EXECUTIVE SUMMARY

1. BACKGROUND

There is an increasing public awareness of the environmental importance of water and the importance of not destroying the natural environment when developing water resources. In semi-arid climates it is very important to find a balance between water resource development and maintaining the natural environment (DWAF 1995a). Recently the needs of the environment, particularly the riverine environment, have been increasingly taken into account and the impact of development is beginning to be taken seriously. The National Water Act of 1998 advocates that the environment is the resource base which needs to be protected. Only once this resource reservoir has been protected and sufficient water is allocated to meet it's requirements will the other users be catered for. The environment will no longer be considered as a user of water, competing with other users such as industrial, agriculture, potable, recreational and municipal users.

The rapid international growth of environmental monitoring over the past two decades has come about due to man's interest in pollution being centred on its effects on living organisms. Public pressure to improve the environment, coupled to the declining international water resources quality, has resulted in biological monitoring enjoying even greater interest in recent times. It is now generally understood that measurements of only the physical and chemical attributes of water cannot be used as surrogates for assessing the health of an aquatic system (Karr and Dudley 1981). Chemical monitoring misses many man-induced disturbances, such as flow alterations and habitat degradation, that impair use of the aquatic habitat. Furthermore, the monitoring of water quality variables often does not reflect short-term events that may play a critical role in determining the ecosystem health. It is now widely accepted internationally that biological assessment techniques should be incorporated into water quality management policies in order to adequately protect aquatic resources. The implications of biological monitoring are that the resource should be protected sufficiently to ensure its sustainable and safe use.

Pollution of South African surface waters by pesticides and fertilizers, mainly of agricultural diffuse origin, and by metals, mainly derived from an industrial point source origin, is a cause of increasing public concern. This concern has escalated rapidly in recent years following major fish kills in Mpumalanga and Eastern Cape rivers. Chemicals (pesticides and metals) released into the environment are transported and redistributed among the different compartments in the environment, with transport across membranes into organisms being one of the processes. The impacts of these pollutants on aquatic ecosystems are either dramatic and obvious, due to immediately lethal doses, or insidious due to gradual accumulation of lethal concentrations in the body tissues and organs of otherwise healthy organisms. In the latter case, ecosystems quietly and dramatically change. The insidious bioaccumulation which lies at the root of public concern and fear, forms the core of this research.

Aquatic organisms tend to integrate all the stresses placed on the aquatic system and reflect combined effects over an extended period of time. Aquatic organisms are recognized as bio-accumulators of pesticides and heavy metals and consequently can be used for monitoring of pesticides and heavy metal eutrophication.

Fish are considered to be a suitable component of the aquatic system to monitor because they integrate the effect of detrimental environmental changes as consumers which are relatively high in the aquatic food chain. Fish as indicator organisms for biological monitoring have a high public profile and consequently are used extensively for conservation status and bioaccumulation studies. Furthermore fish are good organisms to use in biomonitoring and specifically bioaccumulation because : -

- they are relatively long-lived and mobile, are good indicators of long-term effects and habitat changes.
- fish communities usually indicate a range of species representing a variety of trophic levels
- fish are high in the aquatic food chain and are eaten by man, making them important subjects for assessing contamination,
- fish are relatively easy to collect and identify to the species level.
    - Environmental requirements of common fish are comparatively well-known
    - Life history information is known for some species
    - Fish distribution information is available
- aquatic life uses (water quality standards) are typically characterized.
- there are 50 species of fish regarded as endangered species in the South African Red Data Book (Skelton 1993).

Fish do, however, have the following shortcomings as indicators of pollution : -

- they are mobile and can move away from pollution
- their mobility means that the if a fish is caught in an area it might not reflect the pollution of that area

- fish are able to regulate certain elements and by so doing the levels in their bodies might no be a true reflection of the surrounding environment.

It is well known that fish accumulate metals in their tissues and organs when they are exposed to metal polluted water. The uptake of metals occurs via the skin and gills whilst the intake via contaminated food and drinking water. After uptake metals are transported in the blood and thus brought in contact with the organs where the metals can bind to proteins and amino acids. The total intake of all metals are not all accumulated as the levels of most metals are regulated by certain biological strategies and excretion of metals occur via a variety of pathways. Bioaccumulation of metals is also influenced by a variety of environmental factors and certain factors related to the organism itself.

Objectives of study

This report focuses on the bioaccumulation of pesticides and metals in indigenous fish species from six South African rivers. The body loads (1989 - 1993) of pesticides and metals in the fish of the selected rivers will be compared with each other and literature values. A protocol will be tested and, if suitable, can be used to monitor South African rivers for pesticide and metal bioaccumulation levels in fish tissue.

2. METHODOLOGY AND CATCHMENT CHARACTERISTICS

The sampling for this study sites were depend on the understanding of whole catchments and the locations where diffuse and point sources of pollution were expected. The expected variables of concern were analyzed in samples of river water and fish tissue. This research plan integrated information from, and collaborate with, existing catchment studies and research projects being undertaken on five rivers which flow through the Kruger National Park and one Western Cape river. The Mpumalanga and Northern Province rivers that will be studied are: the Letaba River (mainly intensive agriculture along its banks with some industrial pollution, as well as being seriously affected by water abstraction in winter); the Sabie River (agriculture and a limited number of industries); the Luvuvhu River (subsistence agriculture and erratic seasonal flows); the Crocodile River (most intensive irrigation system in South Africa with numerous point and diffuse sources of domestic and industrial pollution) and the Olifants River (intensive and subsistence agriculture and numerous point and diffuse sources of industrial pollution). The Western Cape river chosen viz. the Berg, is a river with intensive agriculture, aquaculture and industry (**Tables 1 and 2**).

During each sampling trip water quality, fish biology and tissues of fish caught were collected for metal and pesticide analysis. Specific species of fish as well as specific tissues were evaluated for use in the biomonitoring of eutrophied rivers in South Africa. The actual water quality and expected pesticides (using actual 1991 usage) in the rivers due to runoff were compared to the findings in the fish tissues. The resultant pesticide values in the fish tissue were used to determine possible human health assessment if the fish were consumed at differing amounts.

Table 1: Characteristics of the catchments of the study rivers.

Characteristics	Crocodile	Letaba	Sabie	Luvuvhu	Olifants	Berg
Catchment area (km²)	10 440	13 200	6 437	3 568	54 500	9 000
Irrigated area (ha)	95 000	34 000	11 300	9 000	103 000	7 500
Afforested area (ha)	172 200	47 520	71 100	14 600	72 000	7 500
Dry land agriculture (ha)	290 000	16 000	11 570	subsistence	1.2×10^{6}	3 267
Mean annual rainfall (mm/a)	879 summer	671 summer	833 summer	731 summer	675 summer	524 winter
Runoff (Mm^3/km^2)	118514 seasonal	59964 seasonal	134314 perennial	89072 seasonal	47475 seasonal	116286 perennial
People/km^2	45.9	92.9	134.8	84.9	84.6	37.4
Industries						
Pulp & paper	✓					
Fruit processing	✓	✓				✓
Saw mill	✓	✓	✓			
Sugar refinery	✓					
Metal refinery	✓				✓	
Winery						✓
Power generation					✓	
Tannery and leather						✓
Small industries	✓	✓	✓	✓	✓	✓
Mining	✓		✓	✓	✓	

Where ✓ = activity occurs in catchment

Table 2: **Major crops (✓) grown in the catchments studied.**

Crop	Crocodile	Letaba	Sabie	Luvuvhu	Olifants	Berg
Sugar cane	✓		✓			
Bananas	✓	✓	✓	✓	✓	
Citrus	✓	✓	✓		✓	
Mangoes		✓		✓		
Tomatoes	✓	✓			✓	
Vegetables	✓	✓	✓	✓	✓	
Maize	✓			✓	✓	
Avocados			✓			
Tobacco	✓			✓	✓	
Paw Paws	✓	✓	✓	✓	✓	
Wheat						✓
Grapes						✓

3. RESULTS

3.1 Water quality

The Olifants River shows a very high mean conductivity values in access of 100 mS/m. These high conductivity values are related to land usage disturbances such as mining, agricultural runoff and rural settlement activities in the catchment. The catchment with the lowest conductivity values was the Sabie (9 to 15 mS/m).

