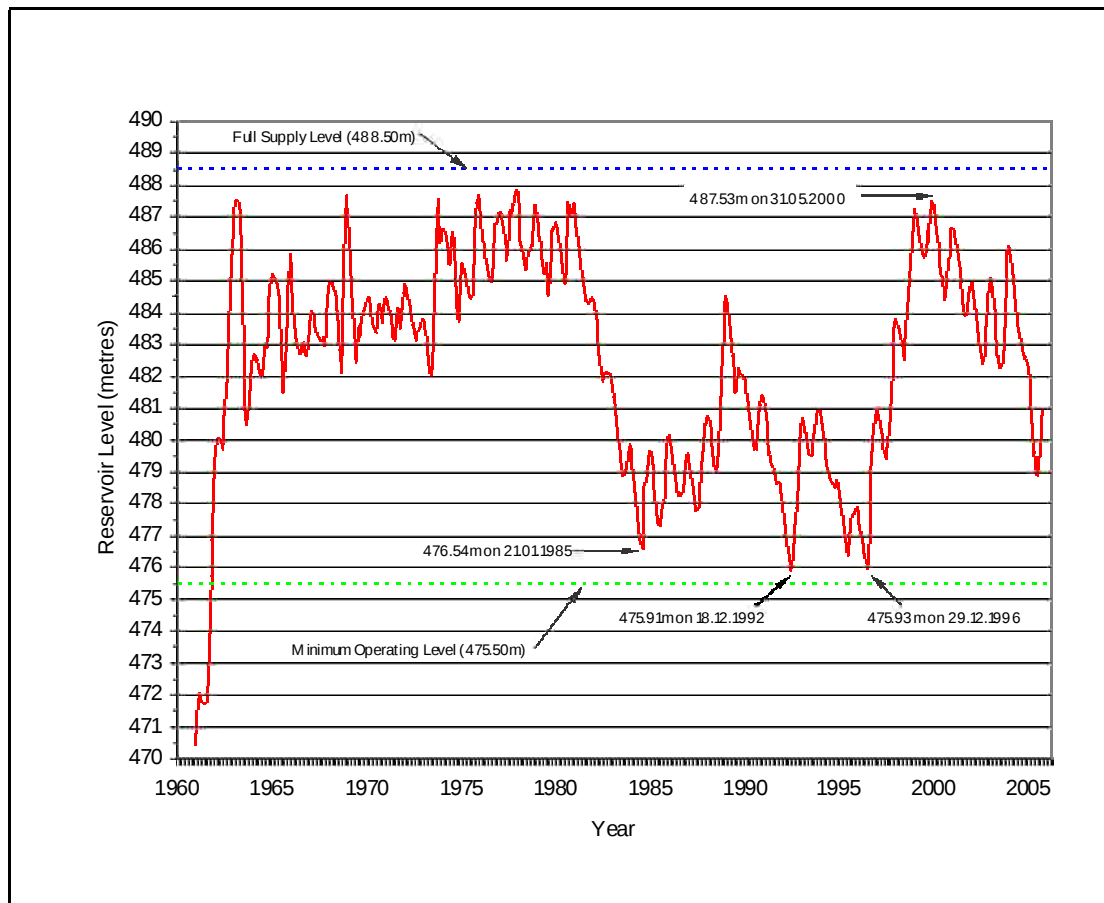


Figure 4.8: Variation of Lake Kariba's end-of -month water levels

Source: ZRA

The water balance results of Lake Kariba from 2003 and 2005 are shown in Figure 4.9. Water hyacinth was observed stranded and left for dead due to the draw down of the Lake level (Figures 4.10 and 4.11).

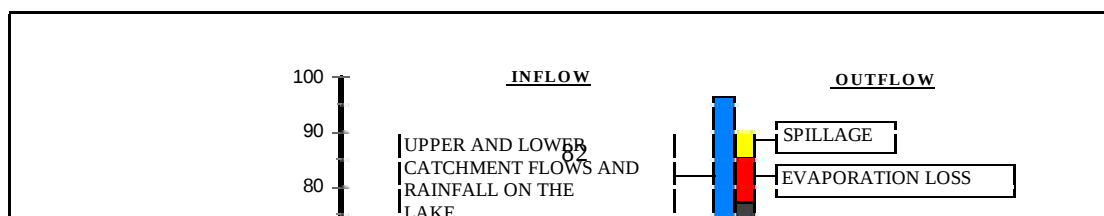


Figure 4.9: Water balance of Lake Kariba from 2003 to 2005
Source: ZRA



Figure 4.10: Water hyacinth stranded in Gatche Gatche Bay after recession. Picture taken on 02/12/04.



Figure 4.11: Water hyacinth left stranded in Charara Bay after water level recession. Picture taken on 02/12/04

The weed status as observed on the hotspot sites is summarized in Tables 4.1(January 2005) and 4.2 (December 2005).

Table 4.1: Weed status at visited hot spot sites in January 2005

Site Name	Date	Max. petiole length (cm)	Max. root length (cm)	Wet weight (g)	No. ramets	No. flowers	No. Leaves	Comments
Sanyati	21/01/2005	20	25	249	3	0	9	Very healthy young water hyacinth
Gatche Gatche	20/01/2005	23	24	273	2	0	7	Fairly damaged plants
Nyaodza	20/01/2005	Nil	Nil	Nil	Nil	Nil	Nil	No weed spotted on water but stranded on shore and flowering
Charara	20/01/2005	35	22	389	2	0	9	Weed in fair health
Crocodile Farm	20/01/2005	Nil	Nil	Nil	Nil	Nil	Nil	No weed spotted

Table 4.2: Weed status at visited hot spot sites in December 2005

Site Name	Date	Max. petiole length (cm)	Max. root length (cm)	Wet weight (g)	No. ramets	No. flowers	No. Leaves	Comments
Mlibizi	8/12/2005	29	24	NT	1	0	9	Long roots indicate low nutrient levels
Sanyati	11/12/2005	28	33	354	1	0	9	Long roots indicate low nutrient levels
Gatche Gatche	11/12/2005	17	24	212	4	0	6	Long roots indicate low nutrient levels
Nyaodza	12/12/2005	Nil	Nil	Nil	Nil	Nil	Nil	Site inaccessible due to shallow water. No weed spotted
Charara	12/12/2005	Nil	Nil	Nil	Nil	Nil	Nil	Site inaccessible due to shallow water. Countable weeds seen floating
Crocodile Farm	12/12/2005	Nil	Nil	Nil	Nil	Nil	Nil	Site accessed by road. Completely clear of weed
ULKRS	12/12/2005	29	5	121	3	0	6	Short roots indicate high nutrient levels

The spread of water hyacinth observed on the Lake decreased between December 2004 and December 2005. This was evident at sites such as Gatche gatche (Figures 4.12 and 4.13) and Mlibizi (Figures 4.14 and 4.15).



Figure 4.12: Water hyacinth – Mlibizi. Picture taken in December 2004.

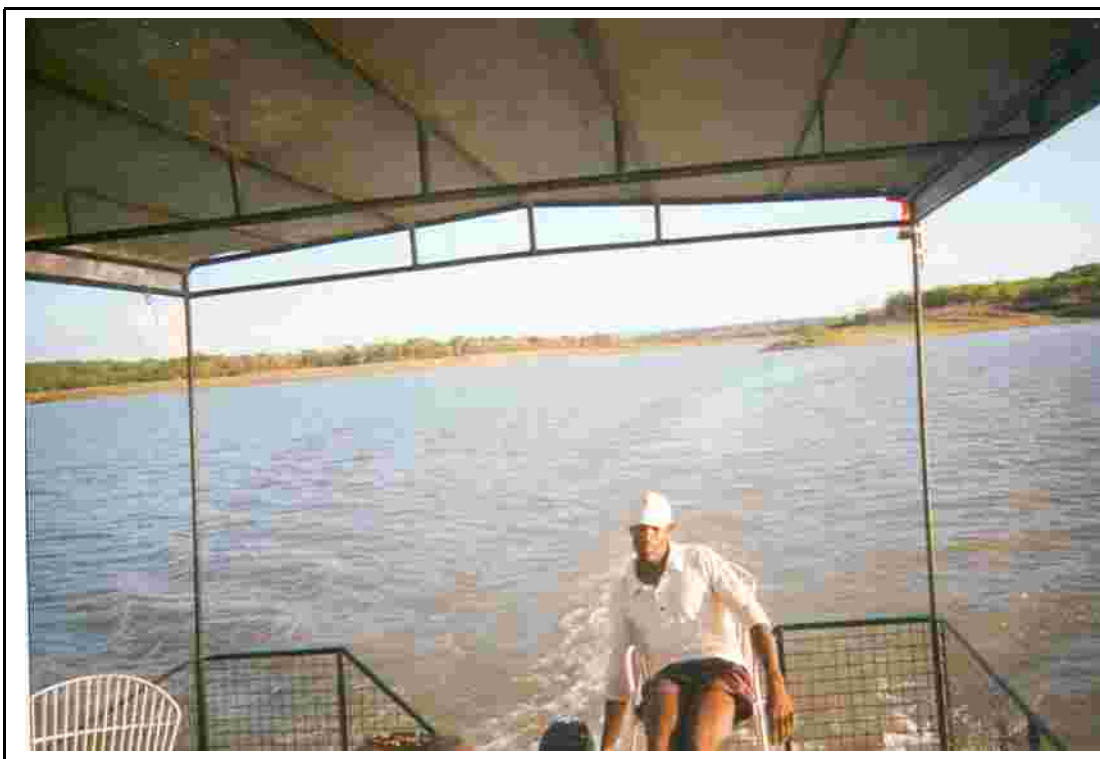


Figure 4.13: Water hyacinth – Mlibizi. Picture taken in December 2005



Figure 4.14: Water hyacinth – Gatche Gatche. Picture taken in December 2004.



Figure 4.15: Water hyacinth – Gatche Gatche. Picture taken in December 2005.

Personal views on the water hyacinth situation on Lake Kariba and use of remote sensing and GIS to monitor the weed were gathered through one-on-one interviews with experts in relevant fields.

The tables below show some water quality results by other researchers (Table 4.3) concerning nutrient levels in relation to water hyacinth growth and also what was found in relation to Lake Kariba during this study (Table 4.4 and Table 4.5).

Table 4.3: Results by other researchers concerning nutrient levels in relation to water hyacinth growth.

Researcher(s)	Nitrates (as NO ₃ -N mg/l)	Total Phosphates (as PO ₄ -P mg/l)	Potassium (as K mg/l)
Singh <i>et al.</i> (1984)	1-35	6	30
Balasooriya <i>et al.</i> (1984)	1-10	1-5	30
Balasooriya <i>et al.</i> (1984)	0.2 – 9.6	0.4 – 0.6	
Reddy <i>et al.</i> (1990)		1.06	
Reddy <i>et al.</i> (1991)			12 – 54

Table 4.4: Results of the sampling campaign done from 1st – 4th December 2004.

Station	Temperature (°C)	Nitrates (as NO ₃ -N mg/l)	Total Phosphates (as PO ₄ -P mg/l)
Sanyati mouth	29.2	6.8	<0.01
Sanyati furthest	32.3	2.7	<0.01
Gatche-Gatche	32.6	14.2	<0.01
Nyaodza	29.1	13.6	<0.01
Charara	30.0	13.9	<0.01
Mlibizi- surface	29.8	13.7	<0.01
Mlibizi- 10m	29.5	10.7	<0.01
zesa		14.4	<0.01

Table 4.5: Results of the sampling campaign done from 19th-22nd January 2005.

Station	Temperature (°C)	Nitrates (as NO ₃ -N mg/l)	Total Phosphates (as PO ₄ -P mg/l)
Sanyati Mouth	30.8	15.2	<0.01
Sanyati furthest	29.0	17.3	0.05
Gatche-Gatche	27.7	15.3	<0.01
Nyaodza	27.6	10.2	<0.01
Charara	29.3	9.5	<0.01
B51 surface	30.0	12.2	<0.01
B51 10 m	28.5	1.00	<0.01

4.1.2 Data processing

(x) Improve image quality

The processing of satellite images to improve quality done using Idrisi 2.0 software.
A guide to the image processing activities in Idrisi 2.0 is shown in Figure 4.16.

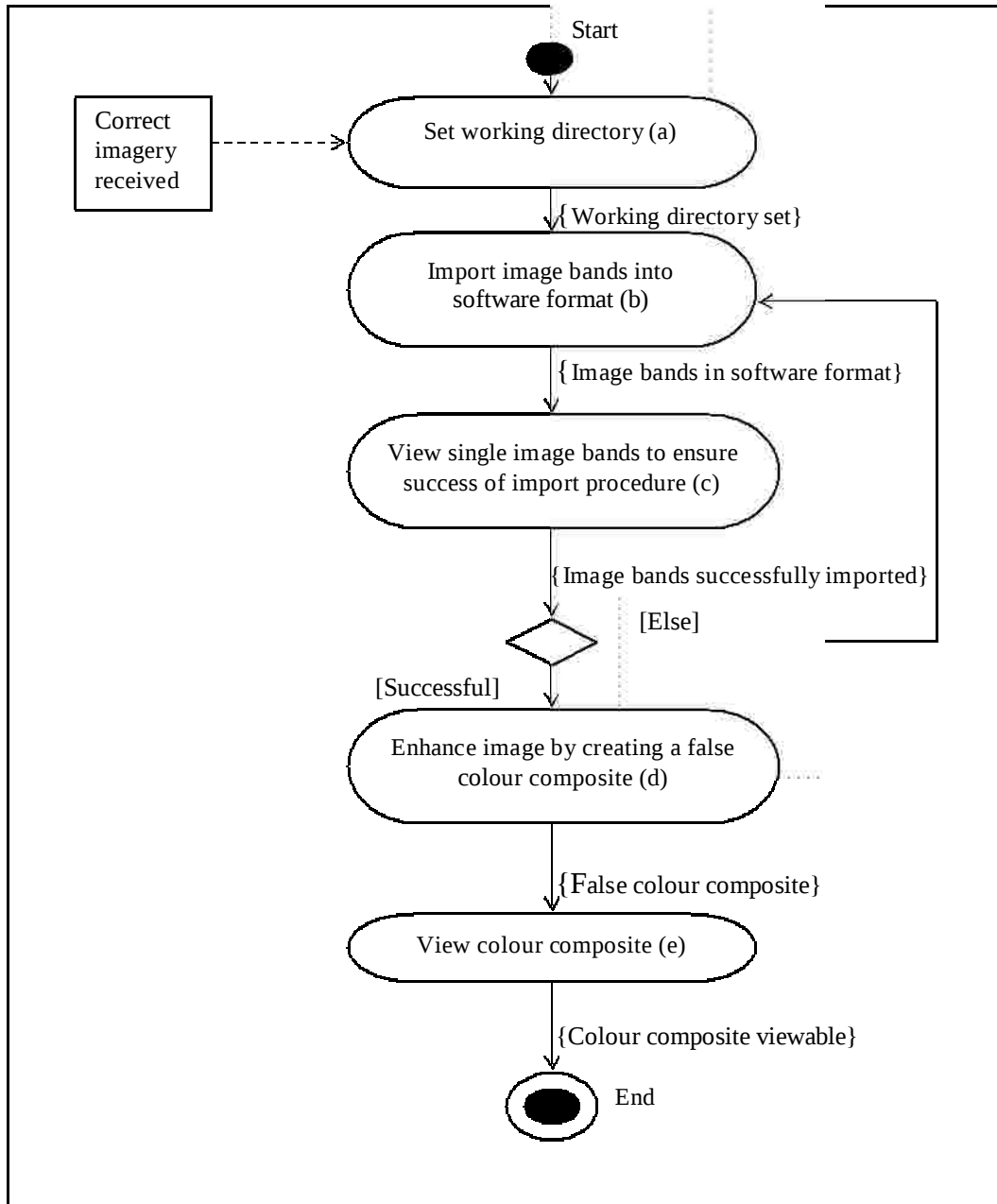


Figure 4.16: Image processing activity diagram

(a) Set the Working Directory

The working directory can be set by selecting either the leftmost toolbar button, or the first option of the leftmost menu item. Either procedure activates the ENVIRON module. With the ENVIRON module (Figure 4.17), one sets the file directory to be used for all input and output of user data. Idrisi users are advised to create separate working directories for each project. This is recommended since it keeps related data files together. However, it is not required. Also set the default reference units and click OK to effect the settings.

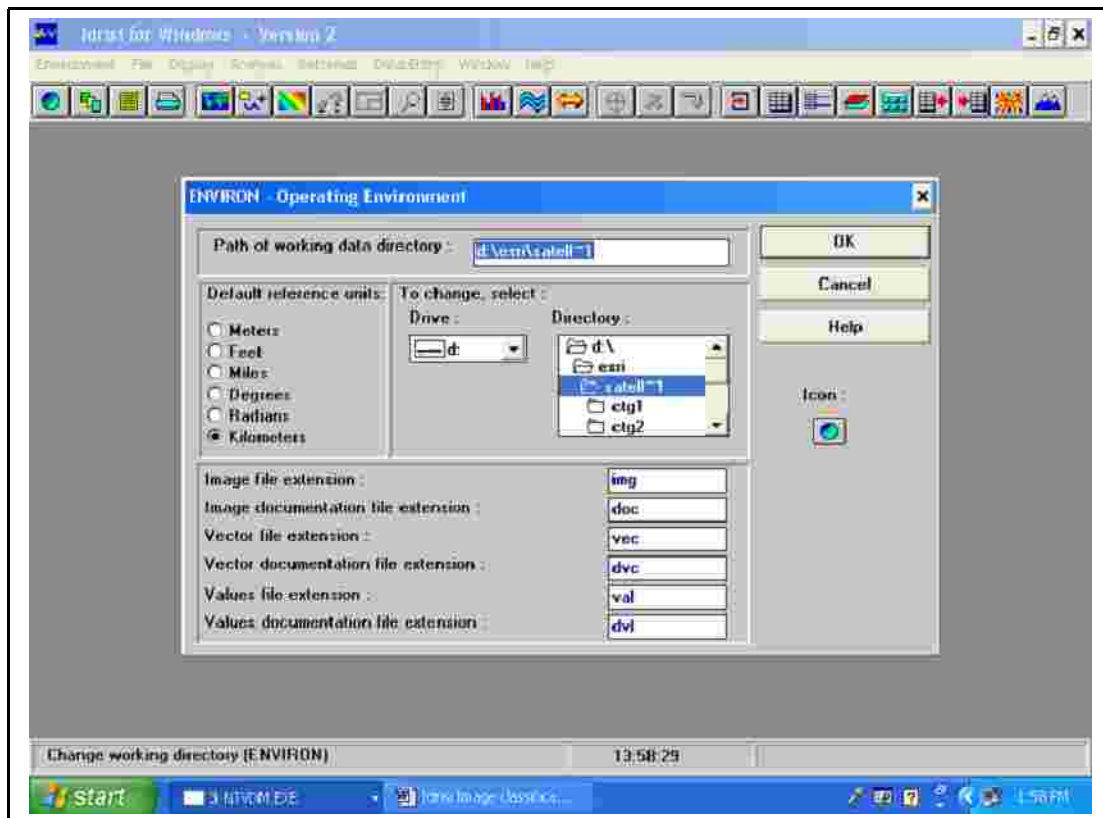


Figure 4.17: Setting the WORKING ENVIRONMENT

(b) Import image into Idrisi using the BILIDRIS Operation

The BILIDRIS dialogue box (Figure 4.18) is accessed through the file menu, import/export, import, general conversion tools and BILIDRIS. BILIDRIS first requires the name of the band-interleaved input file with extension. Then input a prefix of up to characters in length for the resulting band-sequential output images to be produced. The

first image will be named with that prefix plus a "1", the second a "2", and so on. BILIDRIS then requires you to specify the number of bands in the BIL file.

Next indicate whether the file contains no header, a single header for the first band, or a separate header for each band. The default is set to no header. Where there is no header, the header size should be set to 0. If headers are present, specify the size as the number of bytes. Indicate the data type of the input file as 8-bit, 16-bit (Intel/VMS) or 16-bit (UNIX/Motorola). Click on the CONTINUE button to enter the reference parameters (Figure 4.19).

Next, enter the number of columns and rows that the bands contain, and specify the required details about the reference system that should be attached to the resulting files: the minimum and maximum of X and Y coordinates, cell value units, reference system, reference units and unit distance. Click OK and Idrisi will then import the image bands into its format.

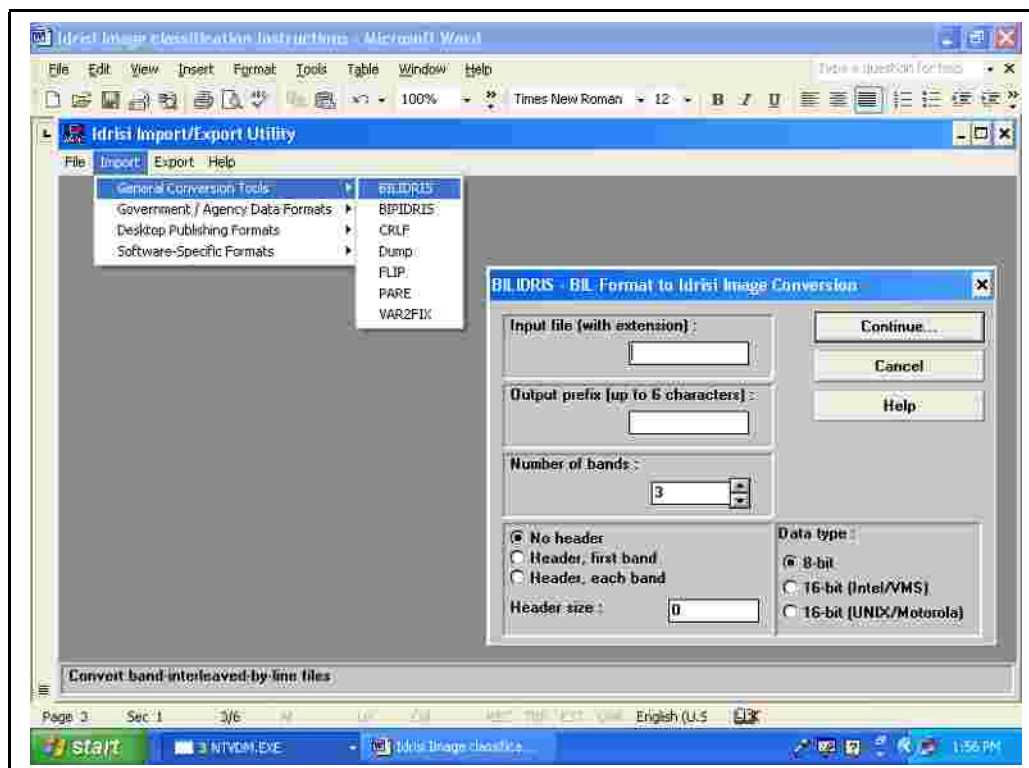


Figure 4.18: The Idrisi IMPORT utility

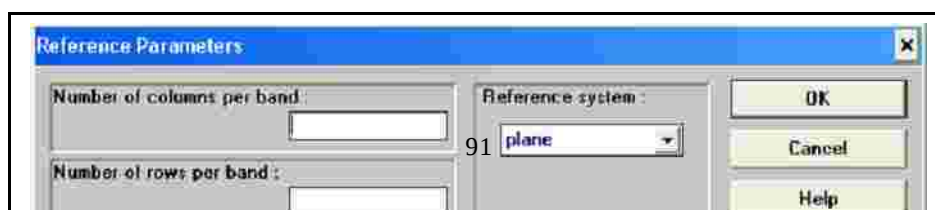


Figure 4.19: The reference parameters of the Idrisi IMPORT utility

(c) **Display image bands with the DISPLAY LAUNCHER**

The DISPLAY LAUNCHER is the module that allows you to open a new display window. It begins the map composition process, and is always the first operation required to create a new map display. It can be accessed in two ways: either by pressing the LAUNCHER icon (the map-like icon that is found fifth from the left edge of the toolbar), or by choosing the first option under the display menu. Doing so opens a dialog box with options to display an image layer, a vector layer, or an existing map composition (Figure 4.20).

