Methodology for the assessment of human health risks associated with the consumption of chemical contaminated freshwater fish in South Africa

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Abstract

Studies have shown that the aquatic environment can be polluted by contaminates that are accumulated by freshwater fish and this may pose a health risk to the consumers of the contaminated fish. Developed counties like the United States of America have developed strategies and associated guidance documentation to conduct chemical contaminant surveys using fish and to use these data to reduce the heath risk to the consumers of the fish. In this paper a generic methodology is presented that will give guidance in the undertaking of fish contaminant surveys to provide information regarding the possible health risk if the fish are consumed by recreational and subsistence fishermen in South Africa. The fundamentals of the methodology are based on catchment information, socio-demographic information of consumers of fish in the catchment, bioaccumulation potential and health risks of analytes, sound sampling design, risk assessment procedures and performing monitoring at different scales and depths. These aspects are presented as 10 major steps in the methodology of which the basic requirements are discussed to focus the surveys and optimise the application of resources. Although the methodology focuses on assessing the possible health risk to the consumers of fish many of the aspects would apply to any investigation aimed at assessing the chemical contaminant levels in fish. Furthermore as these surveys identify areas in the aquatic system where fish have unacceptably high chemical contaminant levels, this information can be used in catchment management programmes to put remedial actions in place that would ensure that the fish populations of the system are fit for present and future human consumption.

Introduction

Pollution of the aquatic environment is one of the worst legacies of development of the 20th century. It is well documented that modern agriculture, industrialisation and urbanisation have negatively affected environmental quality and specifically aquatic systems (Förstner and Wittmann, 1983; Hellawell, 1986; Ellis, 1989; Mason, 1991; Dallas and Day, 1993; Johnson, 1996). In South Africa the pollution of freshwater aquatic systems can be linked to point-source discharges (waste water treatment works and industrial effluents) and diffuse surface runoff (agricultural, mining and urban). As a result of these anthropogenic activities, innocent people as well as other life forms may be exposed to harmful contaminants which may be released without adequate consideration of human health and the environmental effects (Tchounwou et al., 1996).

Effects on human health as a result of exposure to surface water contaminants can occur through contact recreation, drinking water and the consumption of contaminated food for example, fish and shellfish (US EPA, 1991). During contact recreation dermal absorption and incidental ingestion may pose a potential health risk. Drinking water poses a very high health risk; however, the risk can be reduced by effective treatment and by applying drinking water criteria. People consuming fish or shellfish are potentially at risk as these organisms have the potential to bioaccumulate harmful contaminants from the aquatic environment (US EPA, 1991; Bevelhimer, 1995). The contaminants that have been bio-accumulated by the fish or shellfish pose carcinogenic, genotoxic and non-carcinogenic health risks to consumers (Reinert et al., 1991; US EPA, 1991). However, it must be stressed that the consumption of fish is generally beneficial as it provides a good source of protein, vitamins, omega fatty acids and basic minerals (Anderson et al., 1972; Zabik et al., 1995; US EPA, 1997). Additional benefits of consuming fish include a decrease in cardiovascular disease, a reduction in blood pressure in individuals, reduced colon and breast cancer risks, a decrease in pain from arthritis and a decrease in asthma attacks in asthmatics (US EPA, 1997). From the preceding it is evident that the consumption of fish is beneficial to humans, but if these fish are contaminated they pose a health risk to consumers.

As a result of the potential health risk associated with the consumption of chemically contaminated non-commercially caught fish, the United States of America has been issuing fish consumption advisories and bans (US EPA, 1995a;b; 1996; 1997; 1999). Fish consumption advisories are designed to reduce the risk to fish consumers by providing information that would lead to the voluntary restriction of fish consumption to levels that pose limited, if any risk. A fishing ban, on the other hand, involves the banning of the consumption of fish by closing water bodies for fishing and/or banning the possession of contaminated fish. Fish consumption advisories not only aim to minimise the health risk to the consumers of fish but also intend to minimise the negative effects of restricting consumption and fishing (US EPA, 1997).

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Although the United States of America has issued fish contaminant advisories since the mid- 1970s the various Agencies have employed different methods to estimate the risks to human health from the consumption of chemically contaminated fish. Subsequently the United States of America Environmental Protection Agency (US EPA) has developed a series of four documents to provide guidance to Agencies issuing fish consumption advisories for non-commercial fishing (US EPA, 1995a;b; 1996; 1997). From these documents it is evident that a fish consumption advisory programme should consist of:

- fish sampling and analysis, therefore the collection of contaminant data
- risk assessment
- risk management
- a risk communication and associated health advisory programme.

However, much of the information and guidance provided in these documents has a wider application and could assist in the development of any investigation related to the assessment of contaminant levels in fish and shellfish.

A review of the published literature on the occurrence of pollutants in fish from South African freshwater systems revealed that several surveys were undertaken to investigate chemical contaminants in fish. The focus of these investigations was mainly on metal levels (Du Preez and Steyn, 1992; Grobler et al., 1994; Seymore et al*.,* 1995, 1996; Claassen 1996; Schoonbee et al., 1996; Van Vuren et al., 1996; Du Preez et al., 1997; Kotze et al*.,* 1999; Robinson and Avenant-Oldewage, 1997; Heath, 1999; Heath and Claassen, 1999; Avenant-Oldewage and Marx, 2000; Nussey et al*.,* 1999; 2000) and biocide concentrations (Bouwman et al*.,* 1990; Grobler, 1994; Claassen, 1996; Heath, 1999; Heath and Claassen, 1999) in fish. In general these studies describe the species and tissue differences in contaminant bioaccumulation as well as the spatial and temporal variation in contaminant concentrations. Most of these studies were aimed at contributing to the assessment of the health of the aquatic ecosystem under investigation The risks to humans when consuming contaminated fish are seldom addressed and only the publications by Claassen (1996), Heath (1999) and Heath and Claassen (1999) used a risk-based approach to assess the possible health risk to humans when consuming fish from selected rivers in South Africa. Furthermore, at present it is not known if any ban has been placed on the consumption of freshwater fish in South Africa. Bans are usually limited to the consumption of shellfish due to the contamination by saxitoxins (Branch and Branch, 1981; WHO, 1999)**.**

From the preceding it is evident that possible human health risks due to the consumption of contaminated fish from South African freshwater systems have received little attention. This is an unacceptable situation since pollutants from various anthropogenic activities are polluting these systems (Heath, 1999). Furthermore, fish are captured from many of the water bodies in South Africa by recreational and subsistence fisherman, while commercial fishing and cage culture are undertaken at selected systems. Therefore, certain sections of the South African population that consume fish may be at risk from the possible exposure to contaminants accumulated by fish captured from freshwater systems. Information regarding the possible health risk due to the consumption of fish from the freshwater systems in South Africa is therefore urgently required.

The general objective of this paper is to provide a generic methodology that would give guidance in the undertaking of fish contaminant surveys to provide information regarding the possible health risk if the fish are consumed by recreational and subsistence fishermen. Furthermore, it would contribute to the concept of 'health promotion', which is the process of enabling people to take control over their health and thus improve their health. They key is to take steps to prevent health impacts before it is manifested as a health problem (WHO, 2002). It must, however, be stressed that developing and implementing methodologies to manage and reduce the human health risk associated with the consumption of freshwater fish, will also benefit the aquatic ecosystem at large. The ecosystem will benefit as the ultimate goal of the management strategy would be to protect the freshwater aquatic environment and to put remedial actions in place that would ensure that the fish populations of the system are fit for present and future human consumption.

The fundamentals of the methodology are based on catchment information (possible anthropogenic activities that can result in chemical pollution), socio-demographic information of consumers of freshwater fish in the catchment, bioaccumulation potential and health risks of analytes, sound sampling design, risk assessment procedures and performing monitoring at different scales and depth (Fig.1). It is important to note that this methodology is closely linked to the protocols proposed by the USEPA (US EPA, 1995a;b; 1996; 1997) for issuing fish consumption advisories for non-commercial fish and by Heath (1999) for the monitoring of pesticides and metals in South African rivers. The approach by Heath (1999) and the current approach are catchment-based, making it possible to use many of the data and information when undertaking any of the proposed levels of investigation. Therefore, if projects are carefully planned using the same methodology and principles, the data and information can be exchanged, which would ensure the optimal utilisation of resources.

Specific components of methodology

The methodology identifies 10 major steps that should be followed in a hierarchical pattern to perform the assessment (Figs.1 and .2).

Step1: Selection of scale and scope of surveys

Three monitoring levels should be considered for the investigation of the chemical contaminant concentrations in freshwater fish tissue (Figs. 1 and 2). The following is therefore considered for the surveys in South Africa:

- **Level 1:** *Screening surveys* – A national survey of water bodies where freshwater fish are captured for commercial, subsistence or recreational purposes. Fish are therefore selected from sites where the levels of contaminants in edible fish tissue could cause significant health risks to consumers.
- **Level 2:** *Intensive surveys, Phase I* – Conduct intensive surveys at sites with a potential risk as identified during Level 1 surveys. Therefore, determine the magnitude of contamination in edible fish tissue of commonly captured and consumed fish species.
- **Level 3:** *Intensive surveys, Phase II* – Conduct intensive surveys at the sites investigated during Level 2 surveys in order to determine the level of contamination in specific fish size classes as well as the geographical extent of contamination. A Level 3 survey is therefore more detailed than a Level 2 survey.