The nutrient values in the Olifants and Luvuvhu Rivers indicate high mean values. In the Olifants River these relatively high values are due to fertilizers used in agriculture and the mining activities around Phalaborwa. In the Luvuvhu River catchment the nutrients loads originate from agriculture runoff and sewage effluent that is returned to the river in a treated or untreated form. The mean sulphate value for the Olifants River is four times that of the other rivers sampled. These high values originate from the mining activities that occur in the upper and lower catchment.

Results from surveys done to establish potential metals of concern in the catchments studied in this report are shown in **Table 3.** The mean values for iron in the river sampled indicate minor variations between rivers. The Crocodile River, however, yielded a slightly higher mean value due to evident outliers. Values for lead were below the limits of detection for all samples taken. Nickel values recorded in the rivers were lower than the limits of detection for all rivers except the Luvuvhu River where a mean of 20 µg/ℓ was recorded. Mean values for zinc indicate relatively high values for the Crocodile River only, with a mean of 500 µg/ℓ and outliers in excess of 5000 µg/ℓ.

Table 3: **Origins of possible metal contamination to the water quality of each of the catchments** (Chunnet *et al.* 1990, CSIR 1991, SRK 1991, Bath 1992, Claassen 1996, DWAF 1995b+c).

Probable Metal Origin	Possible source of metals in each catchment					
	Berg	**Crocodile**	**Letaba**	**Levuvuhu**	**Olifants**	**Sabie**
Geological	Fe.Zn. Al, Mn	Fe, Al, Mn, Cr, Zn, As	Sb, Cu, Zn, Fe, Mn	Fe, Cu, Mn, Cr	Fe, Al, Ni, Cr, Cd, Sr, Zn, Pb, Sb, Hg, Cu, Mn, V	Cr, Fe, Mn, Al
Agricultural	Zn, Cu, B	Zn, Cu, B	Zn, Cu, B	Zn	Fe, Al, Zn	Zn, B
Tanning and leather finishing	Cr					
Pulp and paper		Al, B, Cr, Co, Cu, Hg, Pb, Mn, Ni, Zn				
Metal Refineries		Mn, Fe, Al, Mn, B			Fe, Al, Cu, Mn	
Mining*		Fe, Al, As, Zn, Cu, Mn	Cr, Zn, Sb, Fe, Mn	Cu, Fe, Zn	Cu, Sr, Mn, Zn	Fe, Al, As, Mn

* Includes leaching from waste rock and low-grade ore stockpiles, as well as direct mine water and effluent discharge.

The highest aluminium levels detected were in the Klipspruit River 100 m above the confluence with the Olifants River. These high aluminium levels detected were 1.9 mg/ℓ which is considerably higher than the levels recorded in the other rivers. The highest arsenic value (15 µg/ℓ) were recorded at the Kaapmuiden site of the Crocodile River. Apart from two sites (30 µg/ℓ) in the Olifants River the levels of cobalt were below the levels of detection in the rivers monitored. Apart from the Sabie River (6 µg/ℓ) the cadmium levels recorded were below the levels of detection. The chromium values monitored were all below the levels of detection. Low levels of copper were found only in the Letaba, Luvuvhu and Olifants Rivers. Only the Meetwal in the Olifants River had a high level of copper (0.12 mg/ℓ). The manganese levels detected in the Crocodile River were generally higher than the other rivers. The Hengel (Fishing) Club had consistently higher values with a maximum manganese value of 1.2 mg/ℓ. The mercury levels recorded were generally lower than the levels of detection with traces being recorded in the Crocodile River (8 µg/ℓ maximum).

3.2 Fish biology

Sixteen species of fish were used for tissues analysis for either pesticide or metal determination (Table 4). Four of these species caught and analyzed are exotic species viz. common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*) largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*). As species were abundant in the catchments surveyed tissues were collected and analyzed from representative specimens.

The stomach content analysis of the fish for the Crocodile and Letaba Rivers are indicated that there were dietary difference between the rivers for some of the fish species especially for *C. gariepinus, O. mossambicus* and *S. intermedius*. The *C. gariepinus* in the Crocodile River were mainly eating plant and detritus whilst the same species in the Letaba River were more omnivorous. The *O. mossambicus* in the Letaba River were eating a wider variety of algal material when compared to the same species in the Crocodile River. The *S. intermedius* in the Letaba River were eating a large percentage of fish which made up less than one percent in the diets of the same species in the Crocodile River.

Table 4: **Common and scientific names of the species of fish from which tissues were taken in the Letaba, Olifants, Sabie, Luvuvhu, Crocodile and Berg Rivers in (1989 - 1993, * = exotic species).**

Common Name	Species	Abbreviation
Large-scale Yellowfish	*Barbus marequensis*	*B mar*
Spotted-tailed Robber	*Brycinus imberi*	*B imb*
Sharptooth Catfish	*Clarias gariepinus*	*C gar*
Common Carp	*Cyprinus carpio**	*C car*
Tigerfish	*Hydrocynus vittatus*	*H vit*
Silver Carp	*Hypophthalmichthys molitrix**	*H mol*
Purple Mudsucker	*Labeo congoro*	*L con*
Plumbeous Labeo	*Labeo molybdinus*	*L mol*
Red-nosed Labeo	*Labeo rosae*	*L ros*
Silver Labeo	*Labeo ruddi*	*L rud*
Largemouth Bass	*Micropterus salmoides**	*M sal*
Smallmouth Bass	*Micropterus dolomieu**	*M dol*
Mozambique Tilapia	*Oreochromis mossambicus*	*O mos*
Butter Catfish	*Shilbe intermedius*	*S int*
Brown Squeaker	*Synodontis zambezensis*	*S zam*
Southern Redbreasted Tilapia	*Tilapia rendalli*	*T ren*

3.3 Metals in fish

Metals per tissue

The tissues of all the fish studied indicated that there was a marked difference between tissues with respect to metal residue levels (**Table 5**).

From the analysis above it indicates that the following tissues have consistently higher metals in the species of fish analyses irrespective of river:

Liver :- Fe, Cu, As, Cd, Co, Mg, Ni, Cd, Hg
Gills :- Zn, Al, Mn
Testes :- Al, Cr

Metals per species

Table 5: **The highest mean metal loads per tissue.** (Tissues with less than three metal determinations were not included).

Metal	Tissues			
	Liver	Gills	Ovaries	Testes
Al	x	xx		xxx
As	xxx	xx		
Cd	xxx	xx	x	
Cr	xx	x		xxx
Co	xxx		x	xx
Cu	xxx	xx		x
Fe	xxx	xx		x
Pb	xxx	xx		
Mg	xxx			
Mn	x	xxx		xx
Ni	x	xxx		xx
Zn	x	xxx	xx	

Where : xxx = highest means, xx = second highest means, x = third highest means.