Set the name and type of file to display, map components, palette to use and click OK to display the required map. The colour composite palette option is alright for weed visualisation purposes. Where a user defined palette exists it can be accessed by selecting the user defined palette option, double clicking the empty rectangle box below and clicking on it in the pick list displayed. The expansion factor will automatically be set when the file to be displayed is selected.

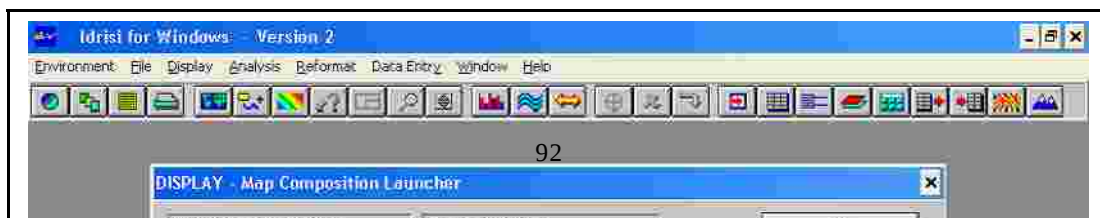


Figure 4.20: The DISPLAY LAUNCHER

Preprocessing of satellite imagery improves visual appearance and geometric accuracy.

(d) Enhance image by creating a false colour composite

The COMPOSIT module produces a false colour composite image from three bands of byte binary imagery. The single band composite can then be used as input to cluster (unsupervised classification) and displayed with the appropriate palette in the DISPLAY module. The COMPOSIT module is accessed through the Analysis menu, image processing, enhancement and COMPOSIT as shown in Figure 4.21.

COMPOSIT requires that you specify the file names containing the blue, green, and red bands to be used as the components of the composite image. Then enter a new name for the output image. One then needs to specify the type of contrast stretch to be used: simple linear, linear with saturation points, or histogram equalization. If one chooses linear with saturation points, there is need to specify the percentage to be saturated from each end of the grey scale. A saturation level of 2.5% often works well as an all-round solution and is thus set as the default. However, for use with cluster, try lower

values (e.g., 1%), while for visual display you may wish to use higher values (e.g., 5%). It is suggested that the false colour composite should be produced using a linear stretch with 1% saturation.

In addition, if you are using Landsat TM data Idrisi recommends the use of bands 3, 4 and 5. These cover the basic image dimensions of greenness, brightness and moisture content, and thus carry almost all of the information in the image. For Spot, use bands 1, 2 and 3 unless band 4 is available in which case different band combinations can be tried. It must also be noted that the spatial resolution for band 4 is lower and the effect it can have on the colour composite when used with other bands of different and higher resolution needs to be examined. Note that in the actual iterative cluster assignment process, the full set of raw data bands is used.

Indicate whether zeros should or should not be omitted as background values. If you choose to omit zeros as background, all input zeros will be omitted from the stretch calculations and be given an output value of zero. The primary reason for choosing this is to avoid having background zeros influence the histogram calculations that are used in the stretch.

Finally, enter a title for the output image to be created.

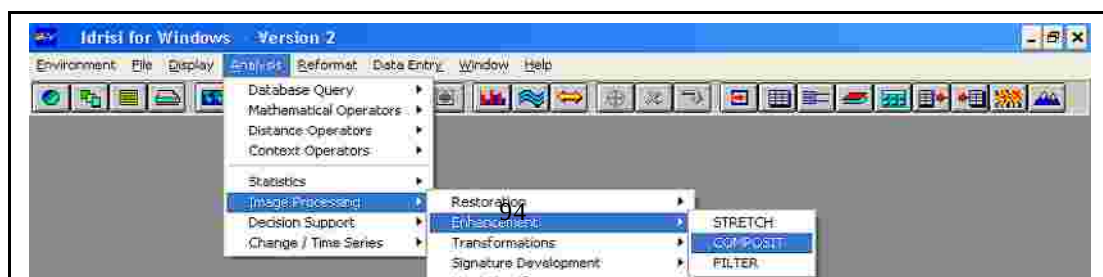


Figure 4.21: The COLOUR COMPOSITE utility

(e) View the false colour composite

The output image (colour composite) created should be viewed to ensure the previous step was successfully executed. The procedure for viewing the image is as outlined in step (c) above.

The 1995 and 1999 Spot images used in this study were already orthorectified (Level 2B) by the vendor and supplied in band interleaved by line (bil) format. Single bands were extracted from the image and imported into Idrisi Software. Landsat TM bands 5, 4 and 3 and Spot 4 bands 3, 2 and 1 corresponding to Red, Green and Blue were used.

(x) Create composite image

To facilitate the visual analysis of the aquatic and neighboring environment, appropriate image enhancement techniques need to be used. The creation of a false colour composite further aids visual analysis. A false colour composite should be created using linear contrast stretching.

The images were enhanced by creating false colour composites that were used as input to the classification stage.

4.1.3 Satellite image classification

(xi) Isolate (classify) weeds

Three classification methods were tested on the false colour composite created from the Spot 4 (28th August 1999) Multispectral image. These are supervised (maximum likelihood), unsupervised (cluster) and hybrid (ISOCLUST) approaches. The resulting images had three (3) classes (supervised) and ten (10) classes (unsupervised and hybrid approaches). The results of this stage are shown in Figure 4.22 (maximum likelihood), Figure 4.23 (CLUSTER) and Figure 4.24 (ISOCLUST). The maximum likelihood procedure requires that the training sites to be used as pure as possible to avoid or reduce misclassification. This is a problem where water hyacinth is mixed with water patches. Figure 4.25 shows that near shore vegetation can be mistaken for scattered weed. This highlights the importance of ground truthing.

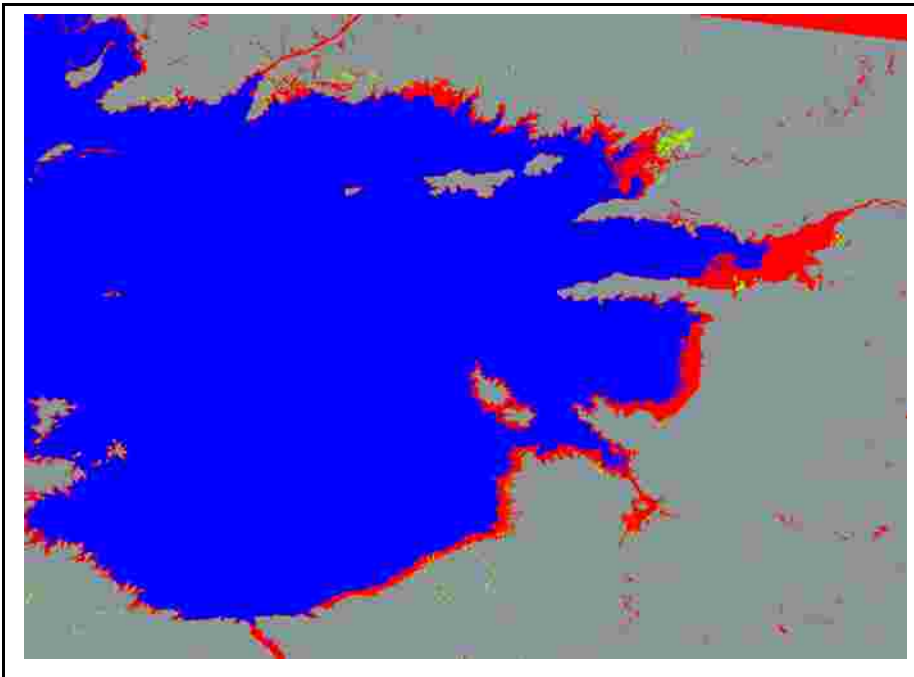


Figure 4.22: Spot 4 (28th August 1999) Multispectral Image classified using the maximum likelihood module

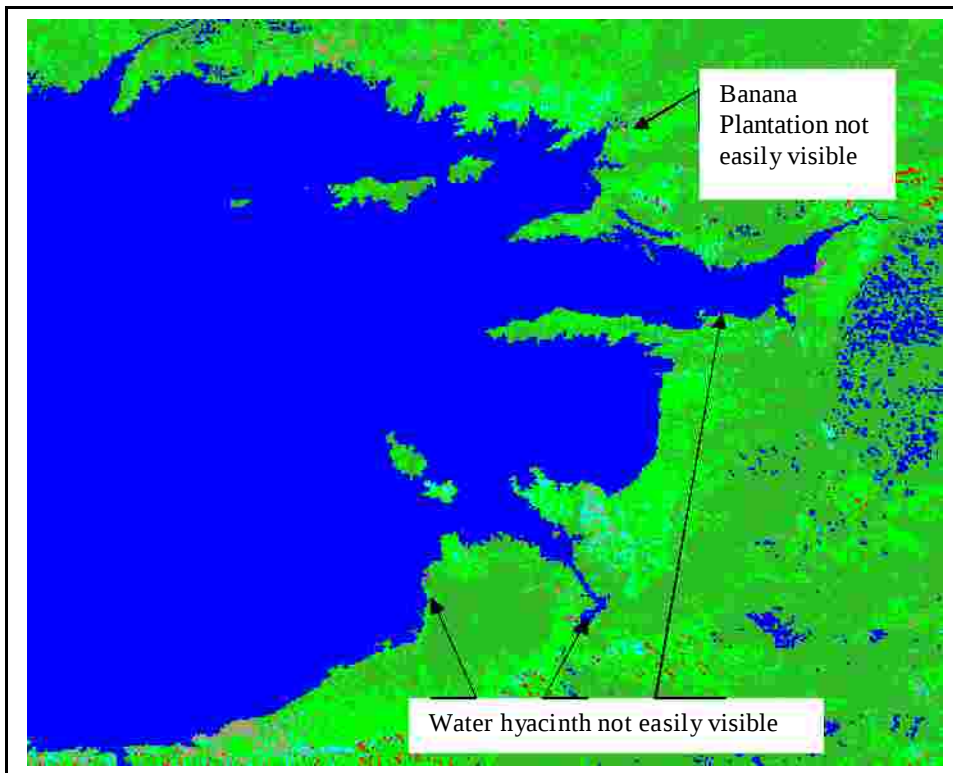


Figure 4.23: Spot 4 (28th August 1999) Multispectral Image classified using the CLUSTER module

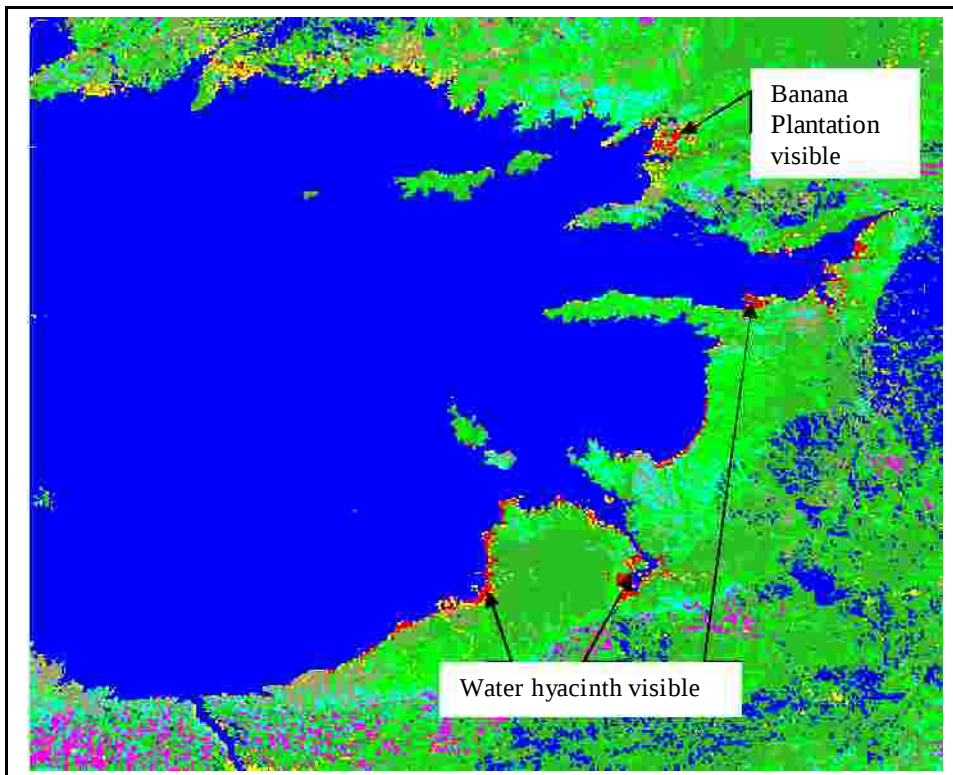


Figure 4.24: Spot 4 (28th August 1999) Multispectral Image classified using the ISOCLUST module

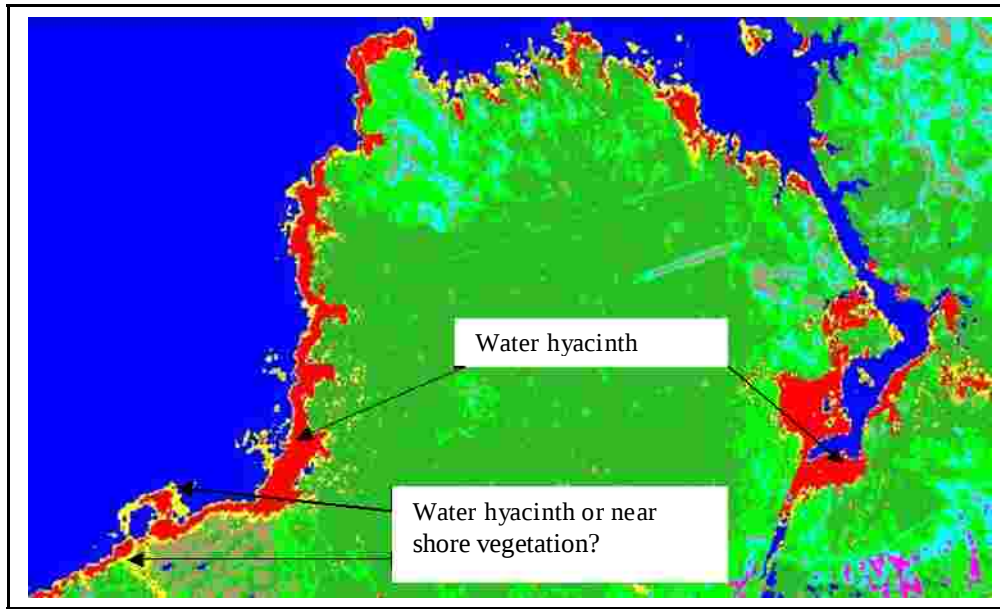


Figure 4.25: Spot 4 (28th August 1999) Multispectral Image showing the possibility of mistaking Scattered weed for near shore vegetation

As can be seen from these outcomes, the ISOCLUST module yielded a better result and was used in this study. The signals representing water and water hyacinth were extracted from the image and merged using the image calculator (mathematical and logical operations) to form representative single clusters respectively. The resulting images were exported to the TIFF format and then to ArcView for editing and analysis.

ISOCLUST is an iterative self-organizing unsupervised classifier based on a concept similar to the well-known ISODATA routine and cluster routines such as the H-means and K-means procedures. It bridges the supervised and unsupervised classification approaches and is suitable for weed monitoring purposes. The steps in the ISOCLUST procedure as implemented with Idrisi 2.0 software are outlined below.

(a) Launch the ISOCLUST dialogue box

The ISOCLUST module is accessed through the Analysis menu, Image processing, Hard classifiers and ISOCLUST as shown in Figure 4.26.

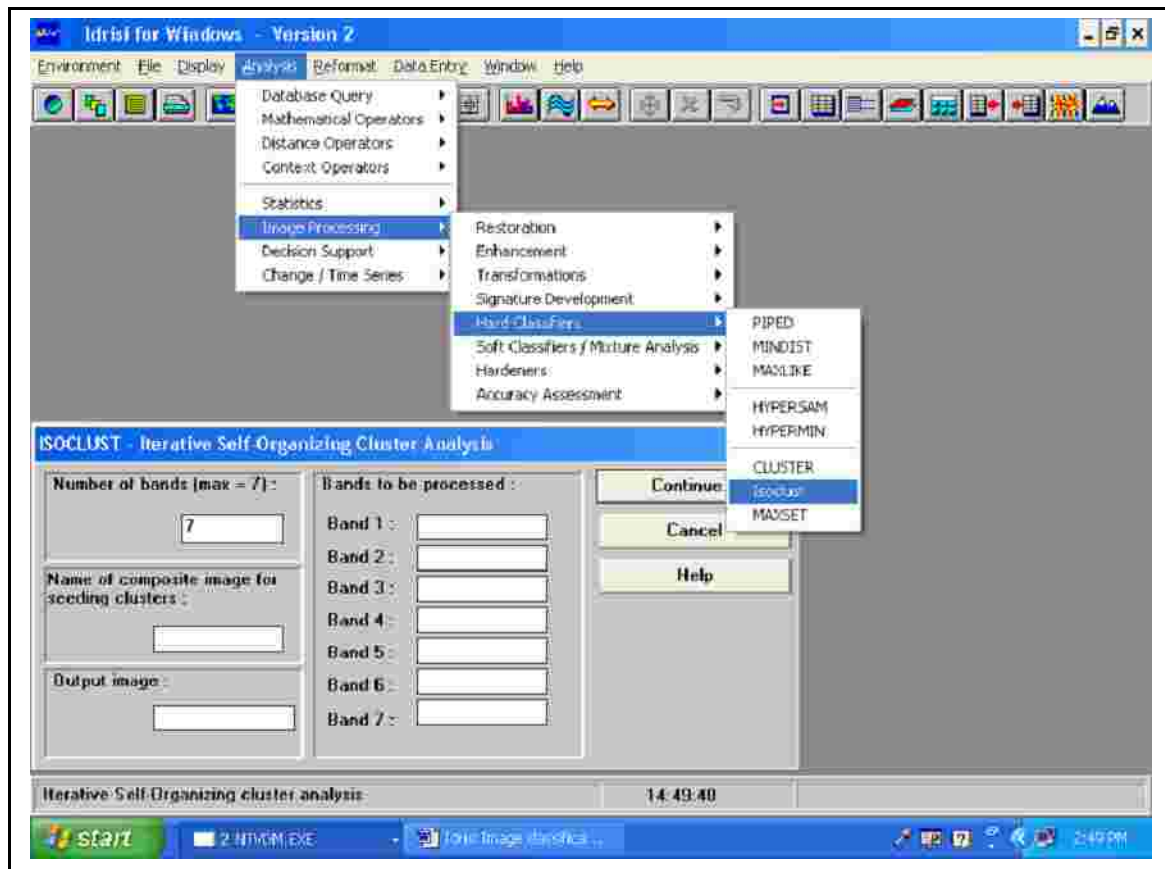


Figure 4.26: ISOCLUST Operation

(b) Enter required parameters in the ISOCLUST dialogue box

ISOCLUST first asks for the number of bands to be used in the classification and their names. The first dialog also requires specifying the name of the composite image to use for seeding clusters, and the name of the output image to be produced. Then click on the CONTINUE button.

(c) View histogram

After clicking the continue button, one will see progress reports at the bottom-right indicating that the CLUSTER and HISTO modules are being run. Then a histogram will appear indicating the frequency of pixels that belong to each seed cluster. These clusters are based on the FINE GENERALIZATION option in cluster, with all clusters being

shown. Examine this histogram for significant breaks of slope. These represent logical levels of generalization from which a classification might be seeded. Once this number of clusters has been chosen, either close the histogram or move it to the side.

(d) Enter required number of clusters and iterations

Specify the number of clusters and iterations desired in the dialog box that appears and click OK. An iterative application of the MAKESIG and MAXLIKE modules in developing the final classification based on all input bands will then be noticed. The clusters to be formed will constitute the legend. For weed spread, 10 clusters would give a fair discrimination of information classes while five is sufficient for high weed spread. Three iterations would do except that more time is required for larger images (e.g. Landsat) depending on the processing capability of the computer (Pentium IV or higher recommended).

(e) View and edit resulting information classes

The information classes resulting from the ISOCLUST operation can be edited using the Legend editor. The interactive LEGEND EDITOR (Figure 4.27) may be activated by holding down the shift key and clicking the right mouse button on the legend category of interest. For raster image legends, the colour of the category may be changed by moving the RGB sliders. For both raster and vector legends, the LEGEND CAPTION may be edited by typing into the LEGEND CAPTION input box. The APPLY button will cause the changes to be shown in the display, while leaving the LEGEND EDITOR dialog box open. Changes must be applied if they are to be saved.