These monitoring levels are selected up-front by governmental authorities at national or provincial level as well as project managers of specific surveys who are responsible for designing fish chemical

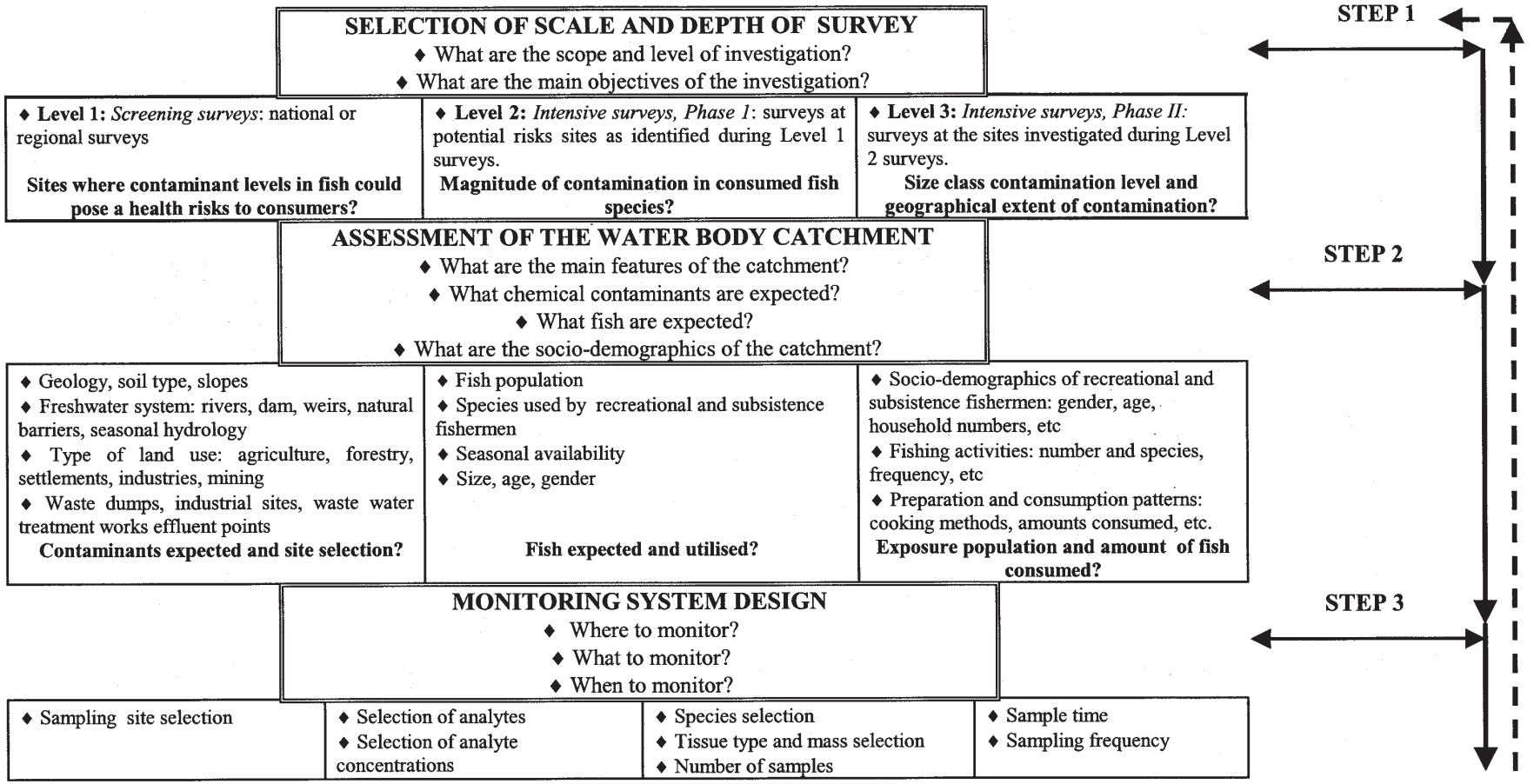

Figure 1
Methodology for freshwater fish chemical contaminant surveys for assessing the human health risks to consumers

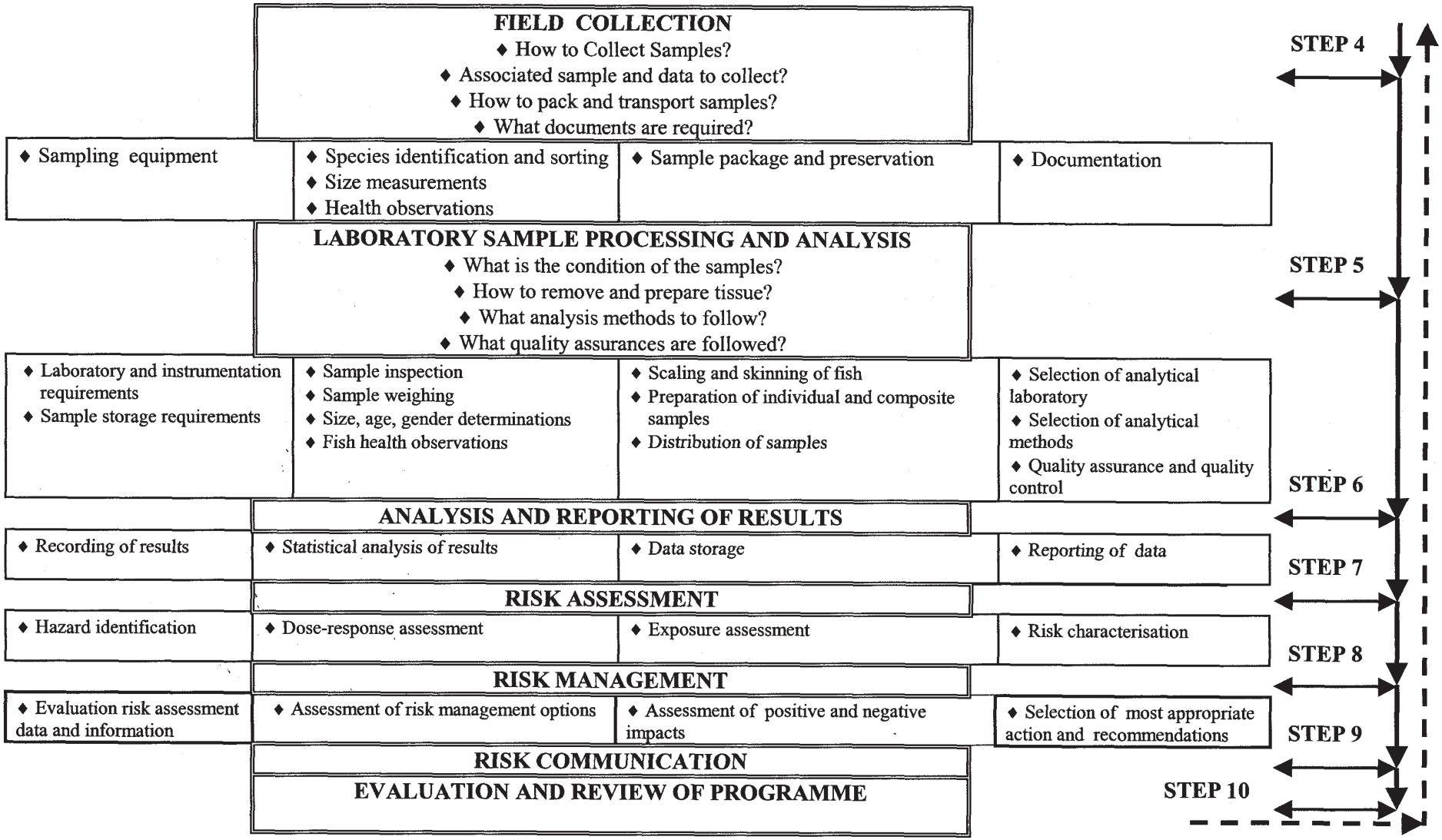

Figure 1
(Continued)

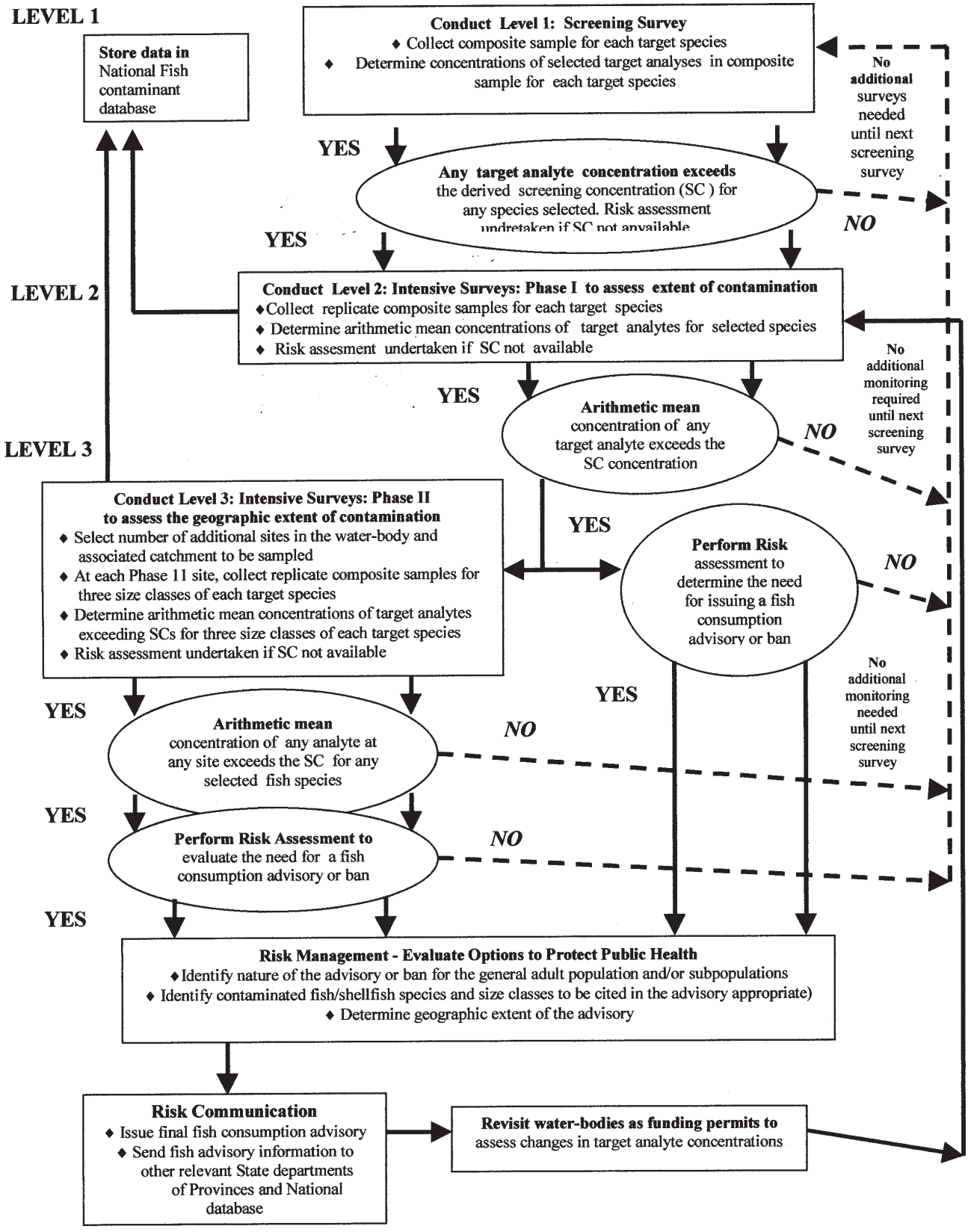

Figure 2
Monitoring levels and activities for the assessment of the human health risk associated with the consumption of chemical contaminated freshwater fish

contaminant surveys (Fig. 1). It is also important to note that these surveys are interlinked and naturally flow from the one to the next (Fig. 2). To be cost- effective these levels should be applied in a hierarchical manner as indicated in Fig. 2.