The following is a synthesis of the species of fish with the highest mean metal body loads:-

Al : *L. rosae* > *L. congoro* > *C. gariepinus*, range 5 to 69782 μg/g.

As : *O. mossambicus* > *B. marequensis* > *C. gariepinus*, range 0.3 to 6.5 μg/g.

Cd : *L. congoro* > *L. rosae* > *C. carpio*, range (0.02 to 10.9.

Co : *L. rosae* > *C. gariepinus* > *O. mossambicus*, range 0.1 to 49.5 μg/g.

Cr : *L. rosae* > *O. mossambicus* > *L. congoro*, range 0.03 to 70.4,

Cu : *L. ruddi* > *L. rosae* > *L. congoro*, range 0.3 to 6 802 μg/g.

Fe : *H. vittatus* > *C. gariepinus* > *O. mossambicus*, range 0.03 to 37 900 μg/g.

Mn : *C. carpio* > *L. rosae* > *L. ruddi*, range 0.4 to 680 μg/g.

Pb : *L. rosae* > *O. mossambicus* > *C. gariepinus*, range 0.4 to 879 μg/g,

Ni : *O. mossambicus* > *T. rendalli* > *B. marequensis*, range 0.09 to 41.7 μg/g,

Zn : *C. carpio* > *L. rosae* > *L. congoro*, range 1 to 776 μg/g.

The species of fish with the highest metal levels were:

L. rosae > *O. mossambicus* > *C. carpio* > *C. gariepinus* > *L. ruddi* > *L. congoro*.

River metal values

The mean metal values detected in the combined fish tissues per river indicate the following order of metal loads per river sampled:

Al	:	Letaba > Olifants > Crocodile > Berg > Sabie.
As	:	Berg > Crocodile.
Cd	:	Olifants > Sabie > Crocodile > Letaba > Berg.
Cr	:	Letaba > Crocodile > Olifants.
Co	:	Letaba > Olifants > Crocodile.
Cu	:	Olifants> Letaba > Luvuvhu > Crocodile> Berg.
Fe	:	Letaba > Luvuvhu > Olifants > Sabie > Crocodile.
Pb	:	Olifants > Letaba > Crocodile > Berg.
Mn	:	Luvuvhu > Berg > Olifants > Letaba > Crocodile > Sabie.
Ni	:	Crocodile > Letaba.
Zn	:	Luvuvhu > Olifants > Berg > Sabie > Letaba > Crocodile.

The metal results of the fish at selected river sites indicate that arsenic, copper, iron, manganese and zinc levels in fish tissues corresponded to known environmental levels of contamination and consequently fish tissues can be used to detect pollution of these metals.

3.4 Pesticide levels in fish

Fish pesticide tissue values

The pesticide levels in the tissues of all the fish studied indicated that there was a marked difference between tissues with respect to pesticide residue levels (**Table 6**).

From the results in this study the following tissues have consistently higher pesticides in the species of fish analysed, irrespective of river:

fatty tissues (fat, testes, ovaries), and liver.

Table 6: A ranking of the highest pesticide concentrations in the fish tissues.

Pesticides	Tissues					
	Ovaries	Fat	Testes	Liver	Flesh	Gut
BHC		xx	xxx	x		
Lindane		xx	x			xxx
Dieldrin		x		xxx	xx	
DDE		xxx		x		xx
DDD		xxx	x			xx
DDT	x	xxx				xx
Diazianon		xx	x		xxx	
Endosulfan		x		xx		xxx
Mercapthion	x			xx	xxx	
Pirimos		xxx		xx		
Aldrin						xxx
Atrazine		xxx	xx	xx		

Where: xxx = highest mean value detected, xx = second highest mean value detected, x = third highest mean value detected.

Pesticides per species

Table 7 is a synthesis of the species of fish studied with the highest pesticide body loads.

These six species of fish with the highest pesticide loads were:

L. molybdinus > *C. gariepinus* > *H. vittatus* > *L. rosae* > *O. mossambicus* > *B. marequensis*

Pesticides per river

The mean pesticide values detected in the lumped fish tissues per river indicate the following order of pesticide loads per river:

BHC : Crocodile > Letaba > Olifants > Sabie > Luvuvhu and Berg.

Dieldrin: Crocodile > Letaba > Olifants > Berg > Sabie > Luvuvhu.

Lindane: Crocodile > Letaba. with traces amounts in the other rivers.

DDD: Letaba > Luvuvhu > Sabie > Olifants > Crocodile > Berg.

DDE : Letaba > Luvuvhu > Olifants > Sabie > Crocodile > Berg (0.0473 μg/g) **(Figure 1).**

Table 7: **The highest mean pesticide values recorded per species of fish (all rivers combined, refer to Table 4 for abbreviations).**

	Species									
Pesticides	***O mos***	***C car***	***L mol***	***B mar***	***S int***	***H vit***	***C gar***	***L ros***	***T ren***	***L con***
BHC				xx		x	x			xxx
Lindane			xxx			xx	x			
Dieldrin	xx					xxx				x
DDE						x	xx	xxx		
DDD						xx	xxx	x		
DDT	x					xxx	xx			
Diazianon			xx	x					xxx	
Endosulfan			xxx	xx			xx			
Mercapthi on			xx				x		xxx	
Pirimos	x		xx						xxx	
Aldrin	xxx									
Heptachlor			xx					xxx		
Atrazine	xx	xxx								

Where: xxx = highest mean value detected, xx = second highest mean value detected, x = third highest mean value detected.

DDT : Letaba > Olifants > Luvuvhu > Crocodile > Sabie > Berg.

Heptachlor: Crocodile River > traces in the other rivers.

Endosulfan: Crocodile River > traces in the other rivers.

Mercapthion: Crocodile River > traces in the other rivers.

Diazinion: Crocodile River > traces in the other rivers.

Pirimiphos: Crocodile River > traces in the other rivers.

Aldrin : Crocodile River > traces in the other rivers.

Endrin : Traces detected in all rivers.

Atrazine: Berg River, traces in other rivers only.

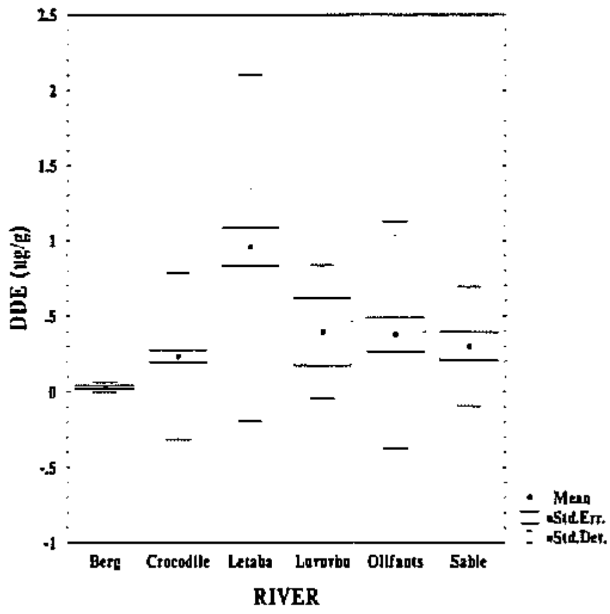

Figure 1: DDE levels in the fish tissues per river.