The ADD CATEGORY button allows you to display more legend categories. When Idrisi for Windows renders a legend, it checks the documentation file to see if legend captions are present. If not, legend categories are shown from 0 to the highest value in the image. (The exception to this is with an auto scale display. In this case the number of palette indices in the auto scale range of the palette determines the number of legend

categories shown.) If any legend captions exist in the documentation file, however, legend categories are displayed from 0 to the last legend caption. Thus if an image with values 0-6 is displayed, but only categories 2 and 4 have captions, legend categories will be displayed for only 0-4. In this case, the ADD CATEGORY button may be used to force the display of legend categories for 5 and 6 so that captions may be entered. The same effect could be produced by using DOCUMENT to add legend captions 5 and 6 to the documentation file.

CANCEL will cause any changes made since the last APPL operation to be ignored and will close the LEGEND EDITOR dialog box. Changes that were applied will remain in effect. To revert to the original display, close the map window and redisplay. The LEGEND EDITOR will stay open until it is closed. It does not remain on top (i.e., with highest priority or "focus") however, since you may also be working with other display components or other modules. If the LEGEND EDITOR becomes hidden, choosing it from the WINDOW menu will give it priority, as will using the ALT/TAB key sequence. When all changes have been made and applied, the LEGEND EDITOR may be closed by pressing the CANCEL button or by closing the dialog box.

Changes made with the LEGEND EDITOR cannot be saved until closure of the displayed map window. After changes are made with the LEGEND EDITOR and the map window is closed, one will be asked whether to save the changed legend captions to the documentation file and whether to save the colour changes to a new palette file. For the former, choosing YES will cause the documentation file to be updated while choosing CANCEL will cause the changes to not be saved. For the latter, enter a new palette file name and indicate whether it should be stored in the permanent library or the working directory.

The default output palette filename is the original palette file used in the display. Change this if you do not wish to overwrite the original palette file. If the palette is one that will be used with several different data sets that reside in different directories, it is useful to save it to the permanent library. If it is specific to a single project, then save it to the

working directory. Pressing OK will save the file while pressing CANCEL will not save the palette file.

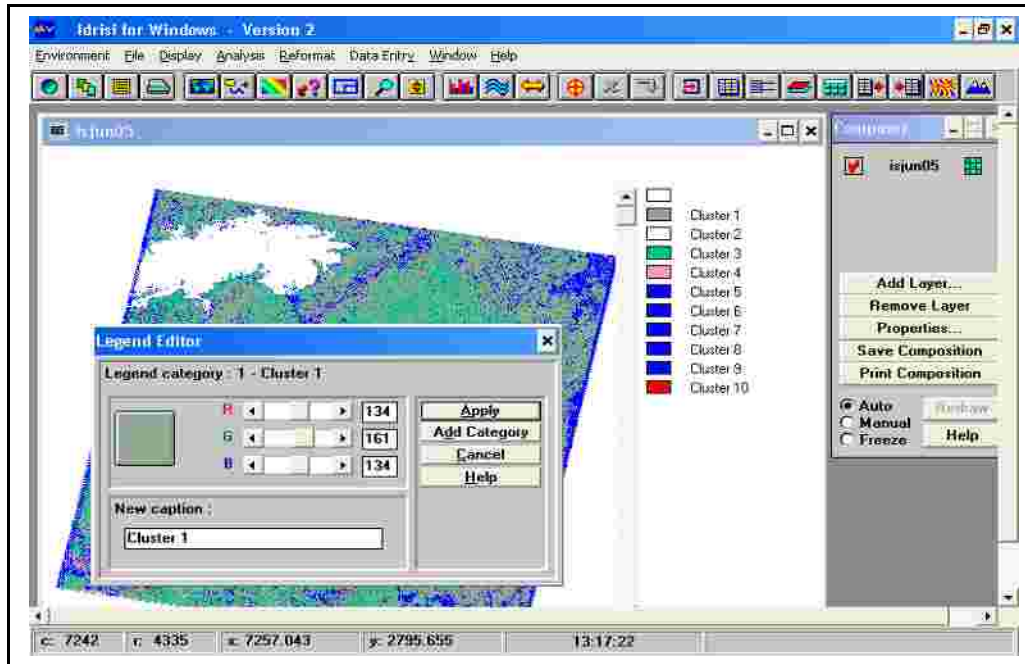


Figure 4.27: The LEGEND EDITOR

(f) Assess classification accuracy

Error calculation in Idrisi is done through the ERROR MATRIX (ERRMAT Module). ERRMAT compares two images for the purpose of accuracy assessment. It is most particularly used in the post-classification assessment of land cover classifications derived from remotely sensed data. One image contains the interpreted land cover map while the second image contains the result of ground truth investigation. From these, ERRMAT creates an error matrix that tabulates the different land cover classes to which ground truth cells have been assigned.

In essence, ERRMAT is identical to CROSSTAB with the exception that no tabulations are made for cells marked with a zero on the ground truth map. Output also includes column and row marginal totals, errors of omission and commission, an overall error

measure, confidence intervals for that figure, and a Kappa Index of Agreement (KIA), both for all classes and on a per category basis.

The ERRMAT module is accessed through the Analysis menu, image processing, accuracy assessment and ERRMAT as shown in Figure 4.28. First input the ground truth image file name, then the categorical map image file name and click OK. The error matrix and associated statistics are then calculated and displayed. You can make a printout of this by clicking on the PRINTER icon.

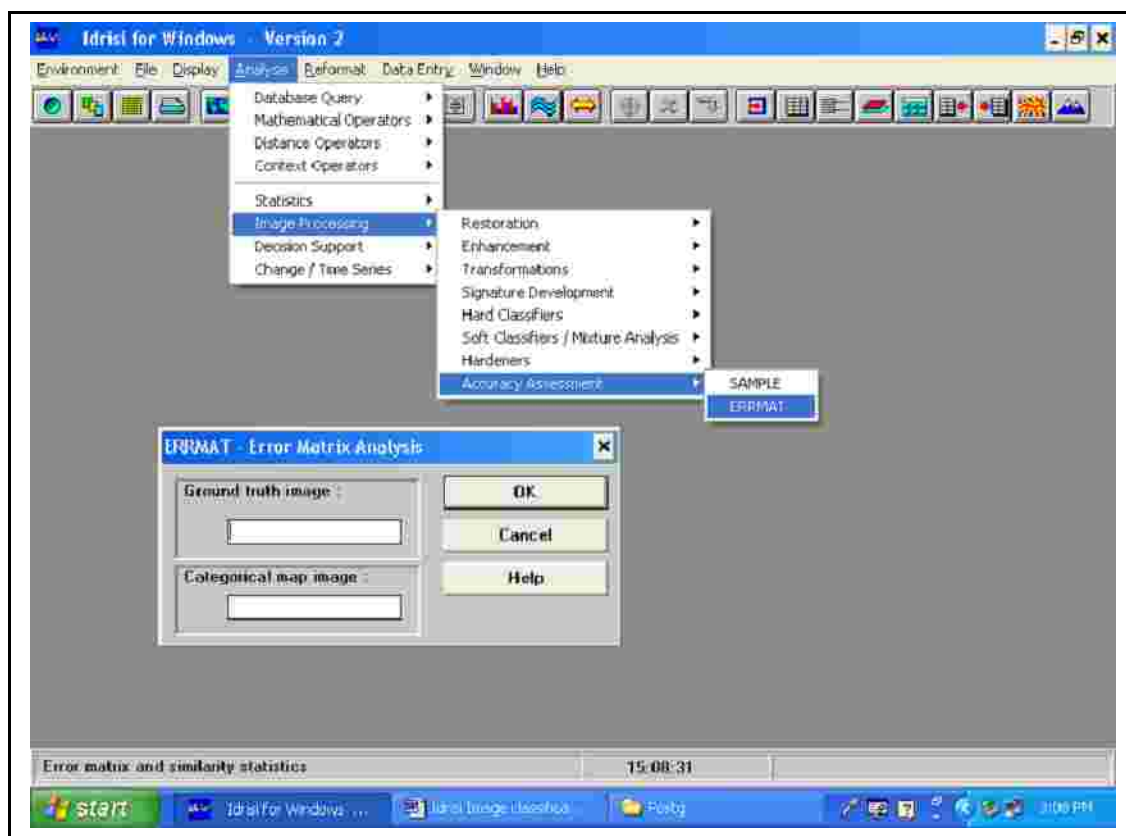


Figure4.28: The ERROR MATRIX Operation

However, since error assessment in Idrisi is only for classification accuracy monitoring, there is also need for an in-process one.

(g) Extract weed and information classes using the IMAGE CALCULATOR

Information classes representing weed or water are extracted from the classified image using the IMAGE CALCULATOR. The IMAGE CALCULATOR interface (Figure 4.29) is similar to that of a hand-held calculator. Some of the symbols are the same, but IMAGE CALCULATOR always produces an image as a result. First choose the operation type: Mathematical Expression or Logical Expression. Use the later when extracting clusters from an image to form a new one.

Then enter a name for the output file, as well as the text for the calculation of the mathematical or logical expression. Expressions can contain up to 255 characters. Use the keypads to form the expression needed. The left keypad contains numeric operand keys, and keys for round and square brackets. The round bracket keys are provided allow prioritization of different parts of the expression. The left keypad also has an insert image button which brings up a file pick list to enable the easy selection of file names. Square brackets must be placed around image names. This will be done automatically if the insert image button is used to enter file names. The right keypad displays the operators available for both mathematical and logical Some of the operators require round brackets. These are automatically written if the operator is chosen from the keypad.

PROCESS EXPRESSION attempts to calculate the expression in the EXPRESSION EDITOR. If a syntax error is encountered, processing and a message is displayed; otherwise IMAGE CALCULATOR's progress bar displays the status of the calculation. Normally processing an expression will create a new image, although if the user has selected Mathematical Expression and entered a syntactically correct expression that does not contain a file operand into the editor, a message box will display the numeric result of that operation. Logical operations always create Boolean images.

The contents of an expression and the output file name can be saved to a text file with an ".EXP" extension using the SAVE EXPRESSION button. A previously saved file can be brought into the EXPRESSION EDITOR using the OPEN EXPRESSION button.

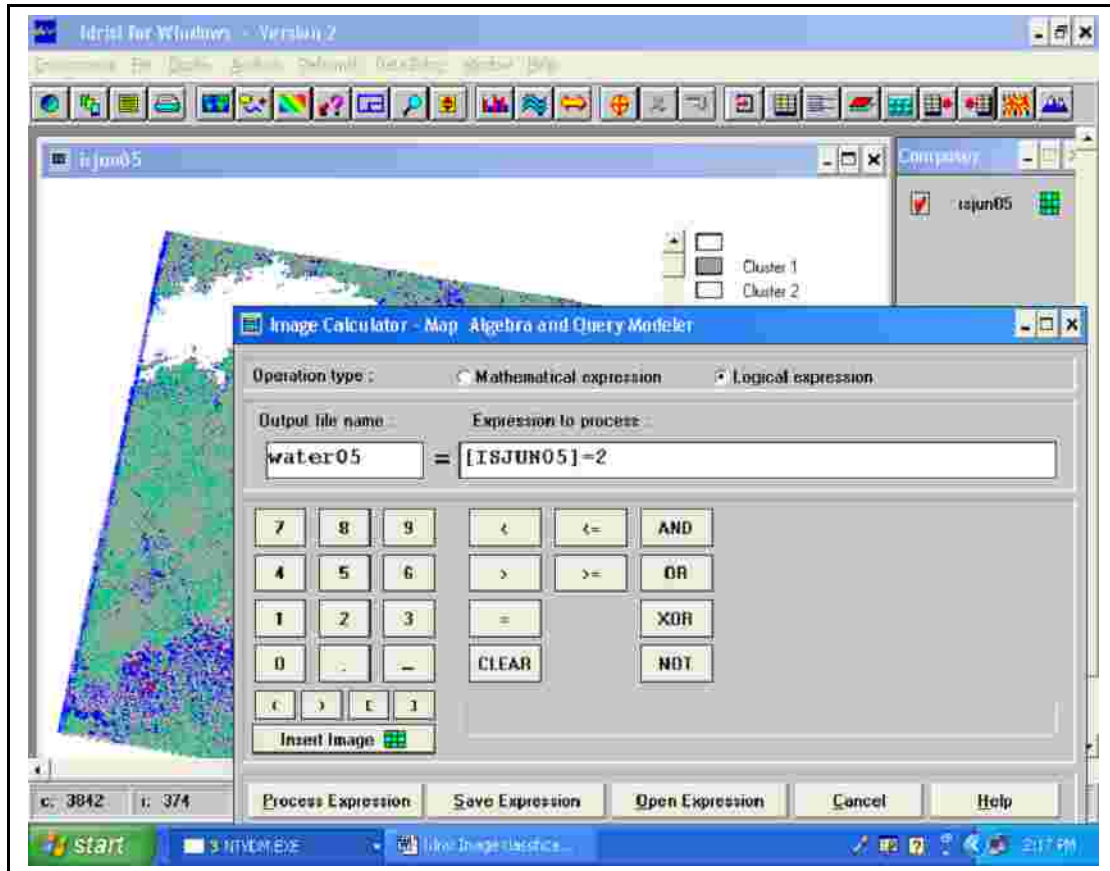


Figure 4.29: IMAGE CALCULATOR Operation

Figure 4.30 below is a summary of the ISOCLUST image classification procedure.

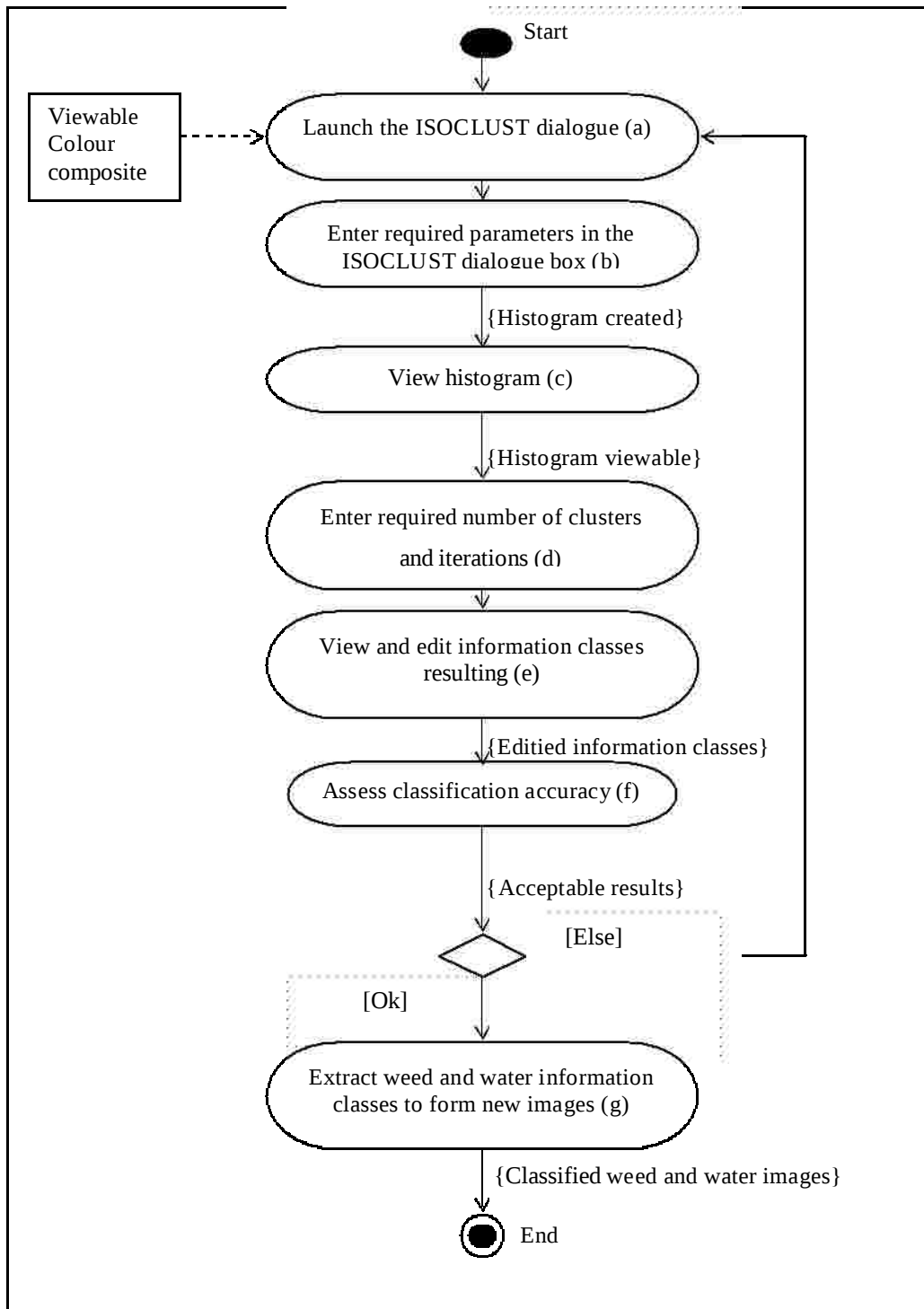


Figure 4.30: Image classification activity diagram

(xiii) Assess error

No error assessment was done in this study since there was no corresponding data to enable creation of an error matrix.

4.1.4 Data analysis

Data analysis constituted analysing images for weed spread, producing maps showing the spread of the weed and storing the data into a database.

(xiii) Analysing images in ArcView GIS 3.2a

The extracted signals (for water and weed) from Idrisi 2.0 were exported to Tiff format and then imported into ArcView software for editing, calculation of the area covered by water hyacinth and further analysis as summarized in Figure 4.31.

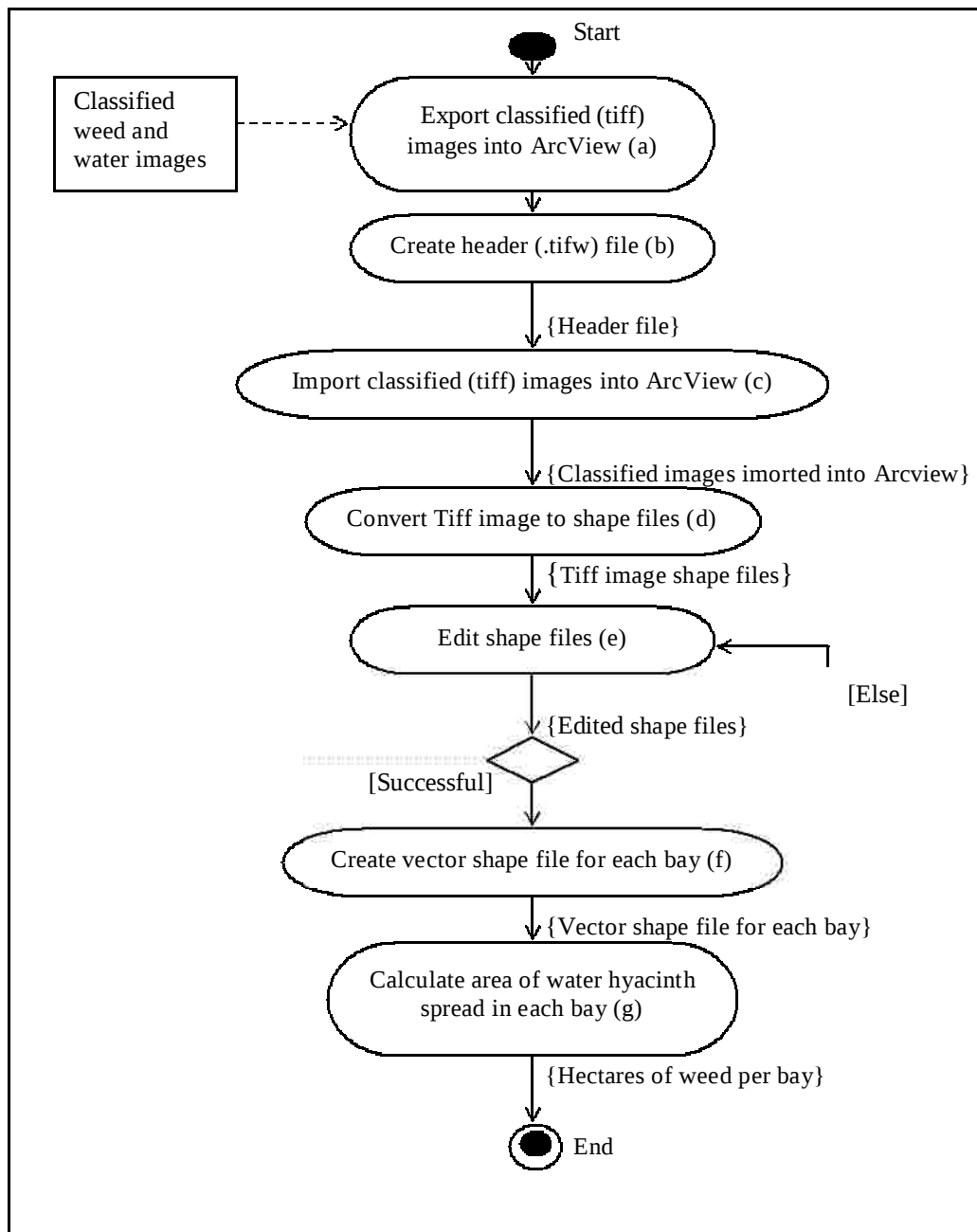


Figure 4.31: Image analysis activity diagram

(a) Export image to Tiff format using Tifidris Operation

The extracted signals (for water and weed) should be exported to Tiff format using the TIFIDRIS operation in readiness for analysis in ArcView GIS 3.2a. The TIFIDRIS dialogue box (Figure 4.32) is accessed through the file menu, import/export, export, desktop publishing format and TIFIDRIS. TIFIDRIS first requires that you specify whether the conversion will be from Tiff to Idrisi for Windows or vice versa.

Since the conversion is from Idrisi for Windows to Tiff, specify the name of the Idrisi file to be exported. Indicate whether you wish to export a palette file with it and if so, specify its name (in case one does not export a palette file with the image, the image file is exported as a grey-level Tiff image). One is then required to specify the page resolution to use. The default, 90 dots per inch, is sufficient. Finally, input a name for the output Tiff file.