TABLE 1
Selected input parameters for use in risk equations (adapted from the US EPA, 1997)

Equation parameter[a]	Values
Maximum acceptable risk level (ARL)	10^{-4} (unitless) 10^{-5} (unitless) 10^{-6} (unitless)
Cancer slope factor (SF)[b] Reference dose (RFD)	$(mg/kg.d)^{-1}$ mg/kg.d
Consumer body mass (BM)	70 kg (general adult population) 70 kg (women of reproductive age) 14.5 kg (young children <6 years)
Average fish meal size (MS)	0.05 kg (children only) 0.10 kg 0.15 kg 0.25 kg 0.500 kg (adults only)
Time-averaging period (TP_{ap})	30.44 day/month (monthly limit) 14 day/14-day period (biweekly limit) 10 day/10-day period (10-day limit) 7 day/week (weekly limit)

[a] Selection of the appropriate maximum acceptable risk level, consumer body mass, and average fish meal size are considered risk management decisions.
[b] The SF[b] and RFDs values are obtained from IRIS (1999) and US EPA (1997).
* Assistant™ or any other risk assessment tool.

Step 2: Assessment of water body catchment

The water body catchment should be assessed in order to determine the processes that drive and determine the water quality in the catchment. The general catchment characteristics (soil type topography, rainfall, hydrology, land-use patterns, vegetation, etc.), anthropogenic activities and potential pollution sources are described and assessed (Fig. 1). Modelling techniques (for example GIS models, pesticide runoff models, effluent dispersal models, etc.) would also aid in identifying possible problem areas and possible pollution sources (Heath, 1999).

It is essential to obtain socio-demographic information (age, sex, body mass, etc.) on the population utilising the specific water body. Information on fish consumption patterns, for example fish species (number of species, type of fish, size classes) included in the diet, the specific edible portion selected for consumption, fish preparation and cooking methods, meal size and frequency of consuming fish by the population should be gathered. If this information is not available it could be obtained using methods such as telephone surveys, mail surveys, personal interviews, daily record-keeping and creel census for the general population at large or specific sub-populations. In countries such as South Africa, with a diversity of cultures, it is of the utmost importance that all the cultural groups are included (where appropriate) in the survey and that the methodology used to obtain information does not exclude individuals from the survey. In South Africa the availability of resources will limit these investigations. It is therefore recommended that the general derived values as indicated in Table 1 be used.

Step 3: Monitoring survey design

Sampling site selection

Sites that have been or are being impacted by potential sources of diffuse and point sources of pollution are identified. Potentially unpolluted sites must also be included, as they will serve as 'reference' of 'preferred state' sites. The following is therefore recommended for surveys in South Africa:

- **Level 1:** *Screening surveys* – Depending on resources, all water bodies where commercial, recreational or subsistence fishing is undertaken should be included. Sites with a high intensity of activities should be selected first. Preferably the sites should be at fishing areas near point sources of pollution (e.g. industrial, municipality and mine discharges, etc.), diffuse sources of pollution (e.g. landfills, intensive agricultural, mining, dredging areas, etc.) and a few sites at potentially unpolluted areas. Other considerations include: (i) proximity to water and sediment sampling sites, (ii) availability of other biological data on the fish species in question, (iii) type of sampling equipment, (iv) accessibility of the site, (v) natural barriers to fish (waterfalls) and (vi) manmade barriers to fish (dam walls, weirs, etc.).
- **Level 2:** *Intensive surveys, Phase I* – All the sites in the Level 1 surveys where there is a potential health risk to consumers of fish. Thus the sites where the screening value for one or more of the selected analytes is exceeded or potential health risk is indicated for one or more of the selected analytes using the computer software package Risk
- **Level 3:** *Intensive surveys, Phase II* – The sites selected should define the geographic range of the contamination as identified during the Level 2 survey. Sites upstream and downstream of point sources of pollution and areas of diffuse sources of pollution are selected. Other geographical features such as barriers to migration (dams, weirs, natural waterfalls) should also be considered.

Selection of analytes and analyte screening concentrations

As an initial assessment the selected analytes as proposed by the US EPA (1995a) should be considered as test analytes (Table 2). The lipid content of the tissue must also be determined. This list can be refined as more catchment-based information on analyte levels of concern becomes available, or as more analytes (for example lead) are identified as potential human carcinogens or non-carcinogens.

To calculate screening concentrations for analytes for South

TABLE 2
Analytes, screening concentrations and risk values recommended for freshwater fish chemical contaminate monitoring in South Africa (adapted from the US EPA, 1995a; 1997)

Selected analyte	Non-carcinogens	Carcino-gens	SC[A] (mg/*l*)	
	RFD[B] (mg/kg·d)	SF[B] (mg/kg·d)$^{-1}$	Non-carcino-gens	Carcino-gens (RL=10^{-5})
Metals				
Arsenic (inorganic)[C]	3 x 10^{-4}	1.5	3	-
Cadmium	1 x 10-3	NA	10	-
MercuryE				
Developmental	1 x 10^{-4} [F]	NA	1	-
Chronic systemic	1 x 10^{-4} [F]	NA	1[F]	-
Selenium[G]	5 x 10^{-3}	NA	50	-
Tributyl tin	3 x 10^{-5}	NA	0.3	-
Organochlorine pesticides				
Total chlordane (sum of cis- and trans- chlordane, cis- and trans-nonachlor, and oxychlordane)[H]	6 x 10^{-5}	1.3	0.6	0.08
Total DDT (sum of 4,4[1]- and 2,4[1]- isomers of DDT, DDE, and DDD)[I]	5 x 10^{-4}	0.34	5	0.3
Dicofol	1.2 x 10^{-3}[J]	0.34	10	-
Dieldrin	5 x 10^{-5}	16	0.6	7 x 10^{-3}
Endosulfan (I and II)	6 x 10^{-3}[J]	NA	60	-
Endrin	3 x 10^{-4}	NA	3	-
Heptachlor epoxide	1.3 x 10^{-5}	9.1	0.1	0.01
Hexachlorobenzene	8 x 10^{-4}	1.6	9	0.07
Lindane (γ-hexachloro-cyclohexane; γ-HCH)	3 x 10^{-4}	1.3[K]	3	0.08
Mirex	2 x 10^{-4}	1.8[L]	2	-
Toxaphene	3.6 x 10^{-4}[JM]	1.1	3	0.1
Organophosphate pesticides				
Chlorpyrifos	3 x 10^{-3}	NA	30	-
Diazinon	9 x 10^{-5} [J]	NA	0.9	-
Disulfoton	4 x 10^{-5}	NA	0.5	-
Ethion	5 x 10^{-4}	NA	5	-
Terbufos	1.3 x 10^{-4}[J]	NA	1	-
Chlorophenoxy herbicides				
Oxyfluorfen	3 x 10^{-3}	1.28 x 10^{-1}	30	0.8
PAHs	NA	7.3[N]	-	0.01
PCBs				
Total PCBs (sum of Aroclors)				
Developmental	2 x 10^{-5}[O]	-	-	-
Chronic systemic	2 x 10^{-5}[O]	2.0	0.2	0.01
Dioxins/furansP	NA	1.56 x 10^{5}	-	7 x 10^{-7}
Lipids	-	-	-	-

NA = Not available in EPA's Integrated Risk Information System (IRIS 1992,1997).
PAH = Polycyclic aromatic hydrocarbon.
PCB = Polychlorinated biphenyl.
RFD = Oral reference dose (mg/kg·d).
RL = Risk level (dimensionless).
SC = Screening concentration.
SF = Oral slope factor (mg/kg·d) $^{-1}$.

A Except for mercury, screening concentrations (for Level 1 surveys) are selected analyte concentrations in fish tissue that equal exposure levels at either the RFD for noncarcinogens or the SF and an RL=10^{-5} for carcinogens, given average consumption rates (CRs) and body mass (BMs) of 6.5 g/day and 70 kg, respectively, for the general adult population.

B Unless otherwise noted, values listed are the most current oral RFDs and SFs from IRIS (1995; 1997).

C Total inorganic arsenic should be determined for comparison with the recommended SC.

D From US EPA (1997).

E Because most mercury in fish and shellfish tissue is present as methylmercury and because of the relatively high cost of analyzing for methylmercury, it is recommended that total mercury be analyzed and the conservative assumption be made that all mercury is present as methylmercury.

F The US EPA has recently re-evaluated the RFD for methylmercury, primarily because of concern about evidence that the fetus is at increased risk of adverse neurological effects from exposure to methylmercury. An oral RFD of 1 x 10^{-4} mg/kg·d based on developmental neurological effects in human infants was included. This oral RFD of 1 x 10^{-4} mg/kg·d is considered protective for chronic systematic effects of methylmercury among the general adult population, women of reproductive age, and children.

G The RFD for selenium is the IRIS (1997) value for selenious acid. The evidence of carcinogenicity for various selenium compounds in animal and mutagenicity studies is conflicting and difficult to interpret.