4. DISCUSSION OF TRENDS

4.1 Metals in fish tissues

In South Africa metal bioaccumulation in fish was first undertaken by Greichus *et al.* (1977) in the Voelvlei and Hartbeespoort Dams. In recent years there has been a dramatic increase in the fish metal bioaccumulation literature that has been generated in South Africa. Rivers that have been studied include the Olifants (Mpumulanga. Coetzee 1996. Du Preez and Steyn 1992. Grobler *et al.* 1994. Seymore 1994. Seymore *et al.* 1994. Kotze 1997). Crocodile (Roux *et al.* 1994). Sabie. Luvuvhu. Letaba. Berg. Vaal (Adendorff and van Vuren 1996) and Jukskei (IWQS 1994) and dams (Loskop, Middleburg - Barnhoorn 1996. Germiston - Bezuidenhout *et al.* 1990. De Wet *et al.* 1994. Schoonbee *et al.* 1996. Kotze 1997 and Krugerdrift - van den Heever and Fry 1994. 1996a and 1996b).

A variety of different water bodies ranging from gold mine polluted dams (Bezuidenhout *et al.* 1990 and De Wet *et al.* 1994. Schoonbee *et al.* 1996). sewage effected dams (van der Heever and Fry 1994, 1996a & 1996b). the middle Vaal (Adendorff and van Vuren 1996). an urban runoff polluted river (IWQS 1994) and various rivers that enters the Kruger National Park (Olifants and Crocodile) after passing through various land usages such as mines and intensive agriculture (Du Preez and Steyn 1992. Seymore 1994. Roux *et al.* 1994. Grobler *et al.* 1994. Coetzee 1996. Claassen 1996. Du Preez *et al.* 1997. Kotze 1997. Robinson and Avenant-Oldewagen 1997). These South African studies have also been undertaken on several species of fish and tissues (**Table 8**). These mean metal values per tissue were converted to a common unit (μg/g dry weight), in order to compare results, using mean tissue moisture contents. The species and rivers were combined. Some 1400 fish have been used in these studies over the past six years.

Intestine : - could be fore-, mid- or hind gut, with or without fatty tissue associated with the intestine. Intestine will also include food in various degrees of decay. In detrivores the intestine contents will be mainly sediment which could have high metal loads. As the majority of this sediment is released in the faeces the metal values associated with intestine need to be treated with circumspect as there is no clear indication that these metals will stay in the fish (be accumulated) or be excreted as faeces. Also attached to intestine could be intestinal fat which can further complicate issues if this is not removed before analysis is undertaken.

The present lack of a bioaccumulation protocol makes interpretation of these tissue results difficult for the following reasons : -

Gills : this could be the whole gill or with or without - lamellae, filaments or rakers. Depending on the turbidity of the river the metals found associated with the gills could only be attached to the gill surface and might not be accumulated in the fish tissues. If the gills were thoroughly washed with distilled water before analysis is undertaken for metal then a different metal accumulation pattern could emerge. The extensive vascular network and large surface area of the gills does, however, make them a suitable organ for metal uptake.

Skin : this could mean muscle, flesh with or without scales or all of these. If fish muscle is used (as it was used in this study) then it is abundant on the fish and can be used to determine the human health risk if the fish are eaten.

Gonads : this could mean testes or ovaries. Normally associated with these tissues is abdominal fat which would need to be removed before analysis is undertaken. The gonads metal loads are highly variable and are also seasonally dependant. In the non-breeding season the mass of gonads available are limiting for use in biomonitoring studies.

The choice of a specific fish tissue for metal bioaccumulation will be dependant on the specific requirements of the monitoring programme.

Table 8: **The mean metal concentrations per fish tissue (all species of fish and rivers combined,** Adendorff and van Vuren 1996, Barnhoorn 1996, Bezuidenhout *et al.* 1990, Claassen 1996, Coetzee 1996, De Wet *et al.* 1994, Du Preez and Steyn 1992, Du Preez *et al.* 1997, Grobler 1994, Grobler *et al.* 1996, Kotze 1997, IWQS 1994, Robinson and Avenant-Oldewagen 1997, Roux *et al.* 1994, Seymore *et al.* 1994, Schoonbee *et al.* 1996, van den Heeven and Fry 1994, 1996a and 1996b). **The shaded areas indicate the tissue with the highest metal load.**

Tissue	Mean metal loads (μg/g dry weight)								
	Zn	Cu	Fe	Mn	Al	Ni	Pb	Cr	Cd
Liver	403	179	1434	25	83	36	19	25	9
Fat	40	8	162	5	30	10	16	4	5
Muscle	110	7	156	9	77	31	15	23	6
Gill	663	14	506	76	167	50	21	48	3
Skin	685	26	529	21	52	40	42	39	
Spleen	211	32	1090	8		256	39		
Vertebrae	498	8	243	30		102	29	42	
Intestine	105	29	582	454		58	30	110	7
Gonads	917	10	294	12	259	35	22	32	3
Bile	6	7	60	2		6	8	7	
Brain	335	100							
Heart	196	42							
Kidney	88	17	230	3		4	8	5	

Metal bioaccumulation studies using fish in South African rivers could use the following tissues:-	
Liver :	**zinc, copper, iron, cadmium**. Liver is a de-toxicant organ and has high loads of these metals. Most fish livers are easy to dissect as a single organ and are large enough to supply sufficient tissue for metal determination.
Gills :	**manganese** and **zinc**. Gills are easy to dissect and have direct contact to any pollutants in the water body.
Vertebrae :	**strontium** and **zinc**. Could be used to determine long term exposure.
Muscle :	**lead**. Should be used to determine the human health risks if this fish tissue is consumed.

4.2 Pesticide residues in fish tissues

Several studies have been undertaken in South Africa on pesticide residues in fish. These studies range from marine and estuarine (de Kok 1985, Sibbald *et al.* 1986), to inland lakes (Greichus *et al.* 1977) and rivers (Piek *et al.* 1981, Bouwman *et al.* 1990, Grobler 1994, Roux *et al.* 1994, Claassen 1996). In order to compare these value the literature values were converted to μg/kg on a wet weight basis (Table 9). Meaningful comparisons of this data are complicated due to the vast variability of methods and tissues used in these studies. For example the tissues used for these determinations were not standardised. The array of tissues varied from whole fish, fish without heads and scales, fillets and muscle and Greichus *et al.* 1977 does not state what tissues were used. To further complicate comparisons are the way that the results are expressed as some are expressed in terms of a basis of fat whilst others are not.

For pesticide bioaccumulation studies using fish in South African river the following tissues are recommended:-	
Intestinal fat:	**DDT, DDD, DDE, Lindane, Endosulfan, Atrazine, Aldrin, Pirimiphos,**
Testes:	**BHC**
Liver:	**Dieldrin**
Muscle:	**suitability of fish for human consumption**

The present lack of a bioaccumulation protocol makes interpretation of these tissue results difficult for the following reasons : -

Gut : as a tissue is not reliable for pesticide residue analysis in fish as the guts with the highest pesticide residue values were found in *L. rosae* in the Letaba River. These "gut" samples were the intestines of the fish which were surrounded by intestinal fat and consequently the high pesticide loads determined are associated with the fatty tissue.

Flesh, skin or muscle : if the actual area where this tissue is collected from the fish and the actual method is specified (dorsal muscle below the start of the dorsal fin, scales removed and skin kept) then this tissue is realistic for pesticide residue analysis as it has an important role in the acceptability of the fish muscle for human consumption.