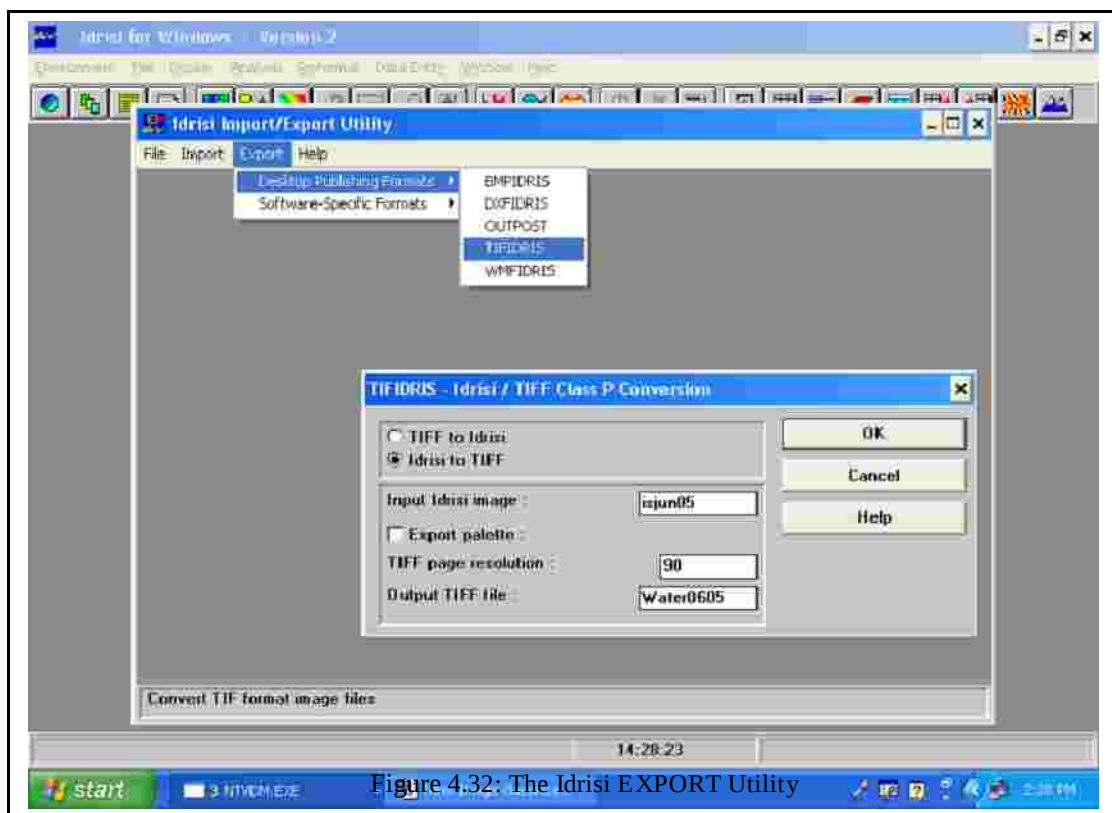


Figure 4.32: The Idrisi EXPORT Utility

(b) Creat a header (.tifw) file

A new header file must be created to keep the coordinate system of the Tiff image exported from Idrisi intact in ArcView. This can be done by typing the necessary information into a simple text file in the “Notepad” program. The following information is needed:

- The dimension of a pixel in map units in the x-direction
- Rotation term of row (which is 0 in our case)
- Rotation term of column (which is 0 in our case)
- The dimension of a pixel in map units in the y-direction
- The x-coordinate of the centre of the upper left pixel in map units (can be found from the original satellite image when opened in Idrisi under file describe (xmin and ymax) or from the files accompanying the satellite image upon purchasing)
- The y-coordinate of the centre of the upper left pixel in map units (can be found in a similar way to x-coordinate above).

An example of a header file for Spot 4 with 20m pixel resolution is given below:

```
20
0
0
-20
X min
Y max
```

The file can be saved as a text file (extension .txt) with the same name as the exported tiff file. However, after the file has been saved the extension has to be changed on the header file by double-clicking on its icon and changing it from **.txt** to **.tifw** so that ArcView can automatically recognise the file. To do this, first open the folder where the files have been stored and thereafter click on the name of the file to change the extension.

(c) Import classified (tiff) images into ArcView

Work with PROJECT components: In ArcView, one works with a PROJECT. A PROJECT is a collection of documents (Views, Tables, Charts, Layouts, Script Editors), document user interfaces, scripts, and other types of objects. When you save a PROJECT to disk, you are saving a complete snapshot of the state of ArcView at the time of the save operation. A PROJECT file on disk is normally a text file with the extension .apr. All activity takes place within a PROJECT. You cannot have multiple PROJECTS open at the same time; however, you can import one PROJECT into another.

Launch ArcView and click CANCEL in the Welcome to ArcView GIS dialogue box. From the File menu, choose NEW PROJECT to create a PROJECT. ArcView creates a new PROJECT called Untitled and opens the PROJECT window (Figure 4.33). When you've completed your work, you can click the SAVE PROJECT button. ArcView then displays a dialog box in which you name and save the PROJECT. If you select the name of an existing PROJECT, ArcView asks if you want to replace it. It is important to set the working directory in ArcView before starting to work with themes. To set the working directory activate the PROJECT WINDOW and select PROJECT, PROPERTIES and under WORK DIRECTORY type the path to the file where the data will be stored (for example, C:\Spot\1999).

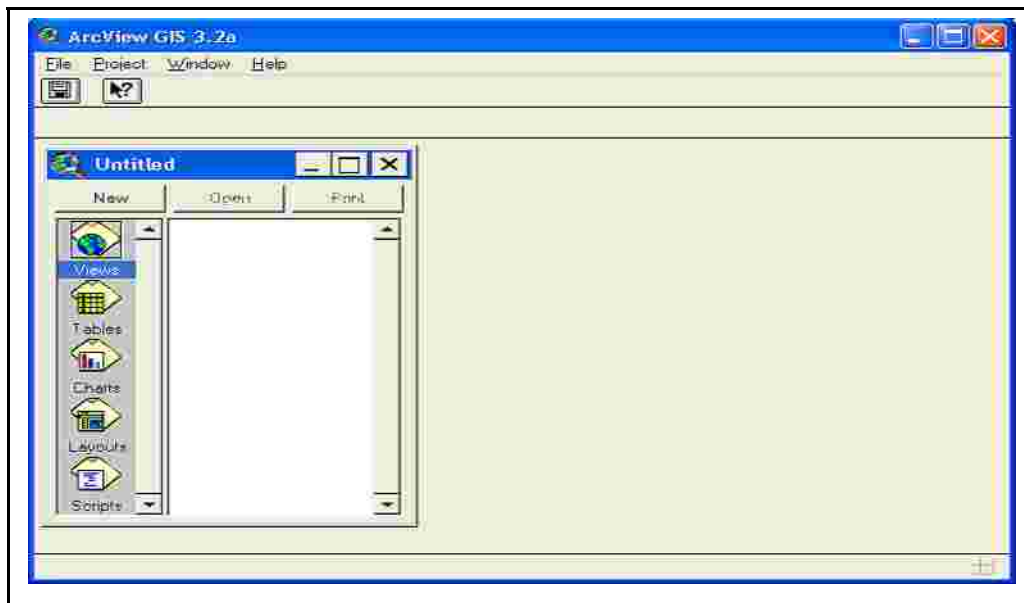


Figure 4.33: The Untitled PROJECT window

The Spatial Analyst extension is required for many activities in the steps below and must be loaded after launching ArcView 3.2a. To load the Spatial Analyst, activate the ArcView PROJECT window. From the File menu, choose EXTENSIONS. This will bring up the EXTENSIONS dialog box. Check the box next to Spatial Analyst in the EXTENSIONS dialog box (Figure 4.34). When you check the box, a check mark will appear. Press OK to load the extension and close the Extensions dialog box. When the EXTENSION loads, it adds new functionality to your current ArcView session. If you want the Spatial Analyst EXTENSION to load automatical every time you start ArcView, press the MAKE DEFAULT button after checking the Spatial Analyst. The next time you start ArcView the Spatial Analyst will automatically load.

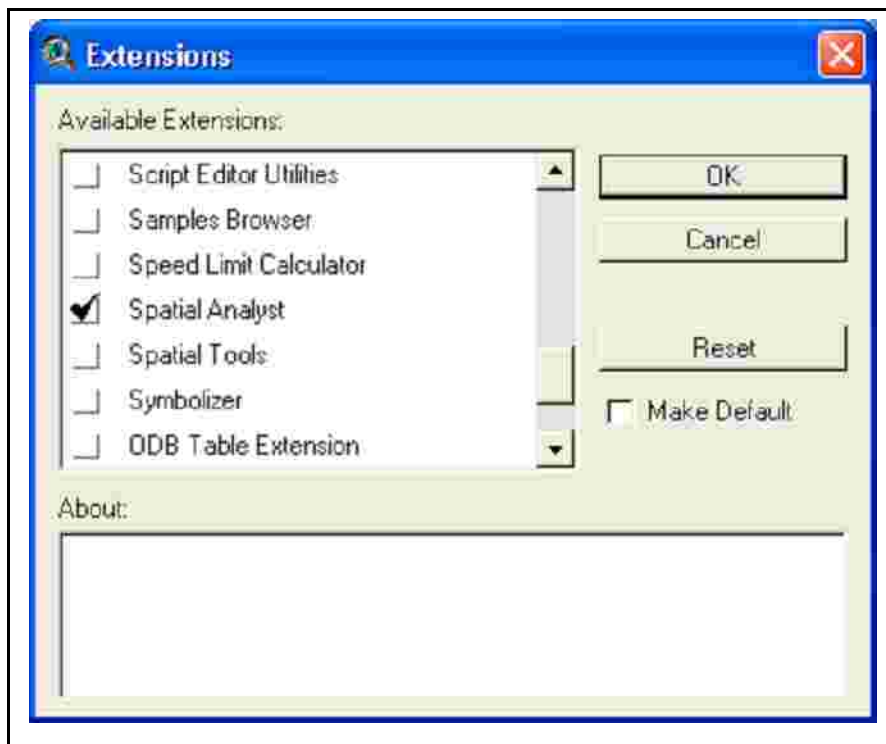


Figure 4.34: The EXTENSIONS dialog box

Edit an image's legend: An image's legend can be edited with the IMAGE LEGEND EDITOR. This enables one to choose the bands and colours used to draw the images in a VIEW and control what they show. An image's legend can only be edited in ArcView after the image has been added as a THEME to a VIEW.

To open or create a PROJECT, choose OPEN PROJECT or NEW PROJECT from the File menu. To create a new VIEW in the PROJECT window, click the VIEWS button and then press the NEW button. A new, empty VIEW will appear in your PROJECT (Figure 4.35). Then add a theme to the VIEW and set the VIEW's properties. Setting a VIEW's properties lets one change the VIEW's name, store comments about the VIEW, specify the coordinate and measurement units the VIEW will use, specify the map projection that will be used, etc. The VIEW's name that appears in the title bar and in the PROJECT window is a VIEW's property. The VIEW's properties should not be set before adding themes or starting to work with a new VIEW created.

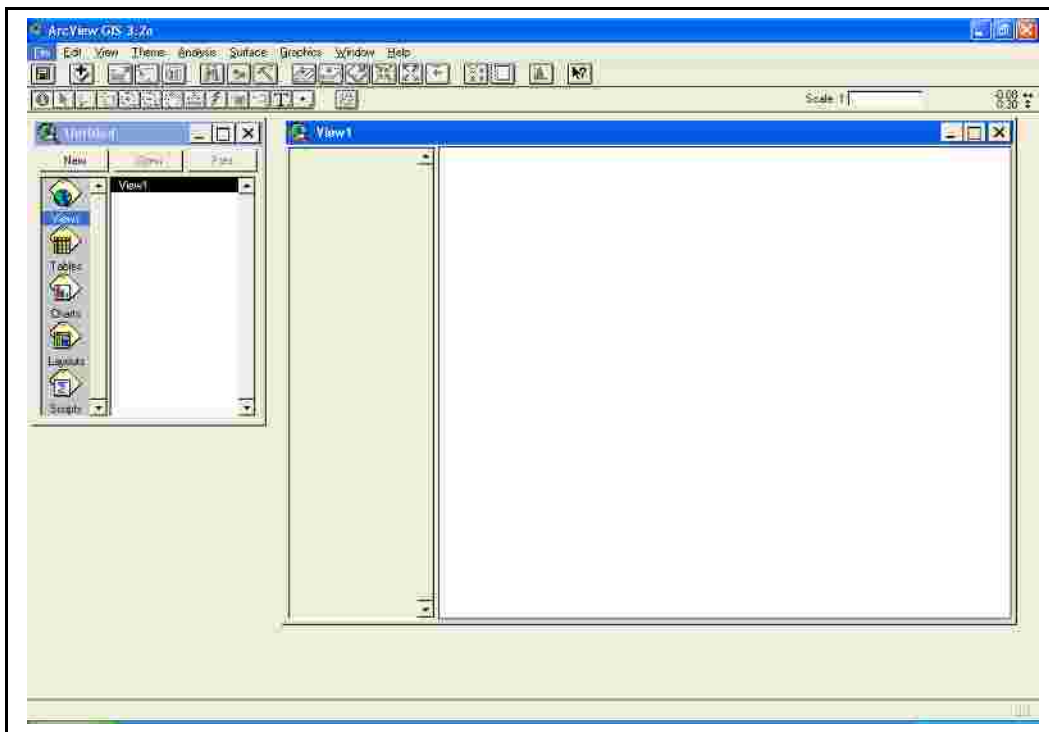


Figure 4.35: A new empty VIEW

Until changing the name of a VIEW, ArcView names new VIEWS in numerical order: VIEW1, VIEW2, VIEW3, etc., according to when they are created. VIEW names may include multiple words, spaces, numbers and punctuation. To change the name of a VIEW either:

- From the VIEW menu choose PROPERTIES. The VIEW Properties dialog box will be displayed. Enter a new name for the VIEW in the NAME text box and press OK.
- Or in the PROJECT window, click once on the name of the VIEW in the list of VIEWS. From the PROJECT menu choose RENAME. Enter a new name for the VIEW and press OK to effect the changes.

After a VIEW is created a THEME can then be added. The ADD THEME dialog box (Figure 4.36) lets you add one or more THEMES to a VIEW from existing data sources. To add several THEMES to a VIEW at once, hold down the SHIFT key and click on them in the list of files. To add an image to a VIEW, either click the ADD THEME button or ADD THEME in the VIEW menu. The ADD THEME dialogue box will appear. In the DATA SOURCE TYPES box, choose IMAGE DATA SOURCE. Navigate to the directory that contains the image you want to add. Double-click on the directory name to list the image data sources it contains or browse to the directory that contains the image of interest. Double-click the image data source you wish to add. The image will be added to the VIEW. When you add a THEME to a VIEW, ArcView does not immediately draw it on the VIEW. This enables one to first edit the THEME's legend, or change the drawing order if there are several THEMES, etc. To draw a THEME that was added, click the check box next to the THEME's name in the VIEW's Table of Contents.

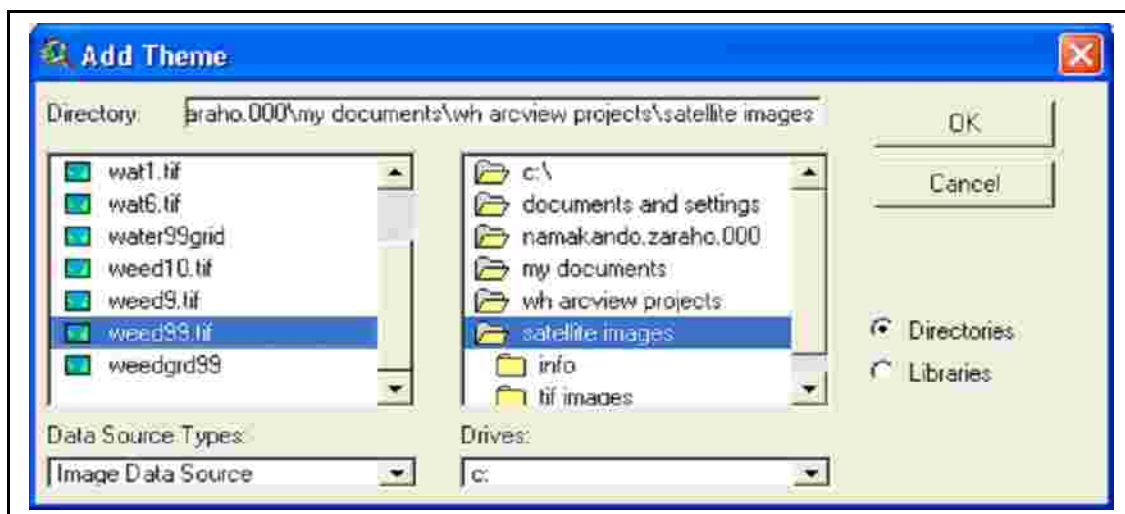


Figure 4.36: The ADD THEME dialog box

After adding a THEME to a VIEW, the display symbol of can then be edited. To edit an image's legend:

- Activate the image THEME of interest in the VIEW's Table of Contents
- Either double-click the name of the image THEME in the VIEW's Table of Contents or click the image THEME once to make it active, and then click the LEGEND EDITOR button or choose EDIT LEGEND from the THEME menu. This will display the IMAGE LEGEND EDITOR dialogue box (Figure 4.37). Click COLORMAP



Figure 4.37: The IMAGE LEGEND EDITOR dialogue box

- In the IMAGE COLORMAP dialogue box (Figure 4.38) that appears, double click the rectangle opposite “0”.

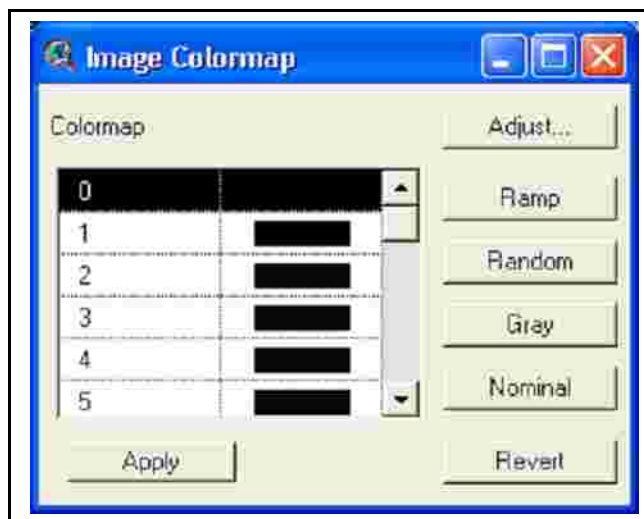


Figure 4.38: The IMAGE COLORMAP dialogue box

- In the COLOR dialogue box (Figure 4.39) that appears, set the Foreground colour to transparent by clicking the top left square marked X..

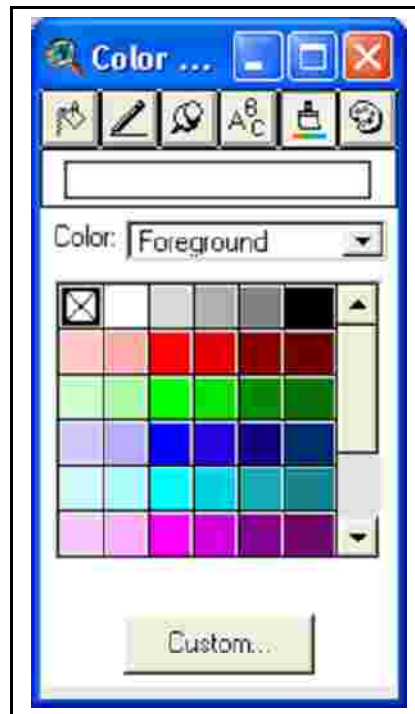


Figure 4.39: The COLOR dialogue box

- Click APPLY on the IMAGE COLORMAP dialogue box. The colour of the features in the THEME the legend is associated with will change and the features will become visible.
- Activate the IMAGE COLORMAP dialogue box and double click the rectangle opposite “1”.
- In the COLOR dialogue box that appears, set the Foreground colour to red (weed) or blue (water) by clicking on the respective COLOR square. The colour of the rectangle next to “1” will change accordingly (Figure 4.40).
- Click APPLY on the IMAGE COLORMAP dialogue box. The colour of the features in the THEME the legend is associated with will change.
- Close the dialogue box.

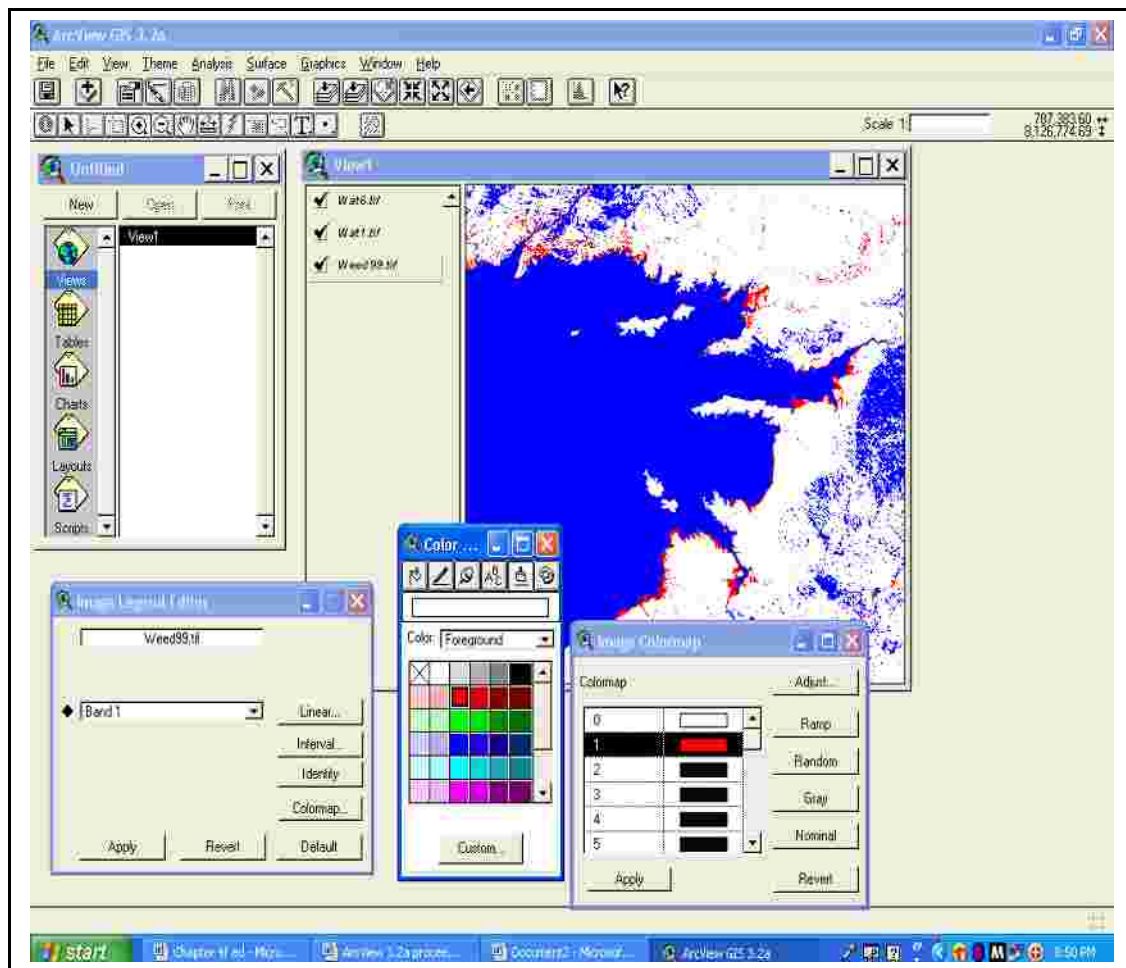


Figure 4.40: Editing the image legend

(e) Convert Tiff image to shapefile

After the tiff files have been opened in ArcView they have to be converted into shapefiles. This is done using the Spatial Analyst extension. The files have first to be converted into grid files and thereafter into shapefiles. It is important to ensure the working directory is set in ArcView before starting to convert the files.