H The RFD and SF values listed are derived from studies using technical-grade chlordane (purity 95%) or a 90:10 mixture of chlordane:heptachlor or analytical-grade chlordane. No RFD or SF values are given in IRIS (1992, 1997) for the cis- and trans-chlordane isomers or the major chlordane metabolite, oxychlordane, or for the chlordane impurities cis- and trans- nonachlor. It is recommended that the total concentration of cis- and trans-chlordane, cis- and trans-nonachlor, and oxychlordane be determined for comparison with the recommended SC.

I The RFD value listed is for DDT. The SF value is for DDT or DDE; the SF value for DDD is 0.24. The use of SF = 0.34 for any combination of DDT, DDE, DDD, and dicofol is recommended. It is recommended that the total concentration of the 2,4' – and 4,4'-isomers of DDT and its metabolites, DDE and DDD, be determined for comparison with the recommended SC.

J The RFD value listed is from the Office of Pesticide Program's Reference Dose Tracking Report, US EPA.

K The SF value listed for lindane was calculated from the water quality criteria (0.063 µg/l).

L **The National Study of Chemical Residues in Fish used a value of SF = 1.8 for mirex from HEAST (1989).**

M The RFD value has been agreed upon by the Office of Pesticide Programs value and the Office of Water of the United States Of America.

N The SF value listed is for benzo[a]pyrene.

O The RFD for PCBs is based on the chronic toxicity of Aroclor 1254.

P The SF value listed is for 2,3,7,8-tetrachlorodibenzo-p-dioxin (US EPA, 1995a; 1997)

TABLE 3
Freshwater fish species that are recommended for consideration for chemical contaminant investigations in South Africa

Family name	Scientific name	Common name	Feeding habits
CYPRINIDAE	*Barbus aeneus*	Small mouth yellow fish	Bottom feeder, omnivorous
	Barbus andrewi [1]	White fish	Bottom feeder, invertebrates and algae
	Barbus natalensis [2]	Scaly	Omnivorous, algae, invertebrates, detritus
	Barbus polylepis	Small scale yellowfish	Carnivorous; algae; and invertebrates
	Labeo capensis	Orange River mudfish	Bottom feeder, omnivorous; algae and invertebrate
	Labeo molybdinus	Leaden labeo	Algae eater from rocks
	Labeo rosae	Rednose labeo	Detritivore; bottom feeder, invertebrates in sediments
	Labeo rubromaculatus [2]	Tugela labeo	Detritivore; bottom feeder, algae and detritus
	Labeo umbratus [3]	Moggel	Detritivore; bottom feeder, soft mud and detritus
	Cyprinius carpio[4]	Carp	Omnivore; bottom feeder
SCHILBEIDAE	*Schilbe intermedius*	Silver catfish/Butter barbel	Omnivorous; middle and surface water feeder
CLARIIDAE	*Clarias gariepinus*	Sharptooth catfish	Omnivorous
SALMONIDAE	*Oncorhynchus mykiss*[3,4]	Rainbow trout	Carnivorous predator; feed on invertebrates, fish, frogs
CENTRARCHIDAE	*Micropterus salmoides*[4]	Largemouth bass	Carnivorous; predator invertebrates, frogs, fish
	Micropterus dolomieu [4]	Smallmouth bass	Carnivorous; predator, feeds on invertebrates, fish
CICHLIDAE	*Oreochromis mossambicus*	Mozambique tilapia	Omnivorous, algae detritus invertebrates
	Tilapia sparrmanii [5]	Banded tilapia	Omnivorous, feeds on algae and invertebrates
	Tilapia rendalli	Redbreast tilapia	Algae and plant eater but also include invertebrates

1. Distribution confined to: Western Cape Province
2. Distribution confined to: KwaZulu-Natal Province
3. Important commercial species
4. Exotic species
5. Mainly important to subsistence fishermen

Africa scenarios it is recommended that the procedure of the US EPA (1995a) be used. It is recommended that for South Africa the screening concentrations for the selected analytes as listed in Table 2 are used if data (for example on body mass and/or concentrations rates etc) are not available to modify them or if resources are not available to derive local screening concentrations. Alternatively the locally obtained chemical contaminant concentrations can be used in the Risk *Assistant™ software package (Risk *Assistant™, 1995) to calculate possible risks. However, this procedure can be more costly. The following is therefore recommended for the South African surveys:

- **Level 1:** *Screening surveys* – Monitor for the relevant selected analytes as listed in Table 2. Refine the list as more catchment-based analyte concentrations and/or information or additional toxicological data for other analytes become available. Use the screening values as listed in Table 2 and adapt these values as more information regarding the local population becomes available. Alternatively, use the obtained chemical contaminant concentrations directly in the Risk *Assistant™ software package.
- **Level 2:** *Intensive surveys, Phase I* – Monitor the selected analytes that exceed the screening concentration. Chemical contaminant concentrations just below or at the screening concentration should be re-assed to determine if they must be further monitored. The same screening concentrations as in Level 1 surveys are used and are only modified if more local population information becomes available. Alternatively use the obtained chemical contaminant concentrations directly in the Risk *Assistant™ software package.
- **Level 3:** *Intensive surveys, Phase II*: – The same recommendations as for Level 2 surveys, but a broader geographical area must be surveyed and different size classes of a specific specie are selected for evaluation. The obtained chemical contaminant concentrations are directly applied in the Risk *Assistant™ software package.

Species selection

Ideally, species from two distinct ecological groups of fish (e.g. bottom feeders and predators) which occur over a wide geographic area should be used. The fish species listed in Table 3 should give some guidance for the selection of fish species for a specific region. The following is therefore recommended for surveys in South Africa:

- **Level 1:** *Screening surveys* – At least one bottom feeder or one predator species selected from the species in Table 3. Preferably include one bottom feeder and one predator species. Focus on the species that the people preferred eating
- **Level 2:** *Intensive surveys, Phase I* – Include the same species as for the Level 1 surveys but include more species if they are captured in sufficient numbers (see sections on size class selection and number of samples).
- **Level 3:** *Intensive surveys, Phase II.* – The same recommendation as for Level 2 surveys.

Size class selection

Some correlation between increasing size (age) of the fish and contaminant concentration has been recorded. If the aim is to link a fish advisory to a specific fish size class while the other size classes of the selected species remain open, then fish in specific size classes must be analysed. The following is therefore recommended:

- **Level 1:** *Screening surveys* – If resources are limited, collect only one size class for each of the selected species and focus on the larger size class commonly consumed. Preferably collect individuals from three size classes from the size ranges commonly consumed.
- **Level 2:** *Intensive surveys, Phase I* – Preferably collect individuals from three size classes, but at least two (large and small) covering the exposure and consumption ranges. Select more size classes if more refinement in the relationship between size classes and advisories is required.
- **Level 3:** *Intensive surveys, Phase II* – The same as for Level 2: Phase I surveys.

Number of samples

In South Africa factors such as the low abundance and availability of fish in some rivers and financial constraints may limit the number of samples collected. The following is therefore recommended for surveys in South Africa:

- **Level 1:** *Screening surveys* – Collection of a composite sample consisting of eight individuals at each site. Preferably three replicate composite samples, each consisting of eight individual at 10 % of the screening sites. The mean length (size) of the individuals of the composite sample must not exceed 10%. Similarly the mean length of individuals in the composite samples to be compared must not exceed 10%.
- **Level 2:** *Intensive surveys, Phase I.* – Collection of five replicate composite samples, each consisting of eight individuals. As this would not be possible (due to small fish populations) for many of the rivers in South Africa, statistical procedures (as indicated) should be used to evaluate the statistical significance of the decision.
- **Level 3:** *Intensive surveys, Phase II.* – The same recommendations as for Level 2 surveys.

Tissue type and mass selection

The sample should consist of the portion of the fish that is consumed by the population under investigation. For South African conditions it is assumed that people usually gut the fish and that fillets are consumed. The following is therefore recommended:

- **Level 1:** *Screening surveys* – A 200 g wet mass composite sample of edible-scaled skin-on or skinless (for fish without scales) fillets (including the belly flap) should be collected. Analyses of skinless fillets must be considered if the complete homogenisation of skin-on fillets is not achievable or if the local consumers only prepare skinless fillets. Each composite sample should consist of eight individual fish; therefore each individual should contribute 25 g wet mass to the composite. A larger composite mass may be required if the number of analytes is increased or if the analytical procedures of the specific laboratory require a larger tissue mass.
- **Level 2:** *Intensive surveys, Phase I* – The same as for Level 1 surveys, but the mass can be reduced if the number of selected analytes of concern are reduced as a result of data obtained during Level 1 surveys.
- **Level 3:** *Intensive surveys, Phase 11* – The same recommendations as for Level 2 surveys.

Other tissues that may be considered include liver, body fat and gonads. However, muscle tissue should always be obtained for analyses. In chemical contaminant surveys where the concentrations of analytes in individual fish must be determined (not generally recommended) 25 individuals per size class must be selected.

Sampling time and sampling frequency

The sampling should not occur during the spawning season including one month prior to and after spawning. The sampling frequency should be determined by the potential severity of the predicted health risk and the importance of the water body to recreational, subsistence and commercial fishing. The following sampling time and frequency of sampling are therefore recommended for the surveys in South Africa:

- **Level 1:** *Screening surveys* – Fish should preferably be collected from March to May and from September to October. Note that the same species may spawn in September and October if rains are early and the temperature is optimal. The frequency should be three years but definitely every five years. However, if potentially high health risks are predicted and the fish population is intensively fished, then annual screening of the specific water body is advisable.
- **Level 2:** *Intensive surveys, Phase I.* – The period must be the same as for the Level 1 surveys. The survey should be undertaken within one year of the Level 1 (screening survey) survey.
- **Level 3**: *Intensive surveys, Phase II*: – The general guidelines for a Level 2 survey should be followed. In many cases it would be feasible and more cost-effective to combine Level 2 and Level 3 surveys.

Step 4: Field collection

Sampling equipment

Various fishing methods are available to collect freshwater fish. The methods employed will depend on the specific water body (for example river or lake), the manpower and the equipment available. It is recommended that gill nets, seine nets and electro-fishing be used to obtain fish samples for South African water bodies.