The following species of fish had the highest pesticide loads in the rivers studied:

Labeo species:	BHC, Lindane, DDE, Heptachlor, Endosulfan
C. gariepinus:	DDD
T. rendalli:	Mercapthion, Diazinon, Pirimiphos
O. mossambicus:	Aldrin
C. carpio:	Atrazine

The review of the limited pesticide studies undertaken on fish in South Africa indicates that due to the lack of standardization of analytical methods (whole fish, decapitated, muscle only etc.) a wide variety of species of fish have indicated high pesticide residues. These species vary from algae eaters (*O.mossambicus*), detritivores (*Labeo* sp.), omnivores (*S. intermedius, C. gariepinus*) and piscivorus (*H.vittatus*).

Table 9 : Literature levels of pesticides recorded in fish in southern Africa (converted to µg/kg wet weight).

Study	DDT	DDD	DDE	Endosulfan	Dieldrin	BHC
Crocodile (Hartbeespoort Dam) Greichus *et al.* (1977) whole fish	*O. mossambicus* 900 *C. flaviventris* 1200	*O. mossambicus* 1900 *C. flaviventris* 1300	*O. mossambicus* 900 *C. flaviventris* 1400		*O. mossambicus* 1200 *C. flaviventris* 1300	
Berg (Voelvlei Dam) Greichus *et al.* (1977) whole fish	*M. salmoides* 500 *L. macrochirus* 600	*M. salmoides* 500 *L. macrochirus* 100	*M. salmoides* 4200 *L. macrochirus* 600		*M. salmoides* 500 *L. macrochirus* 300	
Berg (Voelvlei Dam) Claassen (1996) Various tissues	*O. mossambicus* 7 *C.carpio 10* *M. dolomieus* 5	*O. mossambicus 47* *C.carpio 31* *M. dolomieus 150*	*O. mossambicus* 72 *C.carpio* 39 *M. dolomieus* 20	*O. mossambicus* 5 *C.carpio* 5 *M. dolomieus* 5	*O. mossambicus 5* *C.carpio 5* *M. dolomieus 5*	*O. mossambicus < 1* *C.carpio < 1* *M. dolomieus < 1*
Limpopo (Olifants, Letaba, Crocodile) Pick *et al.* (1981) on a basis of fat (muscle, liver, skin) mg/kg	*O. mossambicus* 565 *C. gariepinus* 152 *Labeo sp.* 43		*O. mossambicus* 1863 *C. gariepinus* 2880 *Labeo sp.* 379 *Barbus sp.* 918	*O. mossambicus* 50 *C. gariepinus* 124 *Barbus sp.* 588	*O. mossambicus* 144 *C. gariepinus* 133 *Labeo sp.* 51	*O. mossambicus* 37 *C. gariepinus* 38 *Labeo sp.* 19 *Barbus sp.* 26
Pongolo Bouwman *et al.* (1990) fillets	*H. vittatus* 15 sd 17 *O. mossambicus* 7 sd 17 *E. depressirostus* 5 sd 7	*H. vittatus* 25 sd 33 *O. mossambicus* 17 sd 31 *E. depressirostus* 9 sd 15	*H. vittatus* 54 sd 67 *O. mossambicus* 12 sd 17 *E. depressirostus* 13 sd 21			
Olifants Grobler (1994) head & fins removed	*C. gariepinus* (1.7 - 2.2) *O. mossambicus* 2.2 *E. depressirostus* 27.9 (2.9 - 72)	*C. gariepinus* (2.5 - 3.7) *O. mossambicus* 1.9 *E. depressirostus* 3.9 (1.0 - 13.2)	*C. gariepinus* 8.0 (2.5 - 26) *O. mossambicus* 5.6 (3.1 - 8.4) *E. depressirostus* 94 (22 - 198)			
Crocodile Roux *et al.*, (1994) muscle			*C. gariepinus* 58.5 *O. mossambicus* 14.9 *C. carpio* 3.9 *B. marequensis* 118.9			
Lowveld Rivers This study All tissues - maximum values	Let, *C. gariepinus 1340* Oli,*C. gariepinus 304* Luv,*H. vittatus 238* Sab, *L. ruddi 120*	Let, *C. gariepinus* 1730 Oli,*C. gariepinus* 283 Luv,*C. gariepinus 1009* Sab *H. vittatus 640*	Let, *L. rosae* 955 Oli,*C. gariepinus 361* Luv,*H. vittatus 516* Sab, *L. congoro 298*		Let, *L. rosae* 197 Oli, *L. congoro* 74	Let, *L. rosae* 7 Oli, *L. congoro 8*

Where: Let = Letaba River, Oli = Olifants River, Sab = Sabie River, Luv = Luvuvhu River.

4.3 Human health risk assessment

The standards established to protect aquatic life in Canada and the United States of America (Water Quality Branch. Environment Canada 1979; National Academy of Science - National Academy of Engineering 1972) recommend that residues in fish muscle (wet weight basis) should not exceed 1.0 mg.kg for t-DDT and 0.5 mg.kg for Dieldrin.

Table 10: Summary of pesticide human risk assessment if fish are eaten from selected South African Rivers.

Exposure	Dieldrin	Lindane	Atrazine	DDT	DDE	Endosulfan
Weekly 50g	▲	▲			▲	
Daily 50g	● ▲ ◆	● ▲			▲	◆
Weekly 150g	● ▲	● ▲			▲	◆
Daily 150g	● ▲ ◆	● ▲ ◆			▲	◆

Where: ▲ = maximum value cancer risk, ◆ = maximum value hazard quotient (non-cancer effects), ● = geometric mean cancer risk

Risk higher than those recommended by the US_EPA were detected for dieldrin. lindane and DDE (**Table 10**) when the maximum level of pesticides detected in the fish tissues was used. Hazard quotients, referring to the non-cancer toxicity, were also higher than the recommended US-EPA value of 1 for Dieldrin. Lindane and Endosulfan.

From the results in the present study there are associated human health risks to eating the fish. These risks are however in the worst case scenarios (highest daily weight of fish eaten daily all year round) and are specifically associated with the fish in the Letaba. Luvuvhu and Crocodile Rivers. If the fish were gutted (i.e. remove fat, liver, testes and ovaries) then the fish would be safe for human consumption (Bouwman *et al.* 1990). This is not always the case as the muscles tissue can be associated with high pesticide loads and the resultant high risk potential as in seen in the present study.

4.4 Pesticide usage compared to fish tissue residues

Mean pesticide body loads per species of fish combined were compared to actual pesticide loads used in each catchment. **Table 11** compares the fish tissues that bioaccumulated pesticides with the actual pesticide usage in the catchments studied.

Table 11: Comparison of actual pesticide usage for the catchments and the bioaccumulation in the fish tissues.

Pesticides	Berg	Crocodile	Letaba	Luvuvhu	Olifants	Sabie
Lindane	-	+	+	-	-	+
Endosulfan	-	+	-	?	-	-
Mercapthion	+	+	-	+	+	+
Pirimosphos	?	+	+	+	+	+
Aldicarb	+	-	+	+	+	+
Atrazine	+	-	-	-	-	-
DDT etc.						

Where:- - = no bioaccumulation, + = accumulation, ? = usage unknown

The general trend is that pesticides do bioaccumulate in the fish tissues according to the actual pesticide usage in the catchments. Atrazine loads in the fish of the Berg River closely resemble the expected values according to the usage of this pesticide in the catchment. The lack of significant atrazine levels in the tissues of the fish in the other rivers studied indicates that this pesticide is not well accumulated in the tissues or if it is it does not remain in the fish tissues for long periods of time. Lindane residues in the fish from all the rivers studied were similar with the exception of the Letaba and Crocodile Rivers. The Letaba, Luvuvhu and Olifants Rivers indicated biomagnification possible from past rather than present lindane usage in these catchments. Only the fish pesticide residues in the Crocodile River indicated accumulation that resembled the actual usage of lindane, Endosulfan, Mercapthion and Pirimiphos in the catchment. Mercapthion residues in the Crocodile River were slightly higher than in the other rivers which agrees with the actual pesticide usage in the catchment.