Activate the image THEME that has to be converted to grid THEME by clicking on it. From the THEME menu, choose CONVERT TO GRID to display the CONVERT TO GRID dialogue box (Figure 4.40). Provide a name and directory for the output grid dataset, then press OK. Choose to add the new grid THEME to the VIEW.

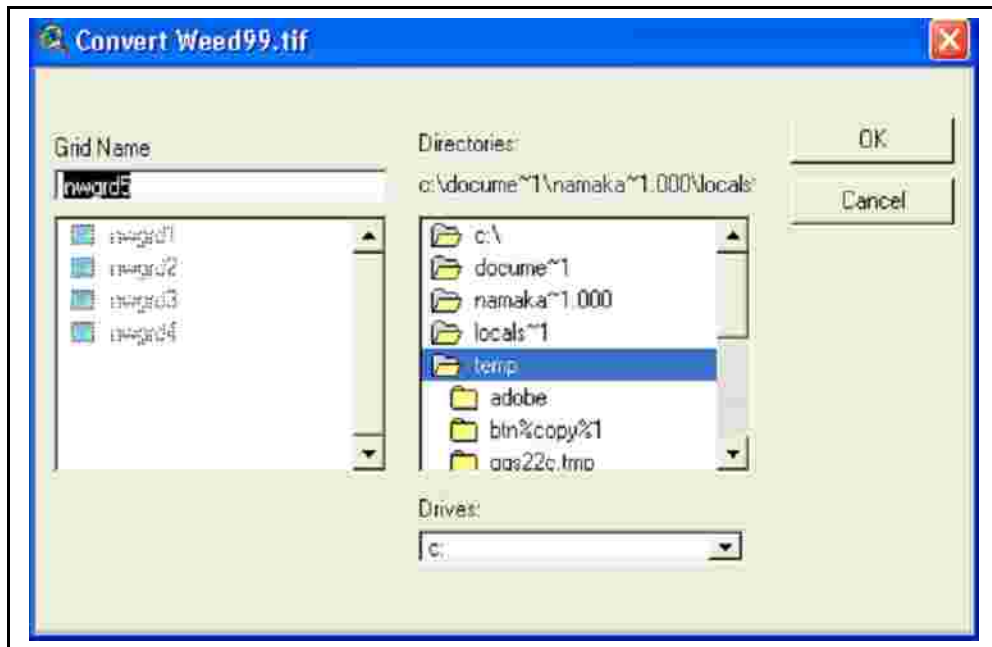


Figure 4.41: The CONVERT TO GRID dialog box

To convert a grid THEME to a polygon feature THEME, click on the grid THEME you want to convert to a polygon feature THEME, to make it active. From the THEME menu, choose CONVERT TO SHAPEFILE to launch the CONVERT TO SHAPEFILE dialogue box (Figure 4.42). The CONVERT TO SHAPEFILE dialog box converts the active THEME into an ArcView shapefile, builds a spatial index for the new shapefile, and lets one add the shapefile as a THEME to the current VIEW. If some features are selected on the THEME converted, only these features will be converted. Provide an output name and directory for the output shapefile created during conversion. Press OK. Choose to add the new polygon feature THEME to the VIEW. By default, the shapefile that is created is in the same map units and coordinate system as the data source of the THEME converted. If the VIEW is projected, one will be prompted for the output shapefile to be in projected units or in the same units as the data source.

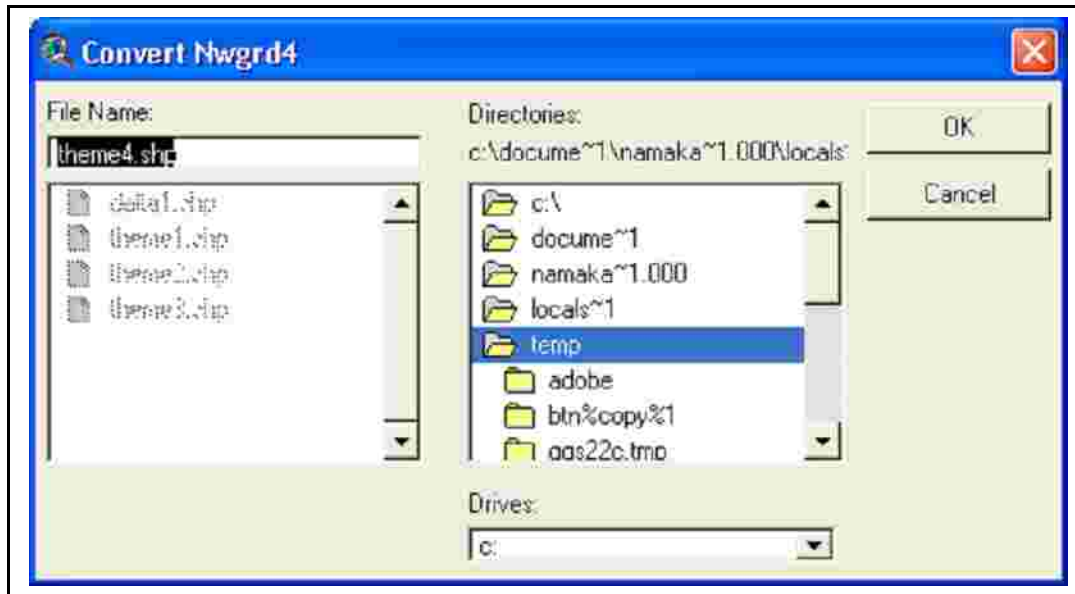


Figure 4.42: The CONVERT TO SHAPEFILE dialog box

(f) Edit shapefiles

After the shapefiles are created, they can be manually edited by deleting the signals indicating vegetation but are outside the Lake or not located adjacent to the Lake water boundary. ArcView allows to edit a THEME that is based on an ArcView shapefile if one has file write permission on the shapefile.

To make a shapefile THEME editable, first activate it. Then choose START EDITING from the VIEW's THEME menu. ArcView allows one to edit only one THEME in a VIEW at a time. The pointer tool can be used to select the features to be deleted. Deleting will be effected by pressing the DELETE key on the keyboard. If one chooses START EDITING on a THEME while editing another THEME, one will be prompted to save the edits on the THEME previously edited before editing on the second THEME is enabled. A dashed line around the THEME's check box in the Table of Contents indicates that one can edit that THEME (Figure 4.43).

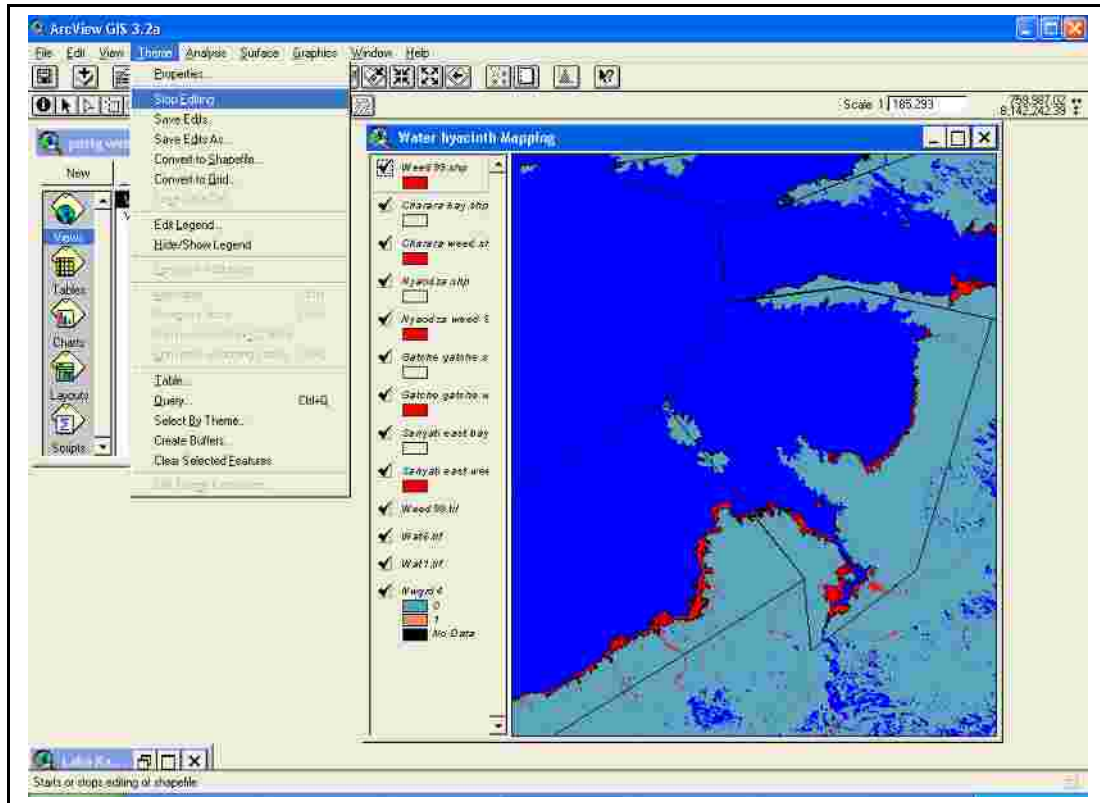


Figure 4.43: Editing a THEME

Choose UNDO FEATURE EDIT from the Edit menu to undo the last edit made to the shapefile. Choosing this option repeatedly enables one to successively undo all the edits made since editing started. UNDO FEATURE EDIT undoes changes to the feature geometry in the shapefile and the corresponding changes to the feature attribute table. The REDO FEATURE EDIT option lets one re-apply the changes.

To save the edits and continue editing, choose SAVE EDITS from the THEME menu. This will save all edits made to the THEME during the current editing session. Once the edits are saved, one can continue to edit the THEME but is unable to undo or redo any edits that were made prior to choosing SAVE EDITS.

To save the edits to a new THEME, choose the SAVE EDITS AS option from the THEME menu. This will save the edits to a new shapefile rather than changing the original shapefile. The edited version of the original THEME will be written out to the new shapefile, editing will be disabled on the original THEME, and the edits will not be written to the original shapefile. The new shapefile will be added to the VIEW as a THEME, the same editing environment and legend will be set for this THEME, and editing will be started on the new THEME automatically. Now any edits done will be to the new THEME.

To stop editing a THEME and commit the edits, choose STOP EDITING from the VIEW's THEME menu. One will be prompted to save the edits.

The display colour for a shapefile can be edited using the SHAPEFILE LEGEND EDITOR (Figure 4.44). The LEGEND EDITOR is launched by clicking EDIT LEGEND in the THEME menu or double clicking the THEME of interest in the VIEW's Table of contents. Double click the Symbol in the LEGEND EDITOR to edit it. Set the required feature colour in the COLOR Dialogue box. Click APPLY the LEGEND EDITOR to effect the colour changes. Close the LEGEND EDITOR and the COLOR dialogue box.

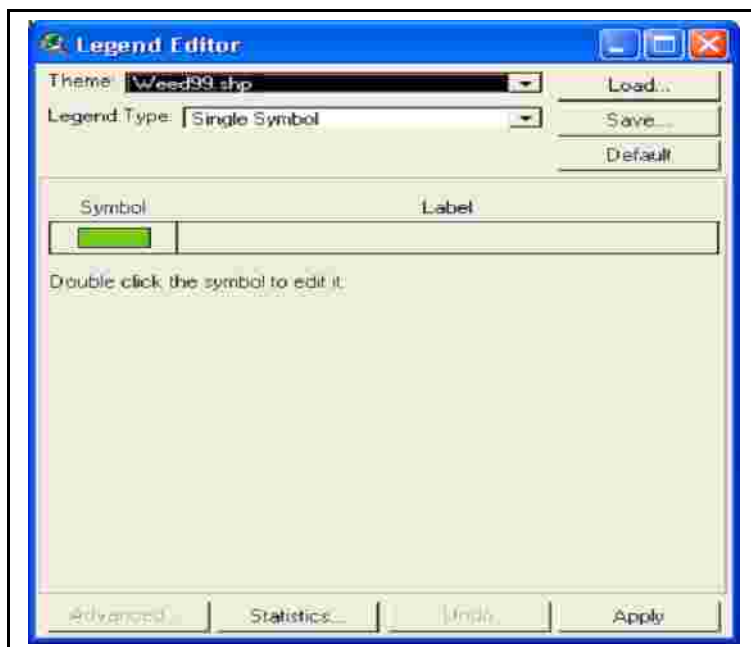


Figure 4.44: The SHAPEFILE LEGEND EDITOR

(g) Creat a vector shapefile for each bay

Creating a shapefile for each bay allows for the THEME on THEME selection analysis. This eventually aids in the selection of water hyacinth (in a weed or water hyacinth THEME) weeds that fall completely within each bay. A shapefile for each bay is an irregular polygon that is transparent and created by onscreen digitising around the water image exported from Idrisi. Shapefiles can be created, for example, for Charara bay, Nyaodza bay, Gache gache, Sanyati bay, etc. To create an irregularly shaped polygon feature, make the THEME active and from the THEME menu, choose Start Editing to put the THEME in edit mode. Click the Drawing tool palette and in the list of tools that pops down, click the Polygon tool. In the VIEW, click the left mouse button where you want the polygon to start, click each vertex around the polygon's boundary and then double-click the final vertex.

The Select by THEME dialog box selects features in the active THEME(s) based on their location in relation to the selected features in another THEME. You can also use this dialog box to select features in the active THEME based on their location in relation to the selected features in the same THEME.

To select a THEME using another THEME:

- Make the THEME active that contains the features you wish to select (water hyacinth THEME).
- In the THEME menu, choose Select By THEME to launch the Select by THEME dialogue box (Figure 4.45).

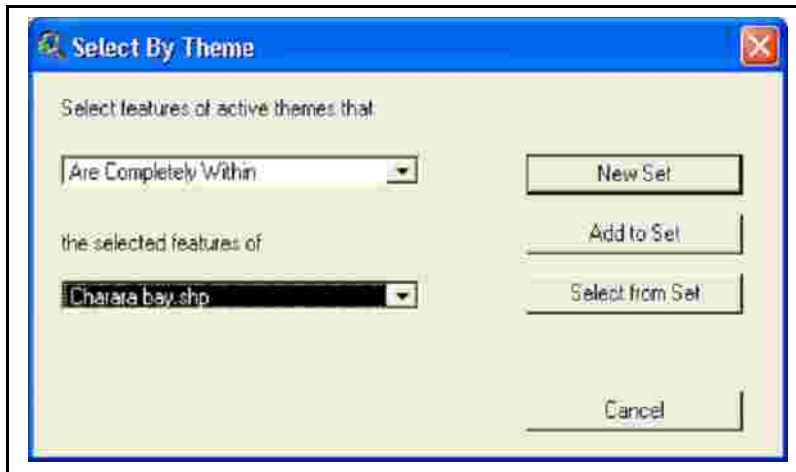


Figure 4.45: The Select by THEME dialogue box

- Choose the spatial relation type (Are completely within). This phrase qualifies the selection. ArcView provides several spatial relation types. The types you see depend on the selector THEME's feature type. In some cases, you may want to pick the selector THEME before choosing the spatial relation type.
- Pick the THEME whose features will be used to make the selection (Shapefile for a bay). This is the selector THEME. ArcView selects features in the target THEMES using the selected features of the selector THEME. If no features in the selector THEME are selected, ArcView uses all the selector THEME's features to select.
- Choose new set as the selection method. The selected features will be displayed in the VIEW using a selector colour (e.g yellow)
- Choose Convert to shapefile from the THEME menu.
- In the Convert to shapefile dialogue box that appears, provide an output name and directory for the output shapefile created during conversion. Press ok and choose to add the new THEME to the VIEW.
- Edit the new shapefile if necessary and save.

After creating a shapefile for each bay and selecting the weed therein (Figure 4.46), the next step is to calculate the spread of the weed in each bay.

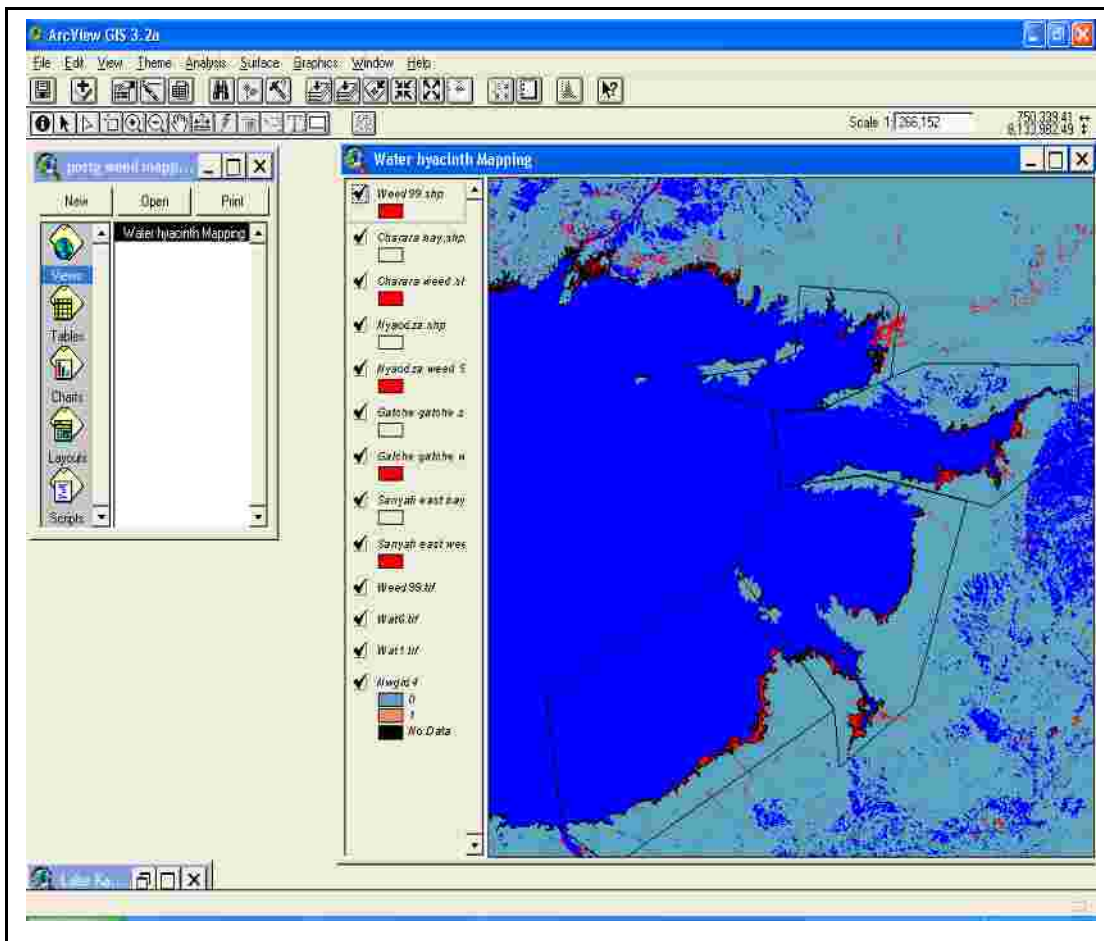


Figure 4.46: Shapefile for each bay

(g) Calculate the area of weed spread

To calculate the area of the weed spread in ArcView:

- Activate the shapefile of interest
- Either click OPEN THEME in the THEME menu or on the OPEN THEME TABLE button to open the THEME attribute table.
- Make the table editable by activating it and clicking START EDITING in the Table menu
- Select ADD FIELD from the Edit menu to launch the FIELD DEFINITION dialogue box.
- Add a NUMERIC FIELD to the table and name it AREA (Figure 4.47)

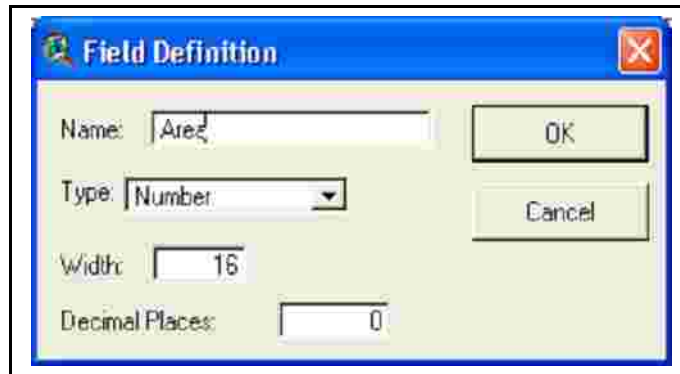


Figure 5.47: The FIELD DEFINITION dialogue box

- Click OK in the Field Definition dialogue box.
- Press the CALCULATOR button to display the FIELD CALCULATOR dialogue box (Figure 4.48).