TABLE 4
Fish Health Assessment Index (FHAI) variables and assigned values[adapted from Adams et al., (1993) and Robinson (1996)]

Variables	Variable condition		Score value for FHAI
Skin	• Normal, no aberrations		0
	• Mild skin aberrations		10
	• Moderate skin aberrations		20
	• Severe skin aberrations		30
Fins	• No active erosion or previous erosion healed over		0
	• Mild active erosion with no bleeding		10
	• Severe active erosion with haemorrhage/secondary infection		20
Eyes	• Normal	• No aberrations evident (good "clear" eyes)	0
	• Exopthalmia	• Swollen, protruding eye	30
	• Hemorrhagic	• Bleeding in the eye	30
	• Blind		30
	• Missing	• Eye missing from the fish	30
	• Other	• Any manifestations which do not "fit" the above	30
Opercules	• No shortening	• Normal	0
	• Mild shortening		10
	• Severe shortening		20
Gills	• Normal	• No apparent aberration in gills	0
	• Frayed	• Erosion of tips of gill lamellae: "ragged" look	30
	• Clubbed	• Swelling of the tips of the gill lamellae	30
	• Marginate	• Gill with a light discolored margin along the distal end or tips of the lamellae of filament	30
	• Pale	• Gills are definitely very light in color	30
	• Other	• Any observation which does not fit above	30
Ectoparasites	• No parasites observed		0
	• 1 – 10 parasites		10
	• 11 – 20 parasites		20
	• > 20 parasites		30

Species identification and sorting

Species should be identified as soon as they are captured. The publications by Jubb (1967), Le Roux and Steyn (1968), Pienaar (1978) and Skelton (1993) should be used to identify South African freshwater fish species.

After capture and depending on the circumstances the initially selected fish species can be transferred to a holding tank filled continuously with water from the site. Fish should, however, not be kept in the holding tank for more than 3 h. Select only fish from the selected species of the required size which do not have damaged skin or fins.

Rinse selected fish in ambient water to remove any foreign material from their body surface. A sharp blow on the skull with clean a wooden club or metal rod should stun large fish. Small fish may be placed on ice to kill them humanely. Stunned fish are then grouped and placed in clean holding trays to prevent contamination. Care should be taken not to stun too many fish at a time in the field, especially during summer, as rate of decay is rapid.

Size measurements

The total body length (mm) of individual fish of the selected species sample must be measured.

Fish health observation

To evaluate the health of the fish it may not be feasible to perform a detailed health assessment as described by Adams et al., (1993), Avenant-Oldewage et al. (1995) and Avenant-Oldewage (2001). However, it is important to at least record gross morphological abnormalities and the body surface parasite load of the fish captured. Based on the Fish Health Assessment Index (FHAI) the following health variables of the selected species should at least be evaluated:

- Condition of skin.
- Condition of fins.
- Condition of eyes.
- Condition of opercula.
- Condition of gills.
- Number of ectoparasites.

TABLE 5
Preservation of fish samples from time of collection to delivery at the laboratory

Sample type	Number per composite	Container	Preservation	Maximum transport time
Whole fish to be filleted and/or whole fish	8	Each fish wrapped in heavy-duty aluminium foil and placed in a waterproof plastic bag.	Cool on wet ice or ice packets **or** Freeze on dry ice only if transport time is more than 24h	24 h 48 h

A description of these variables and the associated sources is given in Table 4. The health of the fish can then be calculated as follows:

$$FHAI_{(fish)} = S+F+E+O+G+P$$

where :
S = skin
F = fins
E = eyes
O = opercula
G = gills
P = external parasites.

The FHAI for a specific species is calculated as follows:

$$FHAI_{(Species\ A)} = \text{median}\ (FHAI_{(fish\ 1,\ species\ A)}, FHAI_{(fish\ 2,\ species\ A)}, \ldots\ldots FHAI_{(fish\ n,\ species\ A)})$$

where:
n = the number of fish sampled of a specific species.

The FHAI for a site ($FHAI_{(site)}$) is then calculated as the median of all the individual species FHAI.

Sample packing and preservation

Each fish should be individually wrapped in extra heavy aluminium foil, placed in a waterproof plastic bag and (depending on the transport time) kept on wet ice packets or frozen on dry ice as indicated in Table 5. On arrival at the laboratory the fish are inspected and processed or stored frozen as indicated in Table 6.

Documentation and document control

The project leader or designated person must develop specific forms to assist with the detailed documentation of the data to be collected, the specific field results, labelling of samples and the transfer of samples to the specific laboratory. The control of documents is vital and the general requirements as required by the International Standard ISO: 17025 (ISO/IEC, 1999) must be followed.

Step 5: Laboratory sample processing and analysis

Laboratory conditions, instrumentation and sample storage requirements

It is preferable not to process samples in the field. If samples are processed in the field a mobile field laboratory or a portable dissection table with an enclosed hood must be used. The working area must be away from any fuel fumes or other possible airborne contaminants. Potential sources of sample contamination include dust (airborne and surface), instruments, and utensils, work surfaces and containers that may come in contact with the samples. To prevent cross-contamination all equipment used in sample processing should be cleaned before each sample is prepared. It is therefore recommended that the samples are not processed in the field and that the sample-processing equipment, container materials and holding time for fish as summarised in Table 6, should be used.

Sample inspection

The individual fish received for processing should be inspected carefully to ensure that they were adequately preserved before and during transportation.

Sample weighing

Following 'good laboratory practice' procedures the wet mass (to the nearest gram) of each fish must be determined. Fish should be weighed and filleted quickly to minimise the formation of liquid during thawing. Excess ice should be wiped off from the fish body surface. As a precautionary approach all liquid should be kept as part of the sample.

Age and gender determination

Fish scales (from the area between the dorsal fin and the lateral line behind the pectoral fin), otoliths or pectoral fin spines (for example from catfish) can be removed for age determination. The scales, spines or otoliths may be stored in small envelopes or plastic bags, which are clearly marked for cross-reference. Scales can be washed in soapy water and mounted between glass slides, whereafter the growth rings can be counted using a microfiche projector. Thin sections of spines and otoliths can be cut and the growth rings counted under a compound microscope.

If the gender of the species cannot be determined by external inspection the gonads must be inspected. The gender of the fish and stage of reproduction can be described using the classification system of gonad development indicated in Table 7.

Fish health observation

The health assessment (as previously described) should preferably be performed during the field collection stage. However, the fish health assessment can be performed in the laboratory but it will not be possible to determine their ectoparasite load as these parasites can detach themselves from dead fish.

Scaling and skinning of fish

Scaled fish must be scaled and the slime removed before filleting. The skin of scaleless fish, for example catfish, is removed prior to filleting. Fish should not be allowed to thaw completely as it is best to fillet fish while ice crystals are still present in the muscle tissue. A fillet including the belly flap and any dark tissue found with the white tissue is then removed from each specimen. Skeletal bones

TABLE 6
Summary of the container materials, equipment, washing material, preservation and holding times per fish tissue from sample processing to analysis (adapted from the US EPA, 1995)

Analyte	Matrix	Equipment	Washing material	Sample container	Storage	
					Frozen	Holding time
Mercury	• Fillets and homogenates.	• Quartz or PTFE or polypropylene or polyethylene or Borosilicate glass. • Dissection knives: Titanium blades andPTFE handles. • Dissection boards:glass or PTFE covered with aluminium foil. • Bench liners: borosilicate glass. • Instruments: quartz or titanium.	• Detergent solution e.g. contrad • Soaked in 50% HNO_3 for 12 to 24 h • Rinsed with metal-free distilled deionised water.	• Plastic or borosilicate glass or quartz or PTFE.	Freeze at < -20°C.	28 days
Other metals	• Fillets and homogenates.	• Quartz or PTFE or polypropylene or polyethylene orBorosilicate glass. • Dissection knives: Titanium blades andPTFE handles. • Dissection boards:glass or PTFE covered with aluminium foil. • Bench liners: borosilicate glass. • Instruments: quartz or titanium.	• Detergent solution e.g. contrad. • Soaked in 50% HNO_3 for 12 to 24h. • Rinsed with metal-free distilled deionised water.	• Plastic or borosilicate glass or quartz or PTFE.	Freeze at < -20°C.	6 months
Organics	• Fillets and homogenates	• Stainless steel or anodized aluminium or borosilicate glass orPTFE or ceramic or quartz. • Dissection knives: Titanium blades and PTFE handles. • Dissection boards:glass or PTFE covered with aluminium foil. • Bench liners: borosilicate glass. • Instruments: Stainless steel or quartz or titanium.	• Detergent solution e.g. contrad. • Soaked in pesticide-grade isopropanol or acetone. Rinsed with organic-free distilled deionised water.	• PTFE or borosilicate glass or quartz or aluminium foil.	Freeze at < -20°C.	1 year

Metals and organics	• Fillets and homogenates	• Borosilicate glass orPTFE or ceramic or quartz. • Dissection knives: Titanium blades and PTFE handles. • Dissection boards:glass or PTFE covered with aluminium foil. • Bench liners: borosilicate glass • Instruments: quartz or titanium.	• Detergent solution e.g. Contrad. • Soaked in 50% HNO_3 for 12 to 24 h • Rinsed with metal and organic-free distilled deionised water.	• Quarts or borosilicate glass or PTFE.	Freeze at < -20°C.	• 28 days for mercury. • 6 months for other metals. • 1 year for organics.
Lipids	• Fillets and homogenates	• Borosilicate glass orPTFE or ceramic or quartz. • Dissection knives: Titanium blades and PTFE handles. • Dissection boards:glass or PTFE covered with aluminium foil. • Bench liners: borosilicate glass • Instruments: quartz or titanium.	• Detergent solution e.g. contrad. • Soaked in 50% HNO_3 for 12 to 24 h • Rinsed with metal and organic-free distilled deionised water.	• Plastic or borosilicate glass or quartz or PTFE.	Freeze at < -20°C.	1 year