5. PROPOSED BIOACCUMULATION MONITORING PROGRAMME PROTOCOL FOR PESTICIDE AND METAL CONCENTRATIONS IN SOUTH AFRICAN RIVERS.

Bioaccumulation must be seen as an additional tool in the toolbox of Ecosystem Health determination. This tool will be used to refine problems as one of the River Health indices of the River Health Programme of DWAF. The overall approach that should be used when planning for the successful implementation of a fish bioaccumulation assessment as outlined in **Figure 2** .This proposed protocol has taken into account the findings of this study as well as numerous interactions with Professors du Preez and Schoonbee's students at Rand Afrikaans University (Barnhoorn 1996, Bezuidenhout *et al.* 1990, Claassen 1996, Coetzee 1996, Seymore 1994, Schoonbee *et al.* 1996, Kotze 1997).

5.1 Appropriate level of assessment

A three levels approach is suggested (**Table 12**).

Level 1: National Rivers Health Assessment - To determine the national status of water bodies and to identify those sites that are harvested (commercially, recreational and subsistence fishing) by humans where edible portions of fish exceed human consumption levels.

Level 2: Human Health Risk Assessment - Conduct intensive follow-ups to determine the magnitude of contamination in edible portions of fish species consumed by humans in water bodies identified in level 1 screening.

Level 3: Impact Assessments or case specific - Conduct intensive sampling at specific sites that are identified by permit applications, by levels 1 and 2, impact assessments etc. to determine the geographical extent of contamination in various sizes and tissues of fish species.

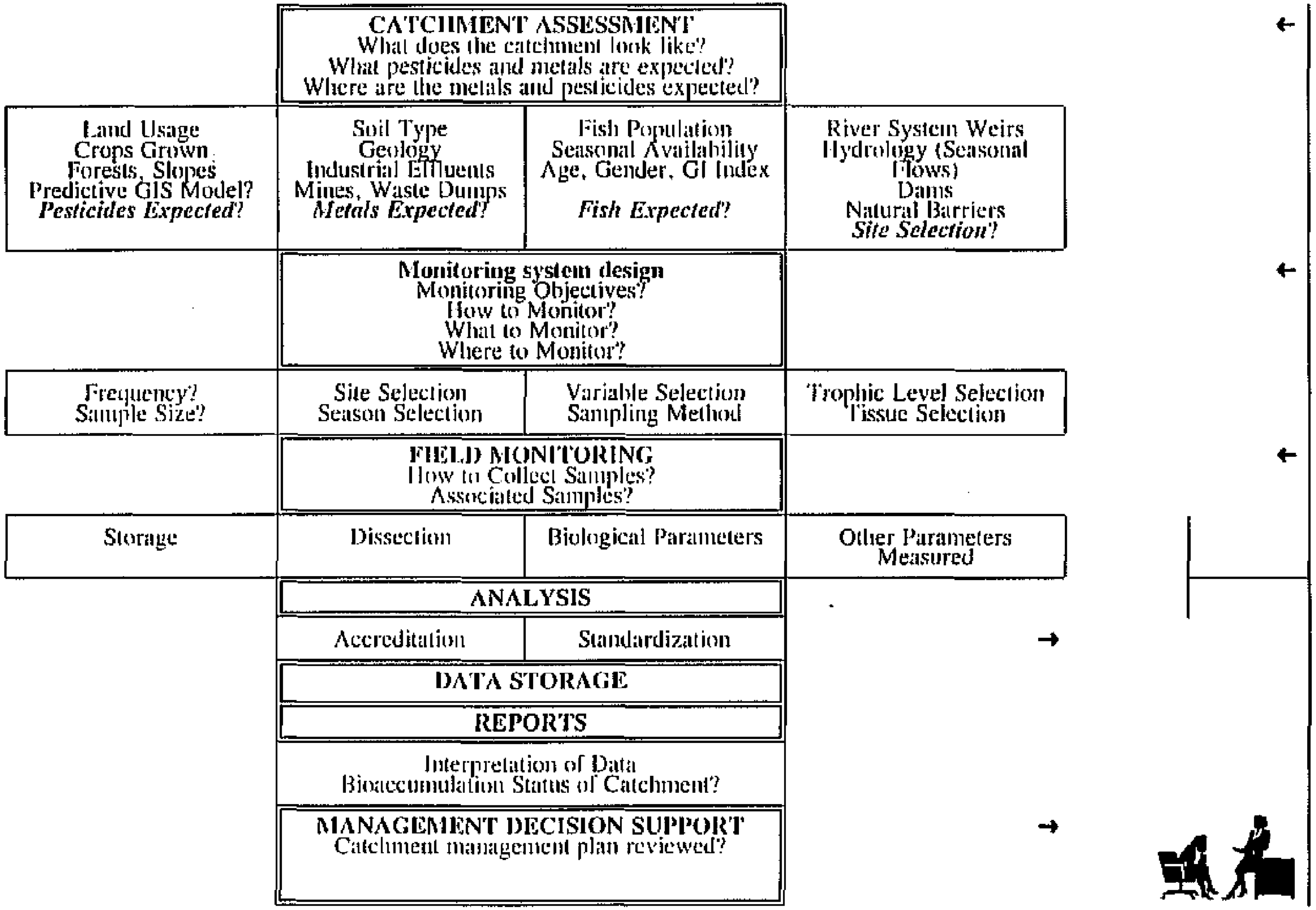

Figure 2: **Proposed bioaccumulation protocol**

Table 12: **Proposed levels of assessment for which fish bioaccumulation can be used.**

	National Rivers Health Assessment		Human Health Risk Assessment		Impact Assessment	
Resolution scale	National - catchments		National- subcatchments - reservoirs		Localised - rivers reaches	
Sites	200 National biomonitoring		Recreational and subsistence protein resources		Impact focussed	
Frequency of sampling	5 yearly		3 to 5 years		Needs based (days to seasons)	
Seasons	Either before or after rainy season		Before and after rainy season		Needs based (days to seasons)	
Purpose	Baseline of status of fish body loads		Human health risk assessment of eating fish		Determine potential impacts of effluents	
	Pesticides	**Metals**	**Pesticides**	**Metals**	**Pesticides**	**Metals**
Fish trophic level	Omnivore	Detritivore - Omnivore	Eaten or utilised species		Most abundant indicator of specific pollution	
Tissues	Fat - gonads	Vertebrae - flesh	Flesh - fat	Flesh	Fat - gonads	Liver - gills
No. of samples	5	5	5	5	> 10	> 10
Sampling method	Gill or seine nets or shocker				Seine or gill nets, or cages	
Variable selection	Organochlorines, triazines	Fe, Mn, Zn, Co, Cu, Al, Mg	Organochlorines, triazines	Hg, As, Cu, Pg, Cr	Impact dependant	
Linkages	National Rivers Health Programme Catchment Situation Assessments		Human Health Risk Assessment databases Department of Health		Waste Load Allocation Impact Assessment Risk Assessment Chemical Speciation Catchment Management Whole Effluent Toxicity Biomarkers	

This bioaccumulation protocol will have close linkages to the following databases or biomonitoring studies:

- Catchment or situation assessments (land usage, diffuse and point sources of pollution)
- Water quality
- SASS4, HAM, RVI, HQI
- Fish biology, IBI, deformities, parasites, blood haematology, population dynamics, length/mass ratios, liver somatic index, fecundity, recruitment, etc.
- WET (Whole Effluent Toxicity) and ecotoxicology
- Sediments as a reserve of metals and pesticide or as a biotransformer

Bioaccumulation can be used on different scales of impact ranging from rapid (days) or acute, to months (semi-acute), or years (chronic).