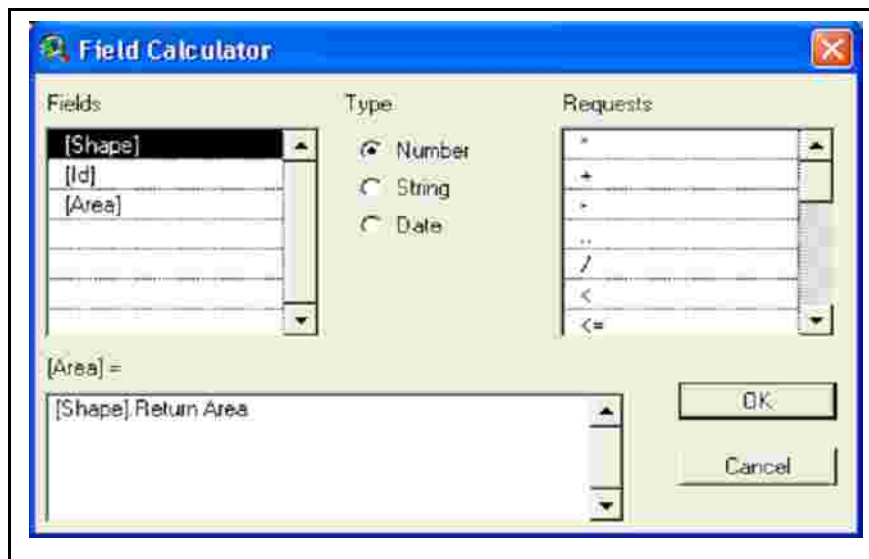


Figure 4.48: The FIELD CALCULATOR dialogue box

- In the Field appearing ([Area]=), type **[Shape].ReturnArea** and click OK. ArcView will now calculate the area of each polygon in the shapefile (Figure 4.49). To get the total area of the weed in the shapefile use the **Sum** function. For more calculations of the weed spread, the data file (.dbf) can be opened in an Excel spreadsheet.

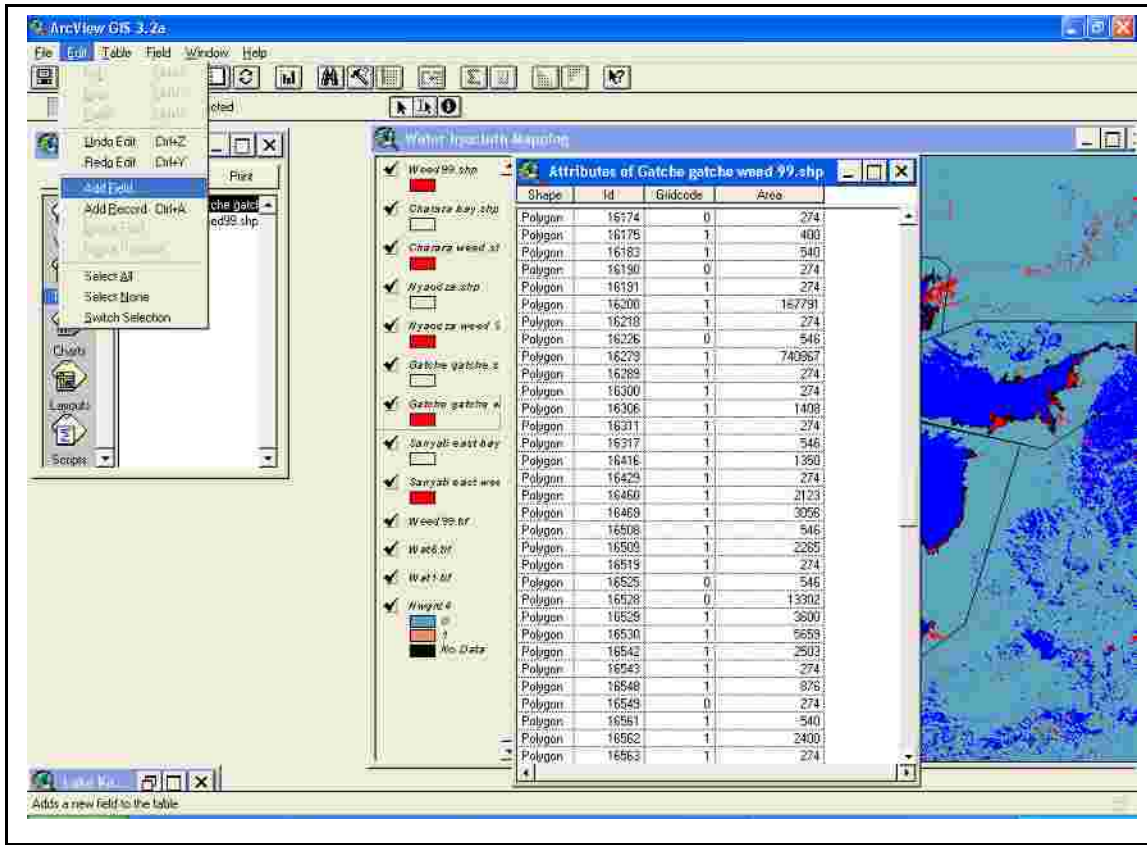


Figure 4.49: The THEME ATTRIBUTE TABLE showing the area (m²) of each polygon in the shapefile

(xiv) Producing maps of water hyacinth spread

This being the key output of the weed monitoring procedure enabled visualisation of the weed occurrence on Lake Kariba. This step further contributed to efficient reporting on the weed situation through inclusion of maps in this written report.

A map of weed spread can be created in a LAYOUT. A LAYOUT is created from components in the PROJECT such as VIEWS, CHARTS, and TABLES. One can also draw various graphics on the LAYOUT too. To create a new LAYOUT in the PROJECT:

- Ensure the THEME to be mapped is displayed in a VIEW that is active.
- From the VIEW menu, click LAYOUT.
- In the TEMPLATE MANAGER (Figure 4.50), select LANDSCAPE and click OK.

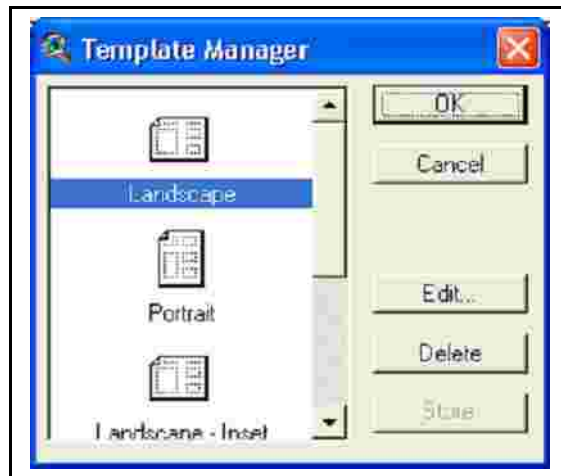


Figure 4.50: The TEMPLATE MANAGER

- Choose NEW LAYOUT in the VIEW-LAYOUT dialogue box that appears (Figure 4.51)

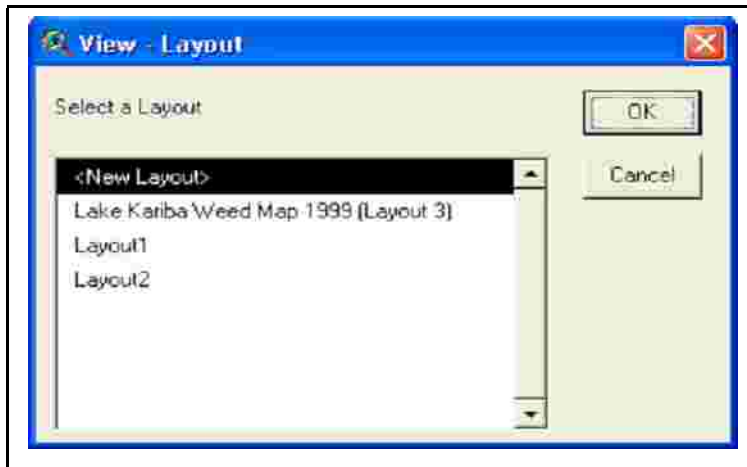


Figure 4.51: VIEW-LAYOUT dialogue box

- Click OK to display a new LAYOUT (Figure 4.52). The LAYOUT will display the THEMES in the active VIEW. The Scale bar, Legend and North arrow are added to the LAYOUT by default. The LAYOUT and its elements can be edited. Double-clicking any graphic in the layout can enable its properties to be changed. In the case of a VIEW or legend, one will see a PROPERTIES menu. For any graphic primitive, the ArcView's Symbol Window will be seen. The Name of the

LAYOUT can be changed through the PROPERTIES dialog box in LAYOUT menu.

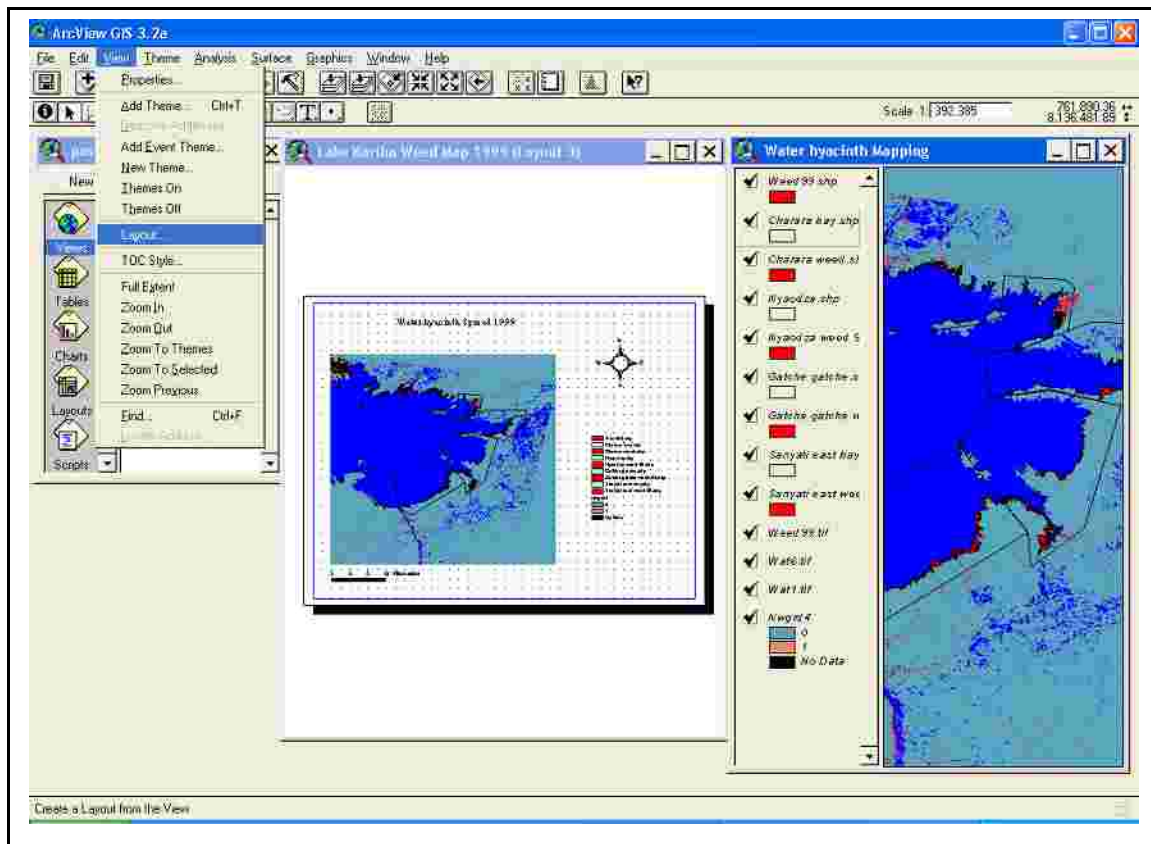


Figure 4.52: Creating a map LAYOUT

- Print the LAYOUT when finally satisfied with its appearance and store a hard copy.
- Activate the LAYOUT, and choose EXPORT from the File menu. Provide the output file name and directory in the EXPORT dialogue (Figure 4.53) that appears. Click OK to export the LAYOUT to JPEG or any supported output format.

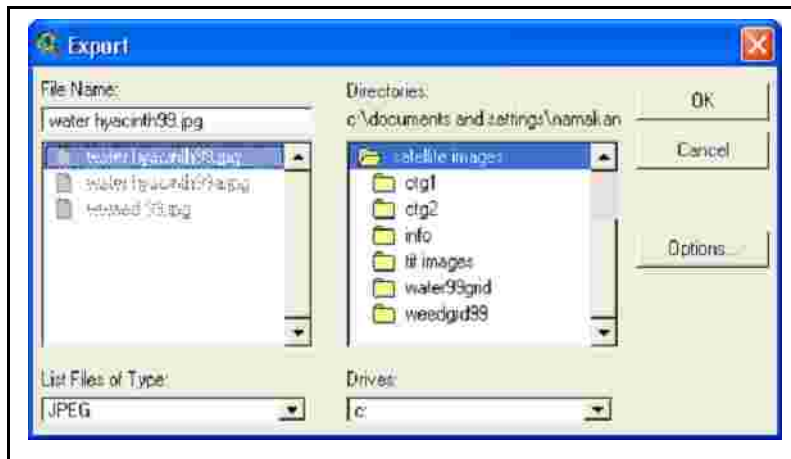
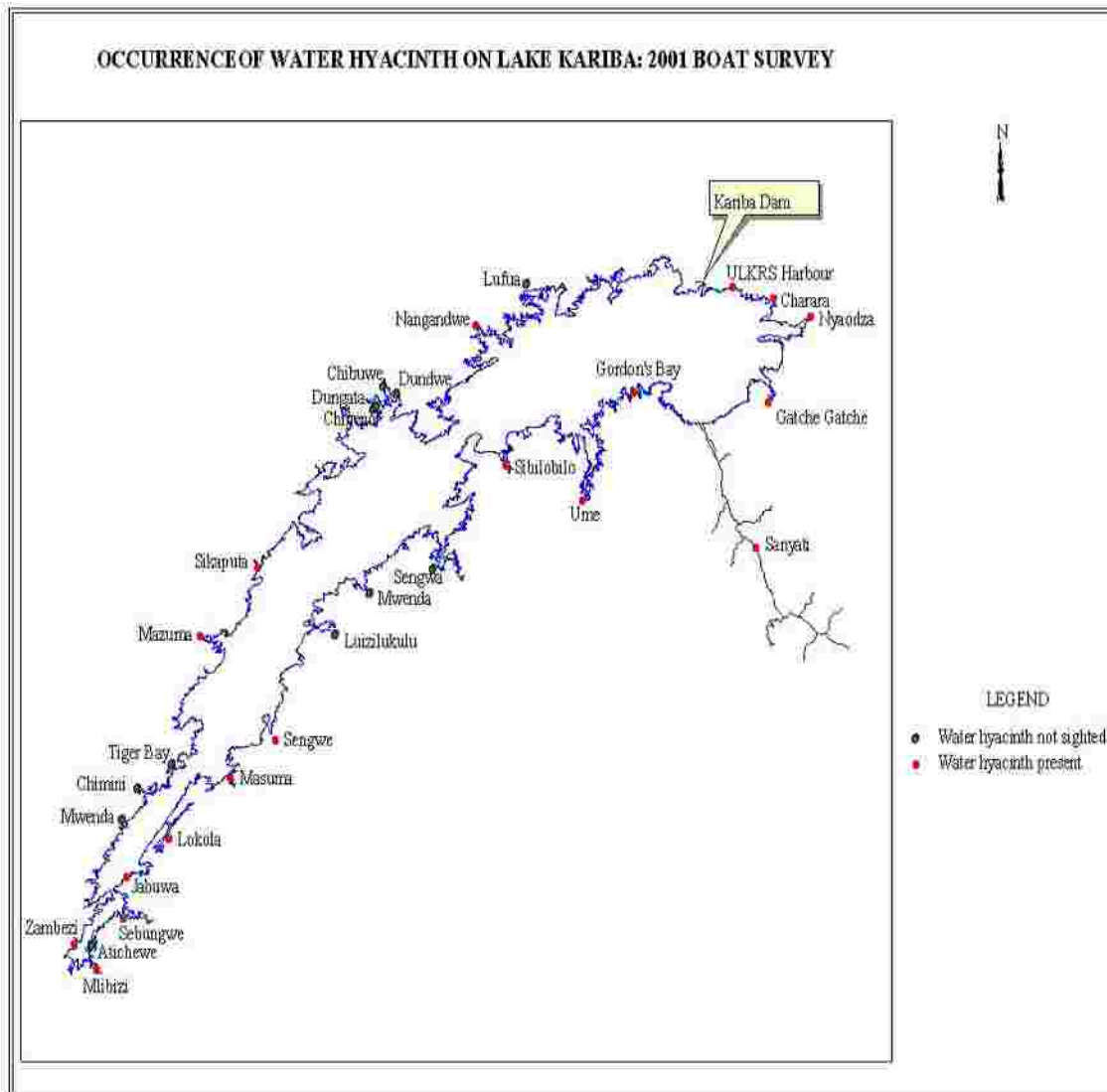


Figure 4.53: The EXPORT dialogue box

(a) Weed occurrence maps resulting from reconnaissance surveys

Latitude and longitude coordinates from the 2001, 2005 and 2007 Lakewide field visits were converted to decimal degrees. Maps showing the location of the water hyacinth (physical sighting) were generated and analysed using ArcView GIS 3.2a software. The results are shown in Figure 4.54 (2001), Figure 4.55 (2005) and Figure 4.56 (2007).



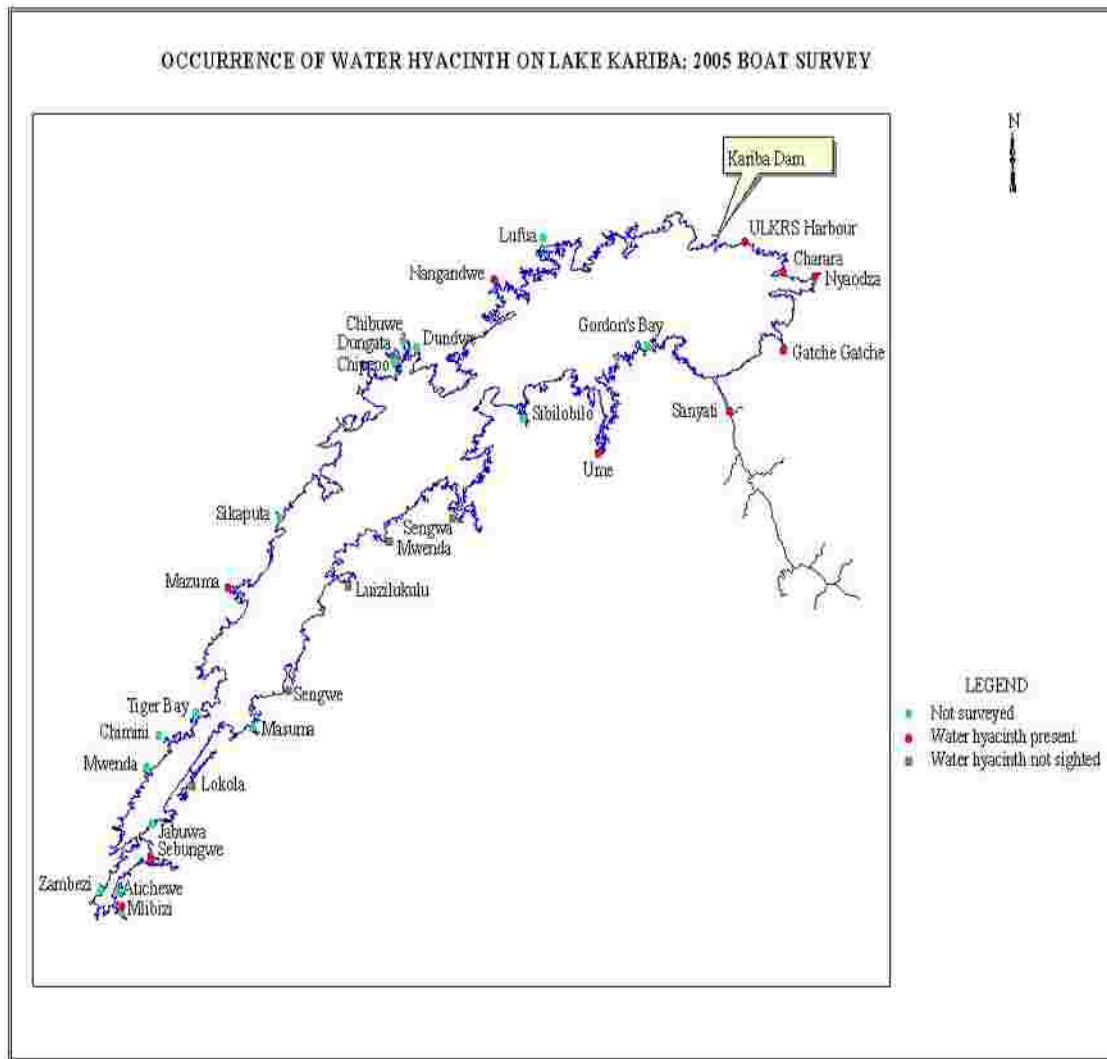
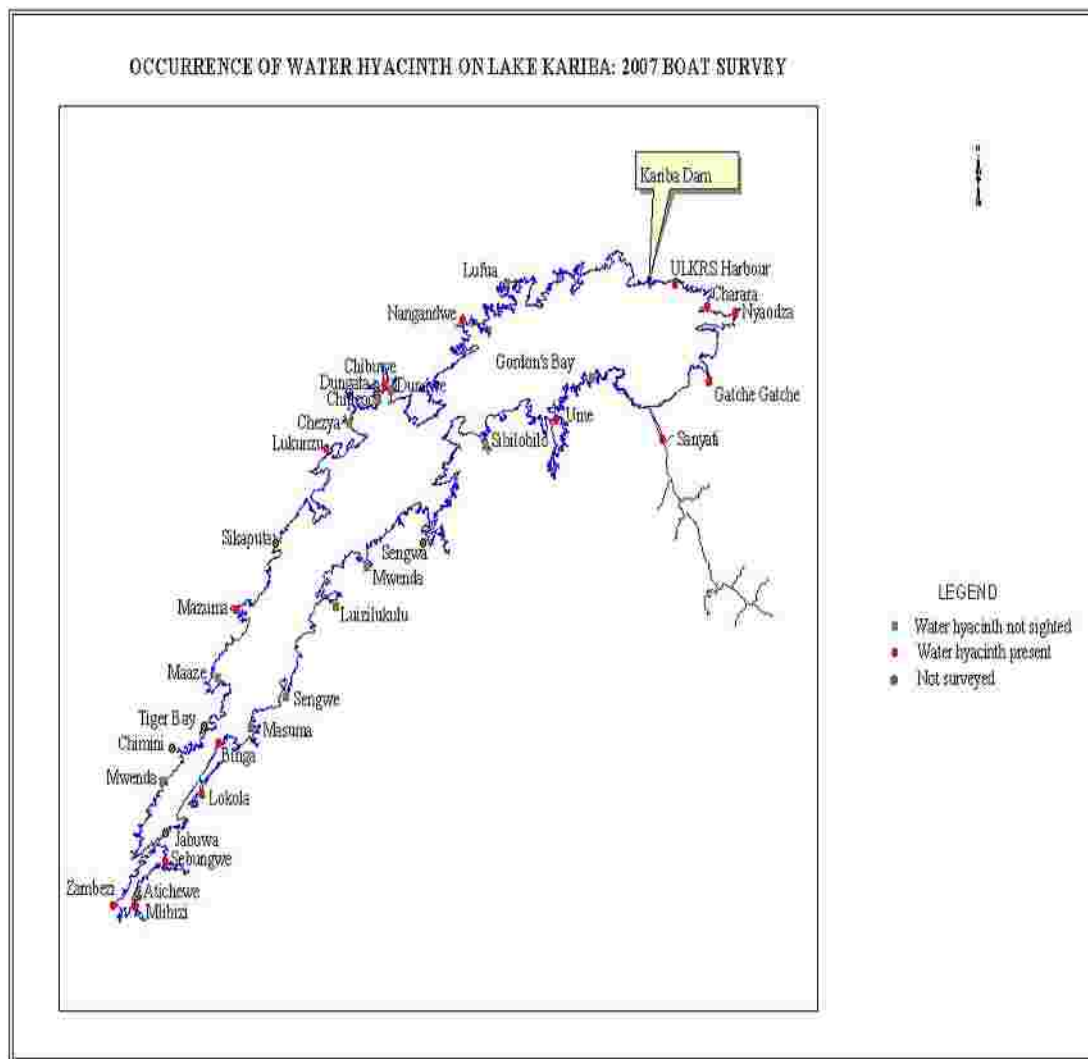


Figure 4.55: Occurrence of water hyacinth on Lake Kariba in April 2005



During the water hyacinth monitoring survey in 2001 on Lake Kariba, 29 sites were visited (Hill, 2001). Water hyacinth was found at 18 sites and not sighted at 11. In 2005 (this study), only 16 sites were monitored due to fuel and time limit or both. The weed was observed at ten and not sighted at six sites. Of the 28 sites visited in 2007 (this study), water hyacinth was found at 16 and not sighted at 12. In 2007, weed was not sighted at four sites where it was present in 2001 on Zimbabwean side. Besides, in 2007, the weed was present at two sites where it could not be sighted in 2001 on the Zambian side. Two sites, Lukunzu River (Zambia) and Binga Harbour (Zimbabwe), not visited during the 2001 and 2005 expeditions were found to have water hyacinth in 2007.