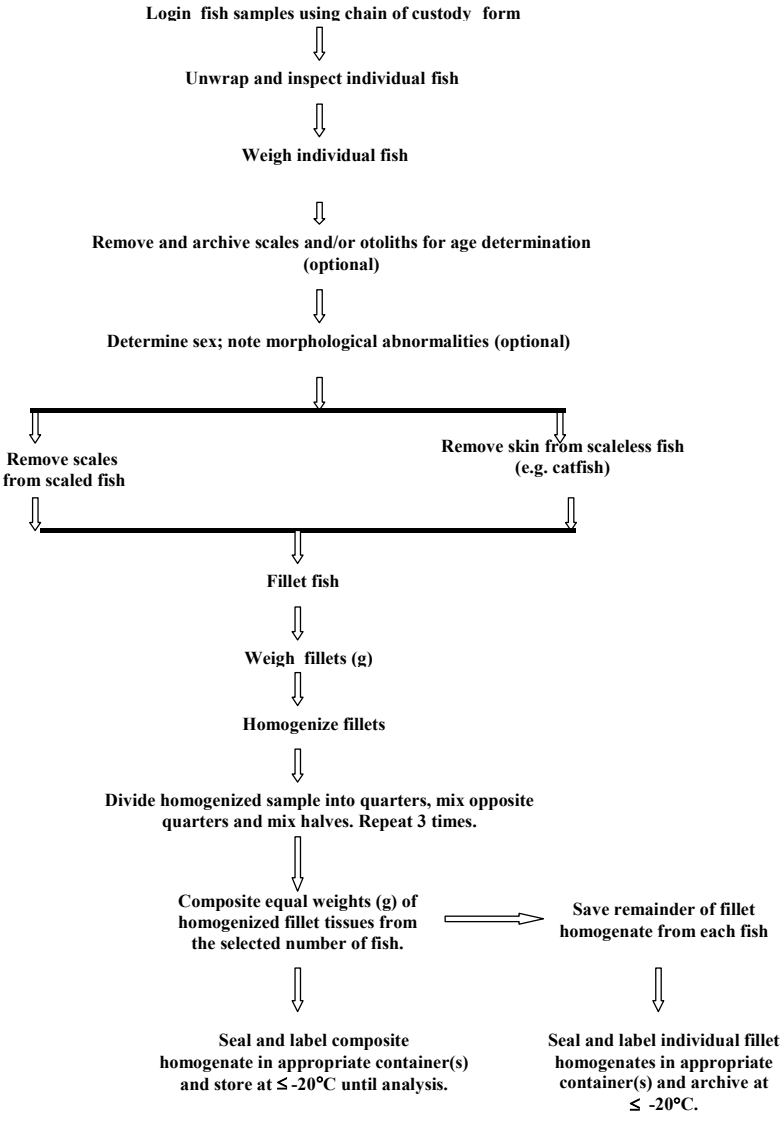

Figure 3

Recommended steps in the laboratory preparation of fish fillet composite homogenate samples (adapted from the US EPA, 1995a)

that may be present should, however, be removed. Puncturing of internal organs must be avoided, as the material released from the internal organs will contaminate the fillets. After removing the fillets they are weighed whereafter they are processed further or stored (Table 6).

Preparation of individual and composite homogenates

The various steps of the preparation of fish fillet homogenates are shown in Fig. 3. It is important to note that grinding should continue until the sample appears homogeneous. Finally the individual homogenates are either processed further to prepare composite homogenates or stored separately as indicated in Table 6.

Composite homogenates are prepared from the same type of individual homogenates (either single fillet of combined fillet) of equal mass. Each composite homogenate is blended as previously described for individual homogenates. After preparation of the composite homogenates they may be processed for analysis or stored as described in Table 6. It is good practice to 'archive' a portion of the individual homogenate sample for reuse if required.

TABLE 7
Criteria for the classification of fish gonad development (Olatunde, 1978)

G1	Stage	Characteristic
0.	Inactive (I)	Small gonads and close to the vertebral column. Gonads transparent and gray.
1.	Inactive-Action (IA)	Testes and ovaries translucent, gray-red. Single eggs just visible to the naked eye. Gonads extending most of the length of the ventral cavity.
2.	Active (A)	Eggs visible to the naked eye. Gonads reddish with blood capillaries, filling 30 to 50% of the ventral cavity.
3.	Active-Ripe (AR)	Ovaries orange-red. (Not *Clarias gariepinus* - gonads remain gray). Testes white with red blood vessels. No milt-drops appear under pressure. Eggs opaque.
4.	Ripe	Sexual products mature. Testes exude milt when pressure exerted. Eggs spherical.
5.	Ripe-Running (RR)	Eggs and milt running with slight pressure.
6.	Spent (S)	Gonads have the appearance of deflated sacs, reddish colour. Occasional residual eggs and some milt.

Distribution of samples

If required aliquots of specific mass (to the nearest 0.1 g as required by the laboratory) are prepared and distributed to different laboratories. Sample deterioration or contamination must be prevented and detailed traceable records of the preparation and transfer of the aliquots to a specific laboratory must be kept.

Selection of analytical laboratory

It is a prerequisite that the selected analytical laboratory perform the analysis using internationally accepted analytical methods and has well-documented quality assurance and quality control systems in place. It is recommended that the analysis be performed by a laboratory which has been accredited under ISO/IEC Guide 25 (ISO/IEC, 1990) or the International Standard ISO/IEC 17025 (ISO/IEC: 1999). The laboratories of the Agricultural Research Council (Private Bag X 313, Pretoria, 0001, South Africa), the CSIR (Environmentek, P O Box 35 Pretoria, 0001, South Africa), Institute of Water Quality Studies (Private Bag X 134, Pretoria, 0001, South Africa) and the South African Bureau of Standards (Private Bag X 191, Pretoria, 0001, South Africa) can be approached to perform the analysis.

Analytical methods

Various analytical methods are available world-wide for the analysis of specific chemical contaminants. The programme manager in collaboration with the laboratory chemist responsible for the analysis discuss the appropriate methods. It recommended that where practical the published methods of the United States Environmental Protection Agency (US EPA) are followed in South Africa (US EPA, 1995a; Internet: EMMIUSER@USVA5.DYNCORP.COM; websites: htpp://www.epa.gov/).

Quality assurance and quality control

The analytical laboratory performing the analysis must have documented quality assurance and quality control systems in place. During the discussions with the laboratory Chemist responsible for the analysis the programme manager must ensure that this issue is addressed. In South Africa the accreditation of methods at laboratories ensures that quality control and quality assurance procedures are in place and routinely followed. It is recommended that only accredited laboratories or laboratories that follow the requirements of the International Standard ISO/IEC 17025 (ISO/IEC: 1999) be used for chemical contaminant analysis. These laboratories should also follow general safety, health and environmental practices as decribed for example by the International Safety Rating System (ISRS, 1994) and the International Standard SABS ISO 14001: 1996 (SABS ISO, 1996).

Step 6: Analysis and reporting of results

Recording of results by the laboratory

The recording of results must be performed according to standard laboratory operating procedures that will ensure the integrity of the results. The following is recommended for the recording of results for South African surveys:

- An analytical result below the method detection limit (MDL), including an analytical result recorded as not detected (that is no observed response) should be assigned a value of half the method detection limit (MDL/2).
- An analytical result recorded between the MDL and the method quantification limit (MQL) should be assigned a value of the MDL plus half the difference between the MQL and MDL [MDL + (MQC – MDL/2)].
- An analytical result recorded at or above the MQL should be recorded as such.

Analysis of results

It is strongly recommended that a statistician be consulted throughout the study. The following is recommended for the analysis of results:

- **Level 1**: *Screening surveys* – The results obtained should be evaluated to determine which of the results is greater than or less than the screening concentration (SC). When the recorded analyte concentration is below but close to the SC, the data on the performance of the laboratory and historic data on water, sediment and fish tissue contamination at the site should be evaluated before further samples are taken. However, if the data of these investigations indicate that further investigation should be undertaken, a Level 2 survey should be initiated. A Level 2 survey will also be undertaken for the analytes that exceed the screening concentrations to verify the level of contamination.
- **Level 2:** *Intensive surveys, Phase I* and **Level 3**: *Intensive surveys Phase II* – The main objectives of the Level 2 and Level 3 surveys are to assess the magnitude and geographical extent of the contamination (special variation) in the various classes of the selected species, to define the geographical region where fish contamination concentrations exceed the screening