National Rivers Health Assessment (Level 1)

This national programme should include this bioaccumulation especially the IBI and use the same sites. This programme will supply baseline data which can be used to compare catchments and be used in management to further determine how well the catchment is being managed.

If a hotspot river or catchment is detected through this programme then the next levels (2 or 3) of bioaccumulation can be activated namely Health Risk Assessment or Impact Assessment.

The frequency of this assessment programme is suggested as every 5 years. The sampling season and method as well as the rest of the suggested National River Assessment for fish bioaccumulation is indicated in **Table 12.**

Human Health Risk Assessment (Level 2)

If a fish of x kg's has a body load of μg/kg what will the human health risk be if a person of x kg eats x grams of fish x days per year? The Human health risk assessment fish bioaccumulation protocol, if implemented, will be able to answer this question.

The major areas where the fish are exploited for protein dietary supplemention should be identified and the fish assessed for bioaccumulation body loads. This would include subsistence and recreational fishing and fisheries where fish are utilised as a protein source. This is a form of a chronic assessment.

The fish from rivers or impoundments can then be rated according to the human health risk assessment and recommendations made on the suitability of the fish or mass of fish that would be safe to eat over a period of time. The results of these fish surveys can then published in a pictorial form in a variety of popular publications such as newspapers, fishing journal and entrances of fishing resorts.

Impact Assessment (Level 3)

In order to determine potential impacts of an effluent (point and diffuse) or a development fish tissue loads can be used to determine the possible impacts by comparing a reference upstream site with a fish from a down stream site. Fish are mobile which makes this approach difficult unless a natural or a man made barrier (waterfall, weir, dam etc.) occurs. Fish in cages can also be used by being placed upstream and downstream of a potential impact. The national bioaccumulation protocol results can be used as a comparison or baseline values per species and tissue and compared to the results of this impact assessment.

The following steps should be used for using fish bioaccumulation in impact assessment (**Figure 2**) :-

- understand the catchment and the dynamics that occur
- baseline water quality
- expected impact
- select sites

The frequency will be determine but should be at least seasonal and flow dependant remembering that the lowest assimilative capacity occurs at the lowest flow season.

- select species and tissues according to expected impact
- determine downstream user requirements
- health risks
- whole effluent toxicity
- chemical speciation and bioavailability of pollutant
- link impact assessments with other biological monitoring indices such as SASS, IBI.

The following steps of the proposed bioaccumulation protocol should be undertaken in order to ensure that the correct data is collected at the right rime and at the required level (**Figure 2**).

5.2 Catchment or systems approach

The sample sites chosen will depend on a thorough catchment situation analysis of potential and actual point and/or diffuse sources of pollution. In seasonal and/or regulated rivers, dam or weirs, are good places for fish sampling. Sites should be chosen downstream of potential sources of pollution and must be easily accessible year in and year out.

5.3 Monitoring system design

Choose sample sites

The sampling sites will be determined largely by the river system in each catchment (weirs, waterfalls, accessibility etc.). Further refinement of the sites will also be determined by the level of monitoring to be undertaken:-

Level 1 : National River Health Assessment will for example use a broader scale with respect to the number of sample sites and sample tokens. The sites chosen will probably only be at the end of a specific order of a river (i.e. before the confluence of two major rivers). The frequency of sampling would also be longer and would be around 5 years (**Table 12**).

Level 2 : Human Health Risk Assessments would have a more specific monitoring system design dependant on needs defined by a preliminary or scaping assessment. If a specific body of water is being used for protein supplementation (via angling) then the human health risks need to be determind. If a human health risk is predicted then the monitoring programme design will need to be customised to effectively determine the seventy of the human health risk.

Level 3 : Impact Assessment monitoring programme design would have the most intense monitoring programme. The resolution and frequency of sampling etc. could be from days to months (**Table 12**).

Number of samples to be taken

A general approach with respect to the number of samples to be taken per level is given in **Table 12.**

There is a high variability in tissue loads within the same species at the same site which should be taken into account when planning the bioaccumulation monitoring programme. This aspect needs to be thoroughly discussed with a statistician before the sampling commences as part of experimental design. The specific requirements of the monitoring programme must also take into account the catchability of the fish. the large size of tissues required for analysis and the high costs of analysis. Furthermore the abundance and availability of fish in some rivers in South Africa is low making the collection of fish difficult. Care must also be taken in not over exploiting fragile fish populations through over zealous destructive capture techniques and too frequent monitoring programmes.

Variable selection

Table 12 indicates the suggested protocol for variable selection for bioaccumulation.

The choice of variables to be monitored will vary from catchment to catchment and from site to site depending land use.

Actual pesticide usage databases will assist variable selection as well as interviews with extension offices of the Department of Agriculture. Metal load estimates from industrial and mining effluents can be determined with assistance form the regional DWAF office. Literature reviews of pesticide and metal accumulatory capabilities needs to be done before variables are selected.

Frequency of sampling

Level 1: It is suggested that for pesticides and metals that the bioaccumulation studies of fish in South African Rivers the National River Health monitoring should takes place every five years. This could be phased in with initial emphasis being on priority rivers as determined by DWAF and conservation organizations.

Level 2: Sampling frequency would be determined by the health risk severity.

Level 3: Sampling frequency would be dependant on the specific objectives of the study as well as the site (river or dam). Initially at least quarterly or until the impact has been determined, the frequency can then be refined.

The timing of sampling of these levels will be dependant on the flow regime in the rivers. During the breeding season (summer) certain species of fish migrate making catching difficult as well as the fish absorbing their abdominal fat and using this reserve for breeding purposes. The best season for maximum concentrations of fat in fish would be pre-breeding when the fish accumulate extra fat reserves for breeding.

Specific tissues

The size of the fish caught will determine the amount of tissue available for analysis. For pesticide analysis *ca* 20 g (wet weight) of tissue are necessary. For metal analysis *ca.* 1 g (wet weight) of tissue is necessary.

The specific tissues to be taken will depend on the purpose of the study (**Table 12**), for example:-

Metals

Level 3 : (Impacts Assessments): Gills and liver are suggested for metals.
Level 2 : (Human Health Risk Assessment): The suggested tissues are muscle and skin.
Level 1 : (National River Health Assessments): Suggested tissues are liver, gills and gonads. For long term studies (trends): liver (iron, copper, cadmium), vertebrae (nickel), intestine (chromium, manganese), gonads (zinc, aluminium), skin (lead).

Pesticides

Level 3 : Gonads - testes (pre-breeding season) and liver are suggested.
Level 2 : The suggested tissues are flesh and fat (associated with fatty muscle).
Level 1 : Gonads : (BHC, DDT, DDE, DDD, Dieldrin) and fat (BHC, DDT, DDE, DDD, Dieldrin).

Trophic levels of fish used for bioaccumulation studies.

Due to the patchy distribution of fish species in South Africa it is of benefit to select specific trophic levels of fish rather than species.

Metals

Level 1 : It is proposed that for metals detritivorous or omnivorous species of fish be collected.
Level 2 : Utilized or most eaten species.
Level 3 : Most abundant species of fish (omnivore) or fish of conservation importance.