However, around the whole Lake, ten sites were found to have water hyacinth in 2001, 2005 and 2007 (Table 4.6).

Table 4.6: Water hyacinth monitoring survey

Station Name	Water hyacinth status		
	2001	2005	2007
ULKRS Harbour	Present	Present	Present
Charara	Present	Present	Present
Nyaodza	Present	Present	Present
Gatche Gatche	Present	Present	Present
Sanyati	Present	Present	Present
Gordon's Bay	Present	Not Surveyed	Not sighted
Ume	Present	Present	Present
Sibilobilo	Present	Not Surveyed	Not sighted
Sengwa	Not sighted	Not sighted	Not Surveyed
Mwenda	Not sighted	Not sighted	Not sighted
Luizilukulu	Not sighted	Not sighted	Not sighted
Sengwe	Present	Not sighted	Not sighted
Masuma	Present	Not Surveyed	Not sighted
Binga Harbour	Not Surveyed	Not Surveyed	Present
Lokola	Present	Not sighted	Present
Jabuwa	Present	Not Surveyed	Not Surveyed
Sebungwe	Present	Present	Present
Mlibizi	Present	Present	Present
Atichewe	Not sighted	Not Surveyed	Not Surveyed
Zambezi	Present	Not Surveyed	Present
Mwenda (Zambia)	Not sighted	Not Surveyed	Not sighted
Chimini	Not sighted	Not Surveyed	Present
Tiger Bay	Not sighted	Not Surveyed	Not Surveyed
Maaze	Not Surveyed	Not Surveyed	Not sighted
Mazuma	Present	Present	Present
Sikaputa	Present	Not Surveyed	Not Surveyed
Lukunzu	Not Surveyed	Not Surveyed	Present
Chezya	Not Surveyed	Not Surveyed	Not sighted
Dungata	Not sighted	Not Surveyed	Not Surveyed
Chipepo	Not sighted	Not sighted	Not sighted
Chibuwe	Not sighted	Not Surveyed	Present
Dundwe	Not sighted	Not Surveyed	Not sighted
Nangandwe	Present	Present	Present
Lufua	Not sighted	Not Surveyed	Not sighted

a. Maps produced from analysed satellite images

Spot 4 (September 1995 and August 1999) and Landsat 7 (September 2001, November 2004, March 2005, June 2005 and November 2005) satellite images were used in this study. The results are reflected in Figures 4.57 through to 4.58. Figures 4.59 through to 4.60 show favourable results while Figures 4.61 through to 4.64 do not show any visible weed spread captured by the satellite images although was spotted during field visits but in different months (December 2004, January 2005 and December 2005).

Table 4.7: Summary of Maps Produced

IMAGE USED	YEAR	WATER HYACINTH STATUS
SPOT 4	Sept. 1995 - Figure4.57	Water hyacinth seen/mapped
	Aug. 1999 - Figure 4.58	Water hyacinth seen/mapped
Landsat 7	Sept. 2001 - Figure 4.59	Water hyacinth seen/mapped
	Nov. 2004 - Figure 4.60	Water hyacinth absent/not sighted
	Mar. 2005 - Figure 4.61	Water hyacinth absent/not sighted
	Jun. 2005 - Figure 4.62	Water hyacinth absent/not sighted
	Nov. 2005 - Figure 4.63	Water hyacinth absent/not sighted

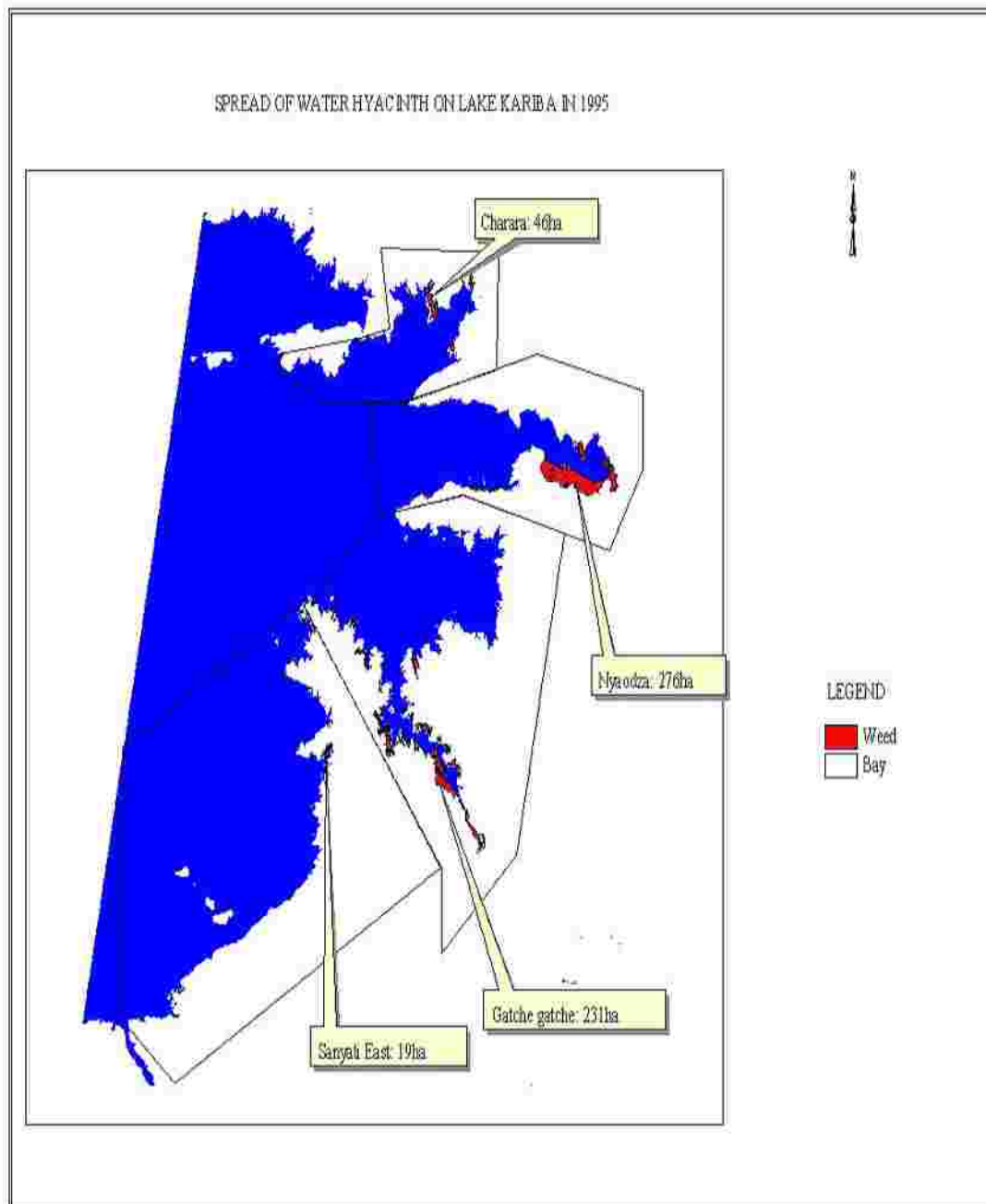


Figure 4.57: Spot 4 Multispectral Image showing the distribution of water hyacinth on Lake Kariba on 21st September 1995.

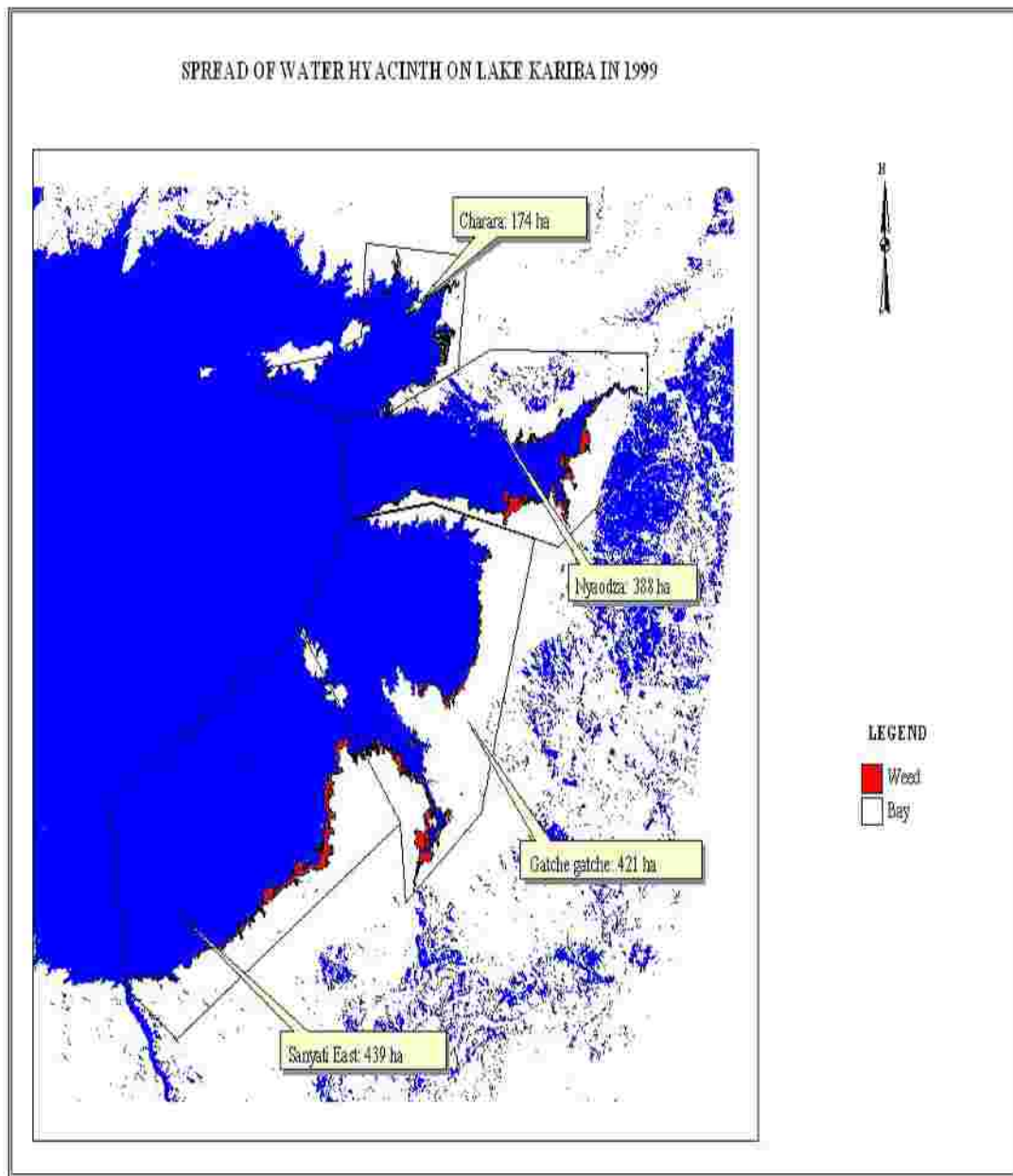


Figure 4.58: Spot 4 Multispectral Image showing the distribution of water hyacinth on Lake Kariba on 28th August 1999.

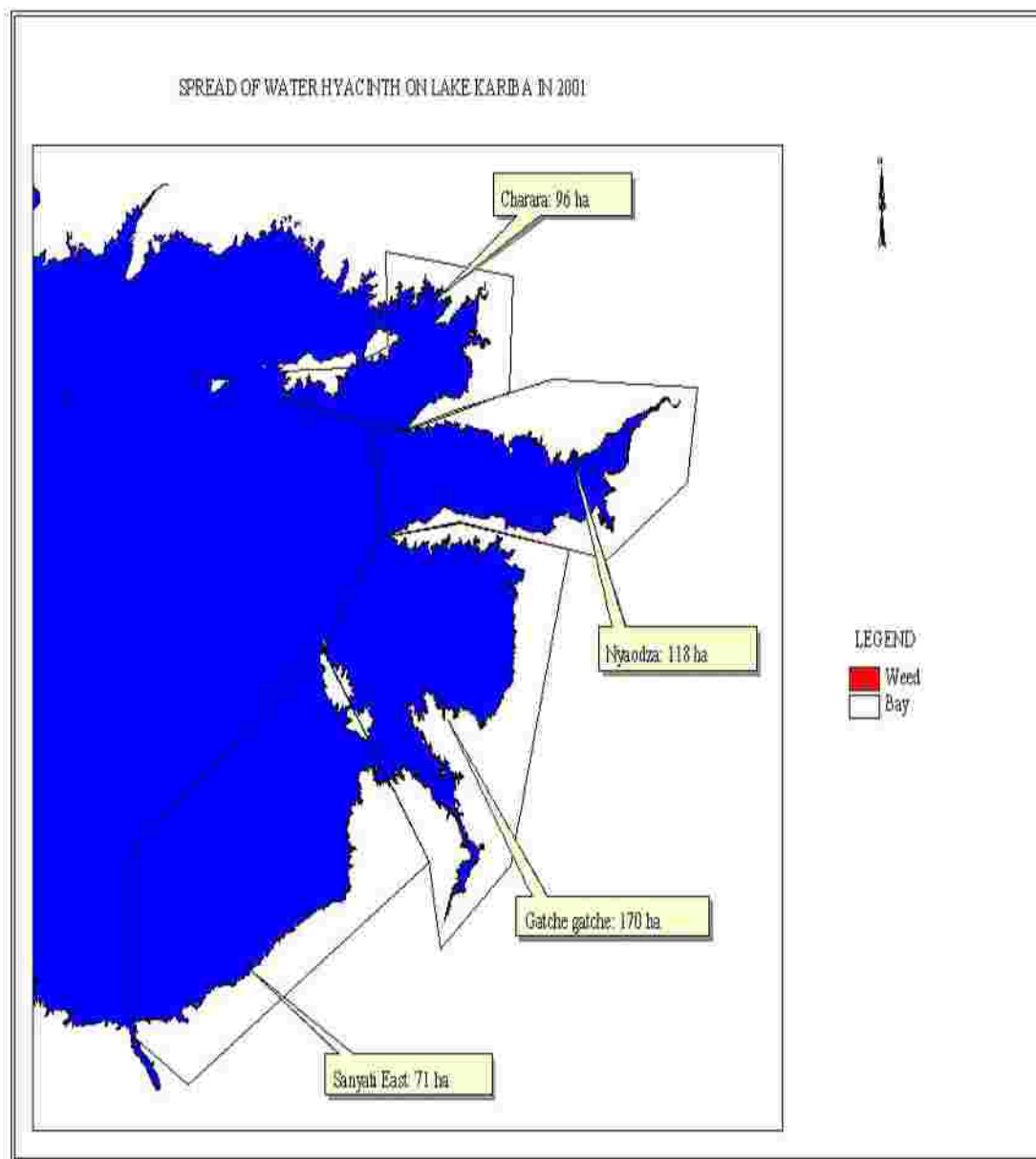


Figure 4.59: Landsat 7 Multispectral Image showing the distribution of water hyacinth on Lake Kariba on 24th September 2001.

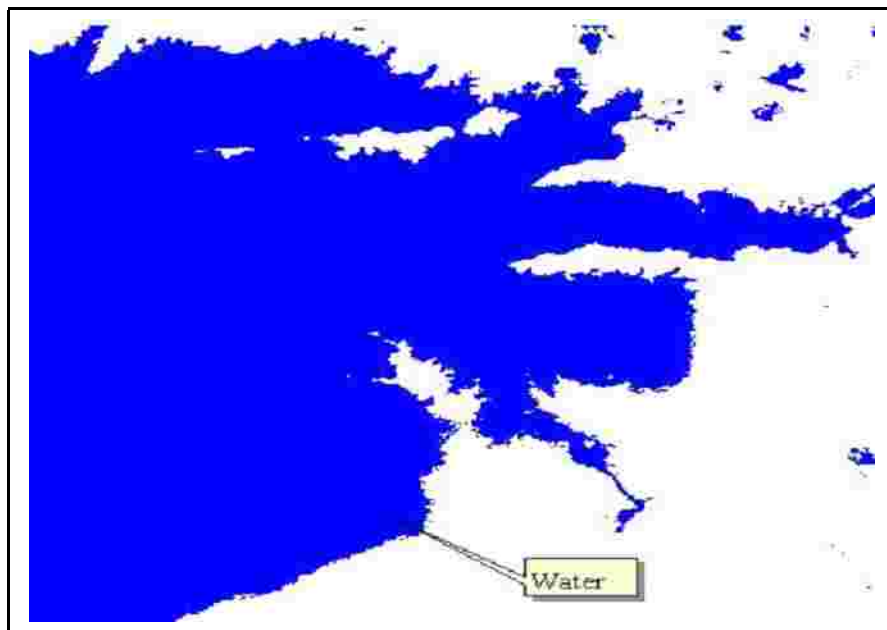


Figure 4.60: Landsat 7 Multispectral Image showing absence of water hyacinth on Lake Kariba in November 2004

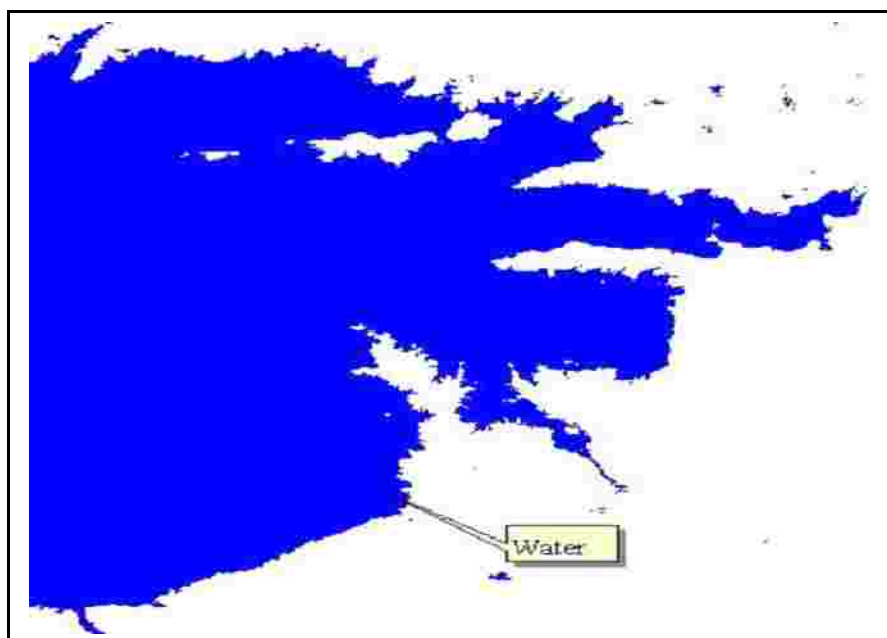


Figure 4.61: Landsat 7 Multispectral Image showing absence of water hyacinth on Lake Kariba in March 2005

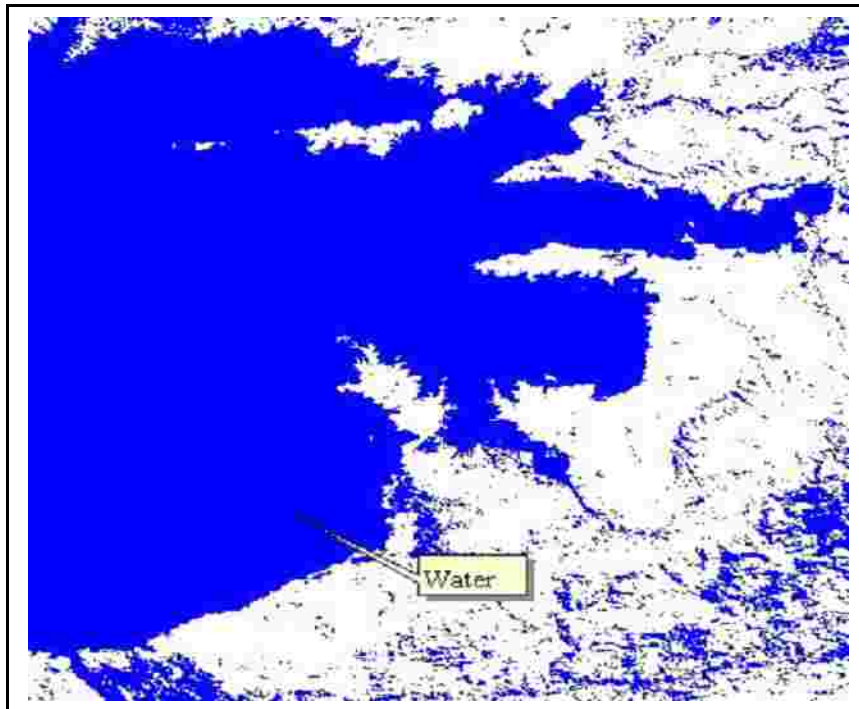


Figure 4.62: Landsat 7 Multispectral Image showing absence of water hyacinth on Lake Kariba in June 2005

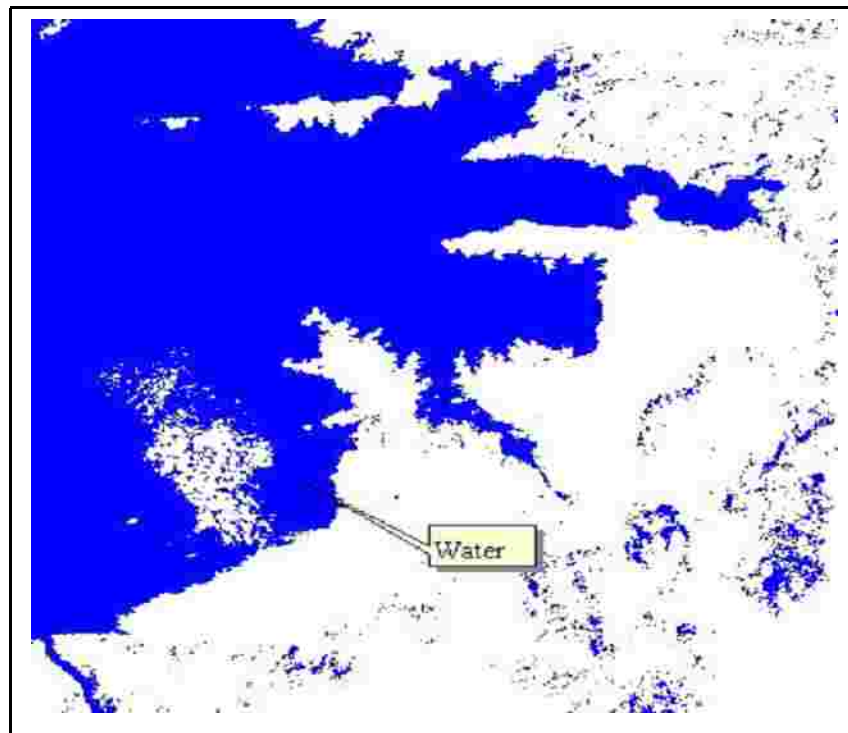


Figure 4.63: Landsat 7 Multispectral Image showing absence of water hyacinth on Lake Kariba in November 2005

(xvi) Input data into database

Weed monitoring data generated from this study is stored in a database for easy storage, management and future reference. This data is available in both hard and soft copy formats.