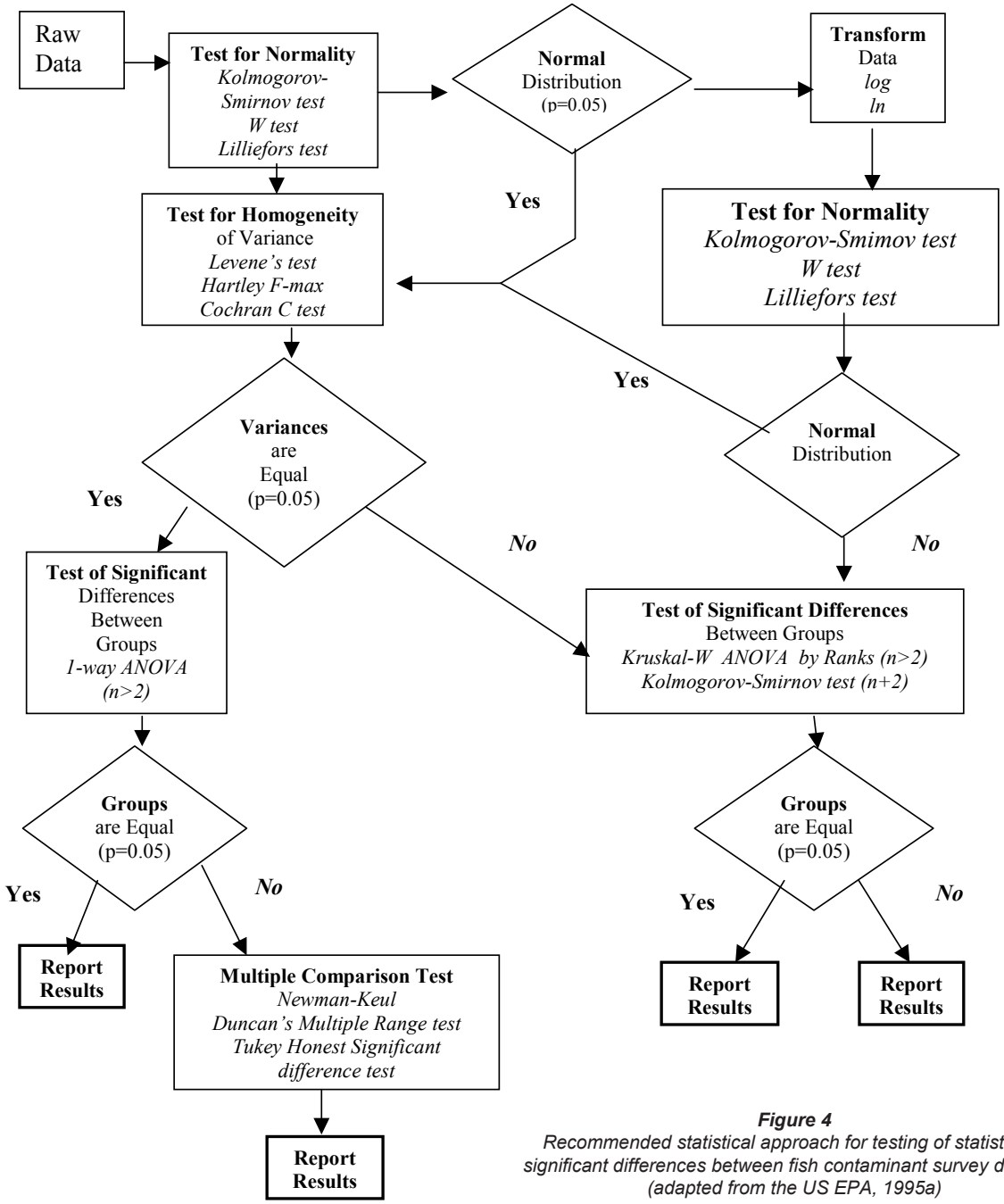

Figure 4
Recommended statistical approach for testing of statistically significant differences between fish contaminant survey datasets (adapted from the US EPA, 1995a)

concentrations, to identify the geographical contaminant concentrations and to assess the fish contaminate concentrations over time (temporal variations). The general statistical approach for comparing replicate chemical contaminant results between two and more groups as summarised in Fig. 4 should be followed.

Data storage

The project manager must develop a data storage system that is structured in such a way to enter the information and/or data in the following data fields:

- Study identification (e.g. project number, title and study type).
- Project manager.
- Sampling site name and GPS coordinates.
- Type of freshwater water body (lake, river, reservoir, etc.).
- Name of water body.
- Sampling date (e.g. DD, MM, YY).
- Sampling time (e.g. HH, MM in a 24h format).
- Sampling gear type used (e.g. seine netting, gill netting, electro-fishing).
- Sampling depth.
- Scientific name of selected species.
- Common name of selected species.
- Composite sample numbers.
- Number of individuals in each composite sample.
- Number of replicate composite samples.
- Predominant characteristics of specimens used in each composite sample:
  - Predominant life stage of individuals

- Predominant gender of individuals (if determined).
- Mean age of individuals (if determined).
- Mean body length or size (mm).
- Description of tissue type (fillets skinned, fillets scaled, whole fish).

- Analytical methods used (including method for lipid analysis).
- Method detection and quantification limits for each selected analyte.
- Sample clean-up procedures (e.g., additional purifying steps for sample extracts or digestates).
- Data qualifiers (e.g., qualifying information about the measurement).
- Percent lipid (wet mass basis) in each composite sample.
- For each selected analyte in each composite sample:
  - Total wet mass of composite sample (g) used in analysis.
  - Measured concentration (wet mass basis) as reported by the laboratory.
  - Units of measurement for selected analyte concentration.
  - Evaluation of laboratory performance (i.e., description of all QA and QC samples associated with the sample(s) and results of all QA and QC analyses).
- In Level 1 surveys (screening surveys) with only one composite sample for each selected species, a comparison between the reported concentration and derived screening concentration (SC) for each selected analyte as well as an indication of whether SC was exceeded must be included.
- In Level 2 surveys (Intensive surveys, Phase I) and Level 3 (Intensive surveys, Phase II) surveys, for each target analyte in each set of replicate composite samples, the following should be included:
  - Range of selected analyte concentrations for each set of replicate composite samples.
  - Mean (arithmetic) selected analyte concentration for each set of replicate composite samples.
  - Standard deviation of mean target selected concentration.

This data should finally stored in a National Fish Contaminant Database managed by DWAF.

Data reporting

The project manager should compile the data reports. The report must contain at least the information compiled for data storage. However, the project manager must discuss the specific requirements with the people responsible for the risk analyses or with the specific client.

Step 7: Risk assessment

Hazard identification

The likelihood that the exposure to a chemical under specific exposure conditions poses a threat to human health is assessed. General information such as the physical and chemical properties of the chemical, routes and patterns of exposure, structure-activity relationships, metabolic and pharmacokinetic properties, toxicological effects, acute and chronic animal exposure studies, human studies, bioaccumulation potential, persistence and prevalence in the environment, and the biochemical fate of the contaminant are reviewed in hazard identification.

The databases such as HEALTH EFFECTS SUMMARY TABLES (HEAST, 1998) Agency Toxic Substances and Disease Registry (ATSDR, 1999), Integrated Risk Information System (IRIS, 1999) and Toxicology Excellence for Risk Assessment (TERA, 1999) should be used to evaluate the toxicity and carcinogenicity of the various chemical contaminants. The software packages Risk*Assistant™ (Risk*Assistant™, 1995) and the US EPA publication of 1997 (US EPA, 1997) make this information readily available. A review of the following would also provide valuable information:

- Information on biocide usage and its chemistry and human health effects.
- Data from previous information on contaminant surveys that have resulted in consumption bans or advisories.
- Analytes that have been recommended for fish contaminant monitoring.
- Information obtained from catchment situation analysis of potential and actual point/or diffuse sources of pollution.

Dose-response assessment

The relationship between the dose of a hazardous chemical (i.e. the amount of the chemical taken into the body through skin contact, breathing and ingestion) and the incidence of an adverse health effect in the exposed population is characterised. Hazardous chemicals can be broadly grouped as those with non-threshold effects (causing carcinogenic and genotoxic health effects) and those with threshold effects (causing acute, chronic or developmental effects). A distinction is therefore made in describing the dose-response variables for carcinogenic and non-carcinogenic chemicals. The above-mentioned toxicity databases and software packages are used to evaluate the dose-response relationships of the various chemical contaminants. The publications by the US EPA (1991, 1997) and Tchounwou et al., (1996) would also provide ready access to this information. The oral reference doses (RFD) for the selected analytes as summarised in Table 2 can be used for South African surveys.

Exposure assessment

The intensity, frequency and duration of human exposure to a chemical in potentially exposed populations are measured or estimated. Information and data on chemical residues in the fish and human consumption patterns are used to identify and describe potentially exposed populations. The following information and data are therefore used:

- The chemical contaminant (analyte) concentrations in fish that have been determined.
- Geographical distribution of contaminated freshwater fish. This information is required when performing risk characterisation during population exposure assessment and in determining the need for further action.
- Information on where contaminated fish have been found in relation to possible sources of potential contamination (from catchment situation analysis, pollution incidents, etc).
- Socio-demographic information (age, gender, body mass, etc.) and fish consumption patterns (number of species, type of fish, size classes included in the diet, the specific edible portion selected for consumption, fish preparation and cooking methods, meal size and frequency of consuming fish). The generally derived values as indicated in Table 1 should be used to derive various exposure scenarios (Table 8) for South African water bodies.

Exposure scenarios must then be developed (for example as in Table 8) that would provide an indication of the potential range of health risks if assumed that different amounts of fish are eaten at different frequencies in a year.

TABLE 8
Exposure scenarios that can be developed from the information in Table1 if the information is not available for a specific population

SCENARIO 1 Mean contaminant concentrations Adult 150 g fish daily	**SCENARIO 2** Mean contaminant concentrations Adult 150 g fish weekly	**SCENARIO 3** Mean contaminant concentrations Adult 50 g fish daily	**SCENARIO 4** Mean contaminant concentrations Adult 50 g fish weekly
SCENARIO 5 Mean contaminant concentrations Child 150 g fish daily	**SCENARIO 6** Mean contaminant concentrations Child 150 g fish weekly	**SCENARIO 7** Mean contaminant concentrations Child 50 g fish daily	**SCENARIO 8** Mean contaminant concentrations Child 50 g fish weekly

Risk-based consumption limits can be derived for contaminants using specific risk equations (see Eqs. 1 and 2), risk values (Table 2) and selected input values (Table 1). Based on a contaminant's carcinogenicity, the allowable daily consumption rate (one fish species and one type of contaminant) of a contaminated fish source is calculated using the following equation:

$$CR_{lim} = (ALR \times BM)/(SF \times C_m) \quad (1)$$

where:

CR_{lim} = maximum allowable fish consumption rate of the species of interest (kg/day). The derived daily consumption limit (CR_{lim}) represents the amount of freshwater fish expected to generate a carcinogenic health risk that is not greater than the maximum acceptable individual lifetime risk level (ALR), assuming that the consumer consumes fish daily at the consumption limit over the person's lifetime.

ALR = maximum acceptable individual lifetime risk level (dimensionless).

BM = body mass of consumer (kg).

SF = oral slope factor or carcinogenicity potency factor $(mg/kg/day)^{-1}$ which is an upper bound risk value.

C_m = measured concentration of chemical (analyte) *m* in the edible portion of the species concerned (mg/kg).

Based on a contaminant's non-carcinogenic health effect the allowable daily consumption rate of (one fish species and one type non-carcinogenic contaminant) a contaminated fish source is calculated using the following equation:

$$CR_{lim} = (RFD \times BM)/C_m \quad (2)$$

where:

CR_{lim} = maximum allowable fish consumption rate of the species of interest (kg/d). The derived maximum daily consumption rate (CR_{lim}) represents the amount of freshwater fish which would probably not generate a non-carcinogenic health risk to a consumer over the person's lifetime (US EPA, 1997).

RFD = reference dose (mg/kg·d).

BM = body mass of consumer (kg).