Pesticides

Level 1 : It is proposed pesticides that piscivorous or omnivores are collected for persistent residues.
Level 2 : Utilized or most eaten species.
Level 3 : Most abundant species of fish (omnivore) or fish of conservation importance.

5.4 Timing of sampling

Levels 1 and 2 : April and September (for the summer rainfall areas) and November to March (for the winter rainfall areas). This enhances the catch per unit effort, reducing sampling time and manpower.
Level 3 : The survey will be needs driven.

5.5 Sampling method

The fishing methodology will depend on the river geomorphology, flow, river width, manpower and equipment. Seine nets would be preferable as only the fish needed can be sampled and the rest returned unharmed. Gill nets can also be used if the river is flowing too fast, its bottom too rocky, too much debris on the bottom or sides or if the river is too deep. For impact assessment cages could be used with fish being placed upstream and downstream of the potential impact.

5.6 Dissection and storage of tissues.

Tissue terminology should be standardised for example muscle (muscle tissue without the skin and scales and deboned as far as possible etc.).

Tissues should be dissected in a clean environment and using clean dissection equipment in order to prevent contamination.

The samples should be stored in clean. clearly labelled glass or plastic containers in a freezer at -5 °C . The samples should not be kept in storage for long periods before analysis is undertaken.

5.7 Analysis of samples

Analytical methods

Need to use Standard Methods (1989).

Quality control

Analysis should be undertaken at accredited analytical facilities using internationally accepted standards.

5.8 Data storage and reporting of results

Data storage

The data base generated by this proposed national bioaccumulation programme must be:-

- coordinated by DWAF
- data bases - open and seamless
- housed at a central and accessible institution
- updated regularly
- free of charge
- available through the internet

Reporting

The bioaccumulation monitoring programme must be designed as a management information system and used as a Decision Support System to compliment DWAF's national water resource management strategies.

The results must be made public in an easy to understand format. Indices need to be developed in order to convey the status of the fish, the river health etc. so that the whole populous of South African can understand what the results mean and what they can possibly do to improve the water quality and aquatic ecosystem status of our rivers.

5.9 Management decision support

Management interventions

If management targets are set then the results of the bioaccumulation monitoring programme must be used to determine the success of the catchment management plan and suitable management interventions undertaken until such time as the targets are reached.

The results of the bioaccumulation assessment can be used as to audit how effective the catchment management interventions have been over a period of time.

6. RECOMMENDATIONS

6.1 Biological Monitoring Development Needs

There is a large amount of development. verification and implementation required before biological monitoring in South Africa can take its rightful role in assisting water quality management. This development needs to be facilitated and controlled so that the aims and objectives of DWAF's policies and mission statement with regards to the aquatic ecosystem are met. With the limited time and money available this development needs to be well co-ordinated (Heath 1993).

6.2 Linkage of Bioaccumulation Studies with Human Health Risk Assessment

International data bases on human health risk assessment must be accessed to determine the risks associated with the human consumption of fish tissues contaminated with pesticide and metals. This is an important issue not only for freshwater fish but for estuarine and coastal fish that are a staple protein source for a large proportion of our population.

6.3 Ongoing Refinement

The bioaccumulation protocol needs to be re-assessed and refined after initial application in rivers. The tissues selected for specific bioaccumulation studies as well as the trophic levels selected for need to be verified in a variety of riverine ecosystems.

6.4 Standardization of Techniques

The analytical techniques used to determine pesticides and metals need to be standardized for comparative purposes. These standard techniques should include sampling procedures. tissues and species used for bioaccumulatory studies. The data reported should also be in standardized units for example μg/g or mg/kg dry weight. This standardization will reduce possible errors in converting from other units.

6.5 Custodian of Results

The data collected on fish and other organisms in terms of bioaccumulation studies should be stored at central institution whose responsibility it should be to update and do quality control on the data collected. DWAF is ideally suited for such a role as they already collected the National, Regional and Compliance monitoring water quality data which should be linked to bioaccumulatory data.

6.6 All Bioaccumulatory Studies Synthesized

The synthesis of all the varied bioaccumulatory studies is imperative. As different organisms and rivers have been studied by different organizations it is now timeous to integrate and interpreted all these studies in order to not have any duplication of studies, and to decide on what organism, tissue, species, method that should be used in a state of nation assessment.

6.7 Research Needs

- Controlled laboratory studies to determine the pesticide and metals uptake rates and response times in fish tissues in typically high turbidity water.

- Correlate pesticide and metal sediment loads with fish tissue loads. High turbidity rivers in South Africa could result in the majority of the pesticides and metals loads settling into the sediments rather than been transported in the river for long distances.

- Tissue selection needs further refinement especially gills, intestine etc.

- Sublethal behavioural changes in breeding success, breeding migrations should be monitored in rivers with high pesticide and metal loads. This would require a combination of laboratory experiments and fish population dynamics and behaviour studies in non-turbid rivers.

- Fish population dynamics (fecundity, mortality etc.) should be compared with bioaccumulated body loads of pesticides and metals.

- Bioaccumulation fish body loads need to be compared with fish health indices.

- Bioaccumulation must be linked in a cost effective manner with IBI and fish health index.

- Areas of aquatic ecosystems (freshwater, estuaries and coastal zone) with high bioaccumulation rates need to be identified nationally and the local subsistence populous informed and educated about possible health risk. Standard practises such as gutting all fish and throwing away fatty tissues should be instilled in these populations.

- Analytical techniques need to be refined in order to allow smaller tissues samples to be analysed especially for pesticide residues. Methods should be develop to allow for the analysis of new generation pesticides. These methods must be standardised and interlaboratory studies undertaken to compare results.

- Natural background origins of metals in rivers needs to be quantified according to the local soil types, geology and land disturbances.

- User friendly, easily understandable icons or cartoons need to be developed as an educational tool for grass roots education at primary schools. Bioaccumulation indices need to be developed for the general public so as the current status of our rivers can be easily understood.

Biological monitoring in South Africa will improve the current water quality management programme. Fish as a bioaccumulator of pollutants can be used to verify the effectiveness and validity of the currently used water quality management programme.

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TERMS OF REFERENCE

The aims of the study, as agreed in the original contract between WATERTEK, CSIR and the Water Research Commission were as follows:

1. To integrate information from, and collaborate with, researchers studying the ecological features of five rivers in the Mpumalanga and Northern Provinces that flow through the Kruger National Park (KNP) and one Western Cape river. Existing data and study sites with habitats specific to selected species of fish will be used in order to maximize fishing efforts.

2. To utilize information from completed and presently undertaken catchment studies of the selected rivers, in collaboration with researchers currently working in the field, to determine the point and possible diffuse sources of pesticides and metal pollution. Existing land usage, estimates of the pesticides most commonly used and the specific metal variables associated with the industries in each river catchment will be used to select the specific variables for analysis.

3. To catch selected species of the larger indigenous fish in these rivers, at sites where pesticide and/or metal pollution is expected. Techniques developed by the researcher in charge of this proposal will be used to selected specific species of fish as well as the particular fish tissues in which pesticide and metal levels will be determined.

4. To establish the current body loads of pesticides and metals present in the larger species of indigenous fish in the selected rivers for the period of study.

5. In collaboration with other researchers and the Department of Water Affairs & Forestry, the current fish body loads and monitoring techniques developed in this report will be proposed for the implementation of a National Bioaccumulation River Surveillance Programme for pesticides and metals in South African rivers.

Anticipated benefits

- Factual information on pesticide and metal levels in selected indigenous fish in five rivers that flow through the Kruger National Park and a major Western Cape river.