CHAPTER 5 – DISCUSSION

5.0 Factors considered in developing the procedure for monitoring water hyacinth

This chapter discusses factors that were necessary for developing a procedure for monitoring the distribution of water hyacinth on Lake using Remote sensing and GIS.

The following research questions were considered in this study:

- What factors contribute to the rapid spread of water hyacinth?
- What is the extent and distribution pattern of water hyacinth on the Lake?
- What is the growth pattern of water hyacinth across different seasons in a year?
- What method of classification is best suited for identifying water hyacinth?
- What are the steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS?

The first question was aimed at identifying the factors that promote the growth and proliferation of water hyacinth on the Lake. Key indicators of the possible outbreak and rapid spread of the weed were isolated. Places on the where these indicators are found were target points for the ground truthing exercise. The effect of water level fluctuation on the proliferation of the weed was also examined.

The second question was to culminate into specifying the threshold size of weed coverage requiring intervention and the types of satellite images required to monitor the weed taking into account its extent and distribution pattern.

The third question would lead to the specification of often and at what time of the year satellite images would be acquired.

Because many image processing and classification techniques exist, there was need to identify the one that enhances the differentiation of spectral signatures and best suited for

monitoring the weed. This would reduce the possibility of classifying near shore vegetation as weed. That is what the fourth question was to achieve.

Finally, the fifth question was to enable the identification of the sequence of steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS.

Answers to these questions contributed to the development and testing of a procedure for monitoring the coverage of water hyacinth on Lake Kariba using satellite imagery.

5.1 Procedure for monitoring water hyacinth using Remote sensing and GIS

The aim of this study was not studying Water hyacinth per se but developing a procedure for monitoring the water weeds. A formal procedure that can easily be implemented to monitor the spread of water hyacinth on Lake Kariba using Remote Sensing and GIS was designed in this study. The software used are Idrisi 2.0 for Remote Sensing (satellite image processing and classification) and ArcView GIS 3.2a (Image analysis, area calculation and map production) as set out in the project proposal. Idrisi 2.0 and ArcView 3.2a were only used in this study to test specific steps (data processing, satellite image classification and analysis) of the procedure.

The designed procedure involves four specific steps or phases aimed at coordinated water hyacinth monitoring. This involves data acquisition, processing, satellite image classification and analysis. The output of the previous step was the input of the next one. The results were then produced as map layouts showing weed occurrence and spread in both soft and hard copy format. Activity diagrams were designed for each step. The activities to be done would be determined by the site (monitoring weed in the eastern basin of Lake Kariba or Lake wide).

Data acquisition involved field work and acquisition of satellite imagery. Thorough preparations need to be done before venturing out for field work. The type of preparation would depend on the kind of field work to be done (whether only surveying the eastern

basin or whole Lake). A decision has to be made at what stage satellite images have to be acquired considering the cost implications. This would determine whether the image would be accessed from the archive or a programmable acquisition ordered.

Data processing included conversion of coordinates obtained during ground truthing to the format supported by ArcView 3.2a software. The coordinate conversion was from degrees, minutes and seconds to decimal degrees. The GPS locations were then plotted in ArcView. Image restoration was performed using the Idrisi software. This is dependent on the processing level of the input imagery. This study is recommending high resolution images for weed monitoring on Lake Kariba (for example Spot, Landsat and others to evolve in future).

For Landsat images, L1G level of preprocessing is sufficient for weed monitoring. Spot scenes processed to level 2A are sufficient. These levels are processed geometrically and radiometrically corrected. To facilitate the visual analysis of the aquatic and neighboring environment, the appropriate image enhancement technique to be used was creating a false colour composite using contrast stretching. In addition, when using Landsat TM data Idrisi recommends the use of bands 3, 4 and 5. These cover the basic image dimensions of greenness, brightness and moisture content, and thus carry almost all of the information in the image. For Spot, use bands 1, 2 and 3 unless band 4 is available in which case different band combinations can be tried. It must also be noted that the spatial resolution for band 4 is 20m and the effect it can have on the colour composite when used with other bands of different and higher resolution needs to be examined.

Satellite image classification was done using the ISOCLUST procedure that combines both the supervised and unsupervised classification methods. After image classification, the extracted signals (for water and weed) were exported to Tiff format and then imported into ArcView software for editing, calculation of the area covered by water hyacinth, map production and data management. The ArcView Spatial Analyst extension was used to convert the Tiff image to ArcView shapefiles for further editing. This conversion from

raster data to vector results in loss of some information that would affect the final area of weed spread found.

It should be noted that the testing of the procedure was faced with constraints. Data was only collected from some of the desired monitoring sites during field work because of limited access due to shallow waters, tree stamps and wild animals. Financial constraints limited the number of field visits and purchase of new satellite images.

5.2 Analysis of results

Factors that influence proliferation of water hyacinth were identified and occur in Lake Kariba. Nitrogen and phosphorous pollution are the key nutrients contributing to the proliferation of water hyacinth. Like any other plant species, water hyacinth and other aquatic weeds require nitrates and phosphates to grow and the higher the concentrations the more the weeds are able to flourish. Municipal waste (point source) and run-off from agricultural land (non-point source) provide pollution that affects the proliferation of water hyacinth in the Lake. In December 2004 an average of 10.2 mg/l of nitrates and <0.1 mg/l of phosphates were observed in water samples from the eastern basin. In January 2005, 13.5 mg/l of nitrates on average were observed in the same area. For phosphorous it was only at one sampling point where the content increased from the previous observation to read 0.05mg/l. While phosphorous content was below the allowable limit set by the Environmental Council of Zambia, nitrates were double the permissible level.

The wind and water current drift the weed in their respective directions. The areas receiving the dominant prevailing winds are potential weed depositories. Some of the weeds were flashed out of the river mouths during the peak river lows of the wet season. The fluctuation of the water level of the lake also plays a role in the cycle of the water hyacinth, stranding being a major regulatory environmental factor of the weed extension during the draw down of the Lake level. As the Lake level increases flooding land that was exposed, fresh germination of water hyacinth was observed probably from the weed

that could have been deposited on the muddy bottom. Weed left stranded but not completely dead (hibernated) on the river banks resuscitated upon accessing water.

The growth pattern of the weed was not always natural due to biological control that has taken its toll on many plants. However, the weed was seen to be in full bloom in the rain season when the ‘‘hot- house’’ habitat conditions occur. Flowering may be seen at any season but is at its maximum during the warm season. Freshly germinated water hyacinth was observed at the onset of the rain season.

Generally, the water hyacinth population and health can be described as low and poor. It is evident that the hyacinth situation is, to a large extent, due to the reduced lake level regime in the past years (levels have continued to go down due to reduced inflows/partial drought during the 2004/5 season). It is also probable that the low commercial agricultural activity in the Sanyati Catchment (Sanyati, Gatche Gatche and Nyaodza) in Zimbabwe could have contributed to a reduced leaching of nutrients from farmlands to the hydrographic zones draining into Lake Kariba.

The spread of water hyacinth on Lake Kariba was found as a fringe along the shoreline, free floating patches and thick floating mats. The weed was neither common on rocky shores nor open waters of the Lake. It is worth noting that not all the parts of the Lake are infested with water hyacinth. By December 2005, the weed extent at Lake Kariba’s hot spot sites was estimated to be about 10 ha. By July 2006 the Lake wide weed situation was not posing any threat except for the Eastern Basin where close monitoring should continue.

Since water hyacinth can double its mass, in the presence of favourable conditions, within 5-7 days, effort should be geared towards addressing the cause of the problem rather than the result. This means that appropriate control measures should be applied immediately water hyacinth is discovered in any part of the Lake.

Three classification procedures were tested on a Spot image of Lake Kariba's Eastern Basin captured on 28th August 1999. This is the data that was available during the study. In all the three types of classification; supervised, unsupervised and hybrid, human intervention is required and the latter is the best procedure (going by the results obtained in this study) among them as it also makes use of the other two. Using the ISOCLUST module (Hybrid method) of Idrisi, the spread of water hyacinth was found to be 174 ha in Charara, 388 ha in Nyaodza, 421ha in Gatche gatche and 439ha in Sanyati East bays totalling 1422 ha. This signifies an increase of 474 percent from the 300 ha of weed estimated in February the same year. Analysed Spot (1995) and Landsat (2001) images reveal 572 ha and 455 ha of weed spread respectively. Classification of the Landsat satellite images for November 2004, March 2005, June 2005 and November 2005 did not reveal or isolate any water hyacinth. This could be due to low levels of weed spread on the Lake and the erroneous data on the images resulting from the Scan Line Corrector (SLC) Off Mode effect.

Error assessment was not performed since it requires an image with corresponding ground truthing data. However, since the position of the weed sometimes changes, field visits should coincide with image capture. Else, ground truthing should focus on stationary objects like near shore vegetation for the collected data to be useful in error assessment.

A comparison of the results of fieldwork and satellite imagery shows that weed spread on the Lake increased from 684ha in 1992 to 4 510ha in 1998 before drastically decreasing to about 20ha in 2007 as shown in Table 5.1.

Table 5.1: Summary of weed-spread estimates on Lake Kariba (1992 – 2007)

Year	Estimated extent of water hyacinth [ha]	Comment
1992	684	April 1992 Landsat image classified in 1998
1994	1988	December 1994 Landsat image classified in 1998
1995	572	Charara, Gache gache, Nyaodza and Sanyati East. September 1995 Spot Image, This study.
1996	3990	Charara, Gache gache, Nyaodza and Sanyati
1997	4000	September, 1997
1998	4510	From the Dam wall to Chete Island, DNPWM
1998	3000	Pre-spray survey, September 1998
1999	300	February 1999
1999	1422	Charara, Gache gache, Nyaodza and Sanyati East. August 1999 Spot Image, This study.
2001	928	August 2001 Lake wide Boat Survey
2001	455	Charara, Gache gache, Nyaodza and Sanyati East. Landsat Image for September 2001, This Study.
2004	50	Charara, Gache gache, Nyaodza and Sanyati. January 2004 Boat Survey, This study.
2004	Not Detected	Charara, Gache gache, Nyaodza and Sanyati East. Landsat Image for November 2004, This Study.
2005	Not Detected	Charara, Gache gache, Nyaodza and Sanyati East. Landsat Images for March, June and November 2005, This Study.
2005	10	Charara, Gache gache, Nyaodza and Sanyati. December 2005 Boat survey, This study.
2007	20	July 2007 Lake wide Boat survey, This study.

CHAPTER 6 – CONCLUSION AND RECOMMENDATION

6.0 Preamble

The objectives of this study were both specific and general (overall). The overall objective of this study was to establish a procedure for monitoring the spread of water hyacinth on Lake Kariba using Remote Sensing and GIS.

The specific objectives were to:

- Identify the factors that promote the growth and proliferation of water hyacinth on the Lake,
- Specify the types of satellite images required to monitor the weed coverage taking into account its extent and distribution pattern,
- Specify the threshold size of weed coverage requiring intervention, how often and at what time of the year satellite images would be acquired and
- Identify the classification technique best suited for monitoring water hyacinth.
- Identify the sequence of steps required to monitor the distribution of water hyacinth using Remote Sensing and GIS.

6.1 Conclusion

The model procedure involving data collection, processing, satellite image classification and analysis was designed in this study for monitoring the spread of water hyacinth on Lake Kariba using Geographic Information System and Remote Sensing.

The factors that contribute to the spread of water hyacinth on Lake Kariba were identified as water nutrients (Nitrogen and Phosphorus), wind and water current action, water level fluctuation and climate.

Water hyacinth occurs as fringe along the shoreline, free floating patches and thick floating mats on Lake Kariba. The spread of water hyacinth on Lake Kaiba was studied using satellite imagery and through boat surveys. Seven (Two Spot and Five Landsat) satellite images were used to map the spread of water in this study. The extent of water hyacinth on Lake Kariba was found to 572 ha in 1995 (Spot), 1422 ha in 1999 (Spot), 455ha in 2001 (Landsat) and not detected by Landsat satellite images captured in 2004 and 2005. The weed spread was visually estimated be 50ha in January 2004, 10ha in December 2005 and 20ha in July 2007 through boat surveys. Overall, water hyacinth spread from 682ha in 1992 to 4510ha in 1998 after which it reduced to very low levels not warranting the use of satellite imagery in 2007.

Water hyacinth requires intervention as soon as it is on any part of Lake Kariba. Different options for monitoring water hyacinth are recommended. One or more options or a combination of the options should be adapted to the circumstances. The weed threshold would determine the type of monitoring and satellite imagery to be used. Ground truthing by boat/ road would be required for mapping the presence or absence of water hyacinth once every month on the Eastern Basin and twice per year on the whole Lake. Monitoring a specific area (hot spot sites) with a threshold of 0.01 ha would be done every quarter using Spot 5 while for routine check monitoring (0.1 ha threshold), Landsat ETM + would be used annually if available. Meris imagery would be used for monitoring high spread of the weed (10 ha threshold) monthly.

In all the above cases, a GPS receiver will be used to take coordinates for ground truthing. To enable direct input and mapping in ArcView 3.2a, field coordinates should be acquired in decimal degrees. Coordinates acquired in degrees, minutes and seconds have to be converted to decimal degrees. With much workload, this would be hectic, time consuming and a source of errors. Higher resolution sensors should be considered as they evolve.

Cloud cover has a notable impact on the quality of images acquired by optical sensors. At times cloud cover can completely spoil imagery. Hence it should be considered when planning for image acquisition. In addition, weather forecasting should also be considered when undertaking ground truthing exercises since storms can be a problem.

Biological control agents affect the growth pattern of water hyacinth on Lake Kariba. However, the onset of the rain season sees the germination of new water hyacinth plants from seeds that could have been deposited in the muddy bottom. The rising water level enables germination of seeds and resuscitation of the weed left stranded on dry land due to receding waters. The enabling warm weather (September –March) in the rainy season coupled with nutrient supply from agricultural farm lands reinforces the growth of the weed that blossoms as it produces flowers and some daughter plants through vegetative reproduction. Maturing flowers produce seeds that are deposited in the water bed pending favourable conditions for germination. During the cool months (April – August), water hyacinth weeds produce daughter plants through vegetative reproduction. As the Lake level draws down, the weed may be seen stranded (and hibernating) on dry ground awaiting resuscitation.

The hybrid classification procedure (Using the ISOCLUS module of Idrisi) was found to be better suited for monitoring the spread of water hyacinth than the supervised and unsupervised methods of image classification.

6.2 Recommendation

Idrisi 2.0 and ArcView 3.2 were used in this study because they were the ones available. Being old, these software are being phased out as technology advances. It is recommended that newer versions of GIS and Remote Sensing Software be used for example Idrisi Andes Version 15.0 for classification of satellite imagery and ArcView 9.2 for GIS mapping and analysis. Other software like Erdas Imagine and Ilwis with both GIS and Remote Sensing functionalities should also be tried and the results compared. It is further recommended that the possibility of monitoring the spread of Water hyacinth

using freeware like Multispec from Purdue University in France, etcetera, be tested and the credibility of results from such software ascertained. Other software could be considered as they evolve on the market.

The use of Radar imagery (that is not affected by cloud cover) to monitor water hyacinth should be explored under priority programmable acquisition. This is due to the fact that the Radarsat Satellite does not regularly capture scenes of Lake Kariba as evidenced from the search results. Besides, capabilities of imagery from Google Earth and Envisat to capture water hyacinth should be assessed.

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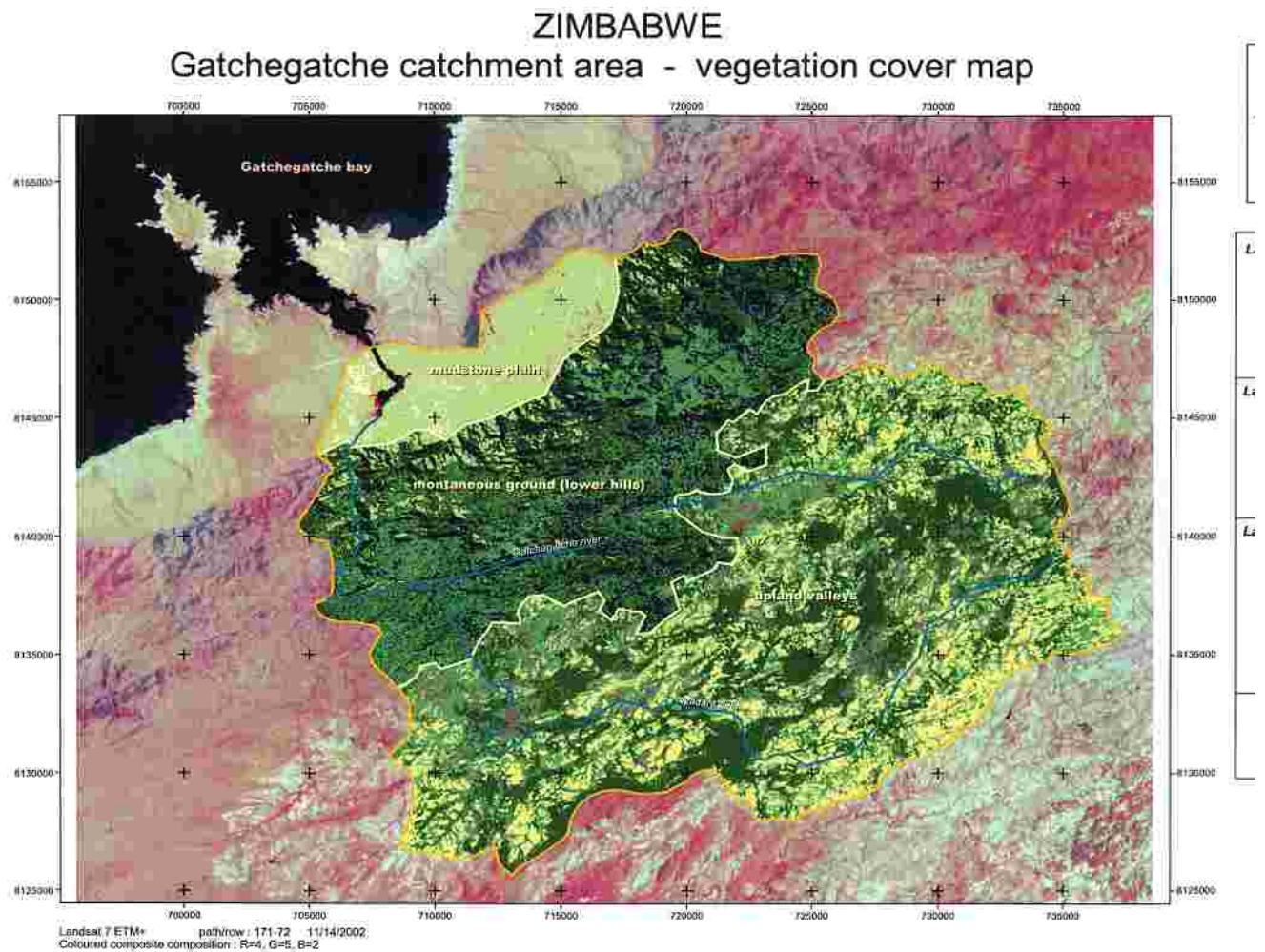
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APPENDIX A: Land use pattern of the Gatchegatche catchment

Source : BRLi/IRD

APPENDIX B: RADARSAT SEARCH RESULTS