C_m = measured concentration of chemical (analyte) *m* in the edible portion of the species concerned (mg/kg).

The above equations can be adapted to include more than one fish species or chemical contaminant. The risk-based consumption limits calculated for the proposed analytes in Table 2 can be used for the consumption of South African freshwater fish if information on the input values and risk values is not available for South African situations.

Presently the total population exposure assessments cannot generally be performed for South African conditions as much of the information and data will not be available to perform the specific calculations. Therefore for South African programmes the proposed information requirements are evaluated and obtained where feasible, considering the specific programme objectives and availability of resources.

Risk characterisation

All the information concerning the hazard identification, dose-response assessment, and exposure assessment is used to characterise and describe the extent of the overall individual or population risk. The most significant quantitative and qualitative aspects of these assessments, the assumptions used and the identified uncertainties are assessed, summarised and discussed to provide an overall estimate of individual risk. If information and data are available this can also be expanded to estimate overall population risk.

The possible cancer risks are derived and described by using the following equation:

Individual lifetime cancer risk = Exposure x cancer slope factor or cancer potency

where:

Exposure = total exposure to a single chemical contaminant from all sources (mg/kg·d).

Cancer slope factor or cancer potency = upper bound of the lifetime cancer risk (mg/kg·d).

The population cancer risk can be calculated as:

Population cancer risk = individual lifetime cancer risk x size of the exposed population

When different exposure levels occur the total risk is the sum of the risk at each level and when multiple contaminant exposures occur, the total risk is equal to the sum of the risks from individual contaminants at each level. These cancer risks are then expressed as *unit cancer risk* (for individuals or populations), representing the lifetime risk due to constant lifetime exposure of one concentration unit of the carcinogen. The unit cancer risk is calculated by the following equation:

$$\text{Lifetime cancer risk} = 1 - e^{-(\text{exposure} \times \text{cancer slope factor or cancer potency})}$$

The possible non-cancer risks are derived and described by using the following equation:

$$HQ = ADD/RFD$$

where:

HQ = hazard quotient for individual lifetime cancer risk. It compares the expected exposure of the chemical contaminant to an exposure that is assumed not to be associated with a toxic effect.
ADD = average daily dose.
RFD = reference dose.

or presented as:

$$HQ = Exposure/RFD$$

where:

HQ = hazard quotient for individual lifetime cancer risk. It compares the expected exposure of the chemical contaminant to an exposure that is assumed not to be associated with a toxic effect.
Exposure = total exposure to a single chemical contaminant from all sources (mg/kg·d).
RFD = reference dose or any other non-carcinogenic exposure limit.

When exposure exceeds the RFD - that is, the HQ is equal to or greater than 1.0 (for a single chemical contaminant or for a combination of chemical) - the possibility of non-cancer risks from the exposure is indicated. In most cases the less serious effects will result in serious effects as exposure exceeds the RFD.

Population non-cancer risk can be defined by the following equation:

$$\text{Non-carcinogenic risk} = \text{population with exposure greater than the RFD}$$

To perform these risk calculations for the chemical contaminants found in freshwater fish from South African systems and for different scenarios the Risk*Assistant™ software package (with assistance from the competent personnel at the CSIR) can be used.

All the data and results that are generated are documented and organised in a way that will facilitate their review and assessment. The risk assessment project leader or designated person should design specific forms to ensure proper documentation. Guidance on the risk characterisation process and examples of how to compile these documents can be found in the US EPA publications (US EPA 1997; Du Preez et al., 2000).

Step 8: Risk management

In the context of the consumption of chemically contaminated freshwater fish, risk management aims to minimise the health risk to fish consumers (especially highly exposed individuals or population groups) as well as the negative effects (see section 'negative and positive impacts') that restricting consumption may have (US EPA, 1996). However, the long-term goal must be to reduce the impacts on the water body to such a level that the contaminant levels in the fish pose no health risk to consumers.

Evaluation of risk assessment data and information

The risk manager evaluates and familiarises himself with the data and information obtained during the risk assessment process. Special attention is given to the assumptions and uncertainties identified during the risk assessment process. Furthermore, it is essential that the risk manager familiarise himself with the sample collection and analysis programme.

Assessment of the risk management options

The risk manager can select from a variety of options to limit consumption of contaminated freshwater fish, thereby reducing the health risk to consumers. Since no single approach is appropriate for all circumstances the following options should be considered:

- **No action**. Unlimited fishing is allowed under this option. This option should only be considered when the risk assessment indicates that no action is required.
- **Fish consumption advisory**. Information is supplied to the consumers that will lead to the voluntarily restrict of their consumption of fish to safe levels. Two types of fish consumption advisories (namely, 'general' and 'quantitative') can be used. General fish consumption advisories provide qualitative guidance on reducing risk through selective fishing, cooking and preparation techniques. In addition to this information quantitative advisories provide consumers with specific information (related to site, species and size) regarding the maximum amount of fish that can safely be consumed over a period.
- **Catch and release**. This option is followed if the consumption of contaminated fish by recreational fisherman is a major concern. Fishing is thus allowed but the anglers are encouraged or forced to release fish after capture. The recreational aspect of fishing is therefore less impacted upon.
- **Fishing ban**. This option is usually followed when the contaminant levels pose a very high health risk. It involves the banning of fish by closing waterbodies to fishing and/or banning the possession of contaminated fish (US EPA, 1996).

The feasibility, efficacy and resource cost of these risk management options differ substantially and must therefore be evaluated. Table 9 gives some guidance as to the feasibility and efficacy of these risk management options.

Assessment of the positive and negative impacts of the risk management options

The risk manager must assess the numerous impacts of the risk management options to limiting the consumption of freshwater fish. In many cases the impacts are site-specific and will depend on local conditions, for example, the population, the economy, and social and cultural factors, to mention only a few (US EPA, 1996). Since no single approach is appropriate for all circumstances the

TABLE 9
Summary of the feasibility and efficacy of the proposed risk management options (adapted from the US EPA, 1996)

Risk management options		Feasibility			Efficacy	
		Staffing	Funding	Regulatory authority required	Consumer education	Source specific risk reduction
No action required		N/A	N/A	No	None	None
Fish consumption	General	Moderate advisory	Moderate guidance	No	Moderate	Low to moderate
	Quantitative guidance	Moderate to high	Moderate to high	No	Moderate to high	Moderate to high
Catch and release	Voluntary	Low to high	Low to high	No	Low to high	Low to high
	Mandatory	High	High	Yes	Low to high	High
Fishing ban	Voluntary	Moderate to high	Low to high	No	Low to high	Low to high
	Mandatory	High	High	Yes	Low to high	High

following possible impacts of the risk management options must be considered by the risk manager:

- **The impact on the basic nutritional needs of the target population and associated health benefits from eating fish**. Fish are generally beneficial as they provide an excellent source of protein and vitamins. Other health benefits include a decrease in cardiovascular decease, reduced risk of colon cancer and breast cancer, and reduction in high blood pressure to mention only a few. In this evaluation the risk manager must consider the present health status of the target population, and their capacity to substitute fish with other food sources (availability of alternative food sources, economic capacity, etc.).
- **Cultural and social impacts**. Fishing and fish consumption may be part of the traditional activities of the affected population (for example, the indigenous people of Maputaland, KwaZulu Natal Province). Fishing may also be a major part of their economic and nutritional base. Furthermore, in South Africa recreational fishing is a primary hobby for many people in which the whole family participates.
- **Economic impact: Cost of fishing**. The potential financial losses due to recreational fishing industry. General increase in costs for recreational fishermen that must visit other uncontaminated water bodies.
- **Economic impact: Cost of food**. Subsistence fisherman may also experience hardship, as alternative protein sources will be more expensive. The local community as a whole may suffer if fish is their main protein source.
- **Economic impact: Cost on tourism**. Local tourism will decline as a recreational fishermen may be forced to visit other uncontaminated water bodies.
- **Economic impact: Cost associated with property values**. The property value of land adjacent to the waterbody that is affected by the limitation on fishing may be negatively affected.

From the preceding it is evident that the risk manager must carefully evaluate all the benefits and negative impacts of the various risk management options. The risk manager must discuss the various options with policy-makers, community leaders and community members (interested and affected parties) to ensure they have a good understanding of the possible impacts that may occur as a result of the various options put forward.

Selection of the most appropriate action and recommendations

The final selection of the most appropriate management option is the most critical decision the risk manager has to make. The selection is based on all the information collected and assessed during all the previous phases of the project. It is important that all the resource implications and the practicality of all the risk management options form part of this final analysis.

After consensus between the interested and affected parties (policy-makers, scientific and health advisors, community leaders and members of the community) and the risk manager has been reached, the most appropriate risk management option for dealing with the consumption of freshwater fish is made by the risk manager. Recommendations regarding the remedial action to be taken in order to reduce the chemical contaminant load in the water body and ultimately in the fish population can also be made. This information would be of great value in focusing some of the catchment management objectives of other programs, for example the National River Health Programme and that of the Catchment Management Agencies as stipulated in the Water Act (36/ 1998).

In South Africa the final risk management option and the additional recommendations should be submitted to DWAF for implementation. The implementation by the DWAF must however be done in collaboration with other governmental organisations (the Department of Health, provincial environmental, nature conservation and tourism departments, local governmental structures), the Catchment Management Agencies (CMA's), non-governmental organisations (NGO's) and the local community in the region.

Step 9: Risk communication

In the context of the consumption of chemically contaminated freshwater fish risk communications aim to 'share' information between all role-players to minimise the health risk to fish consumers (US EPA, 1995b). The risk communicator thus also focuses on health promotion. The development and implementation of a risk communication strategy usually involves:

- Problem analysis during which the risk communicator familiarises himself/herself with the programme
- Audience needs assessment (identification of the target population, their specific information needs and the best way to communicate with them)
- Communication strategy design and implementation (addresses the what, how, when and the person responsible for the communication)
- Continuous evaluation of the programme (US EPA, 1995b).

Presently it would not be feasible to develop a complete risk communication strategy and implement this for South African water bodies as it is time-consuming and resource-intensive. The following should be considered during risk communication related to freshwater fish for surveys in South African:

- **The risk communicator uses** the risk assessment and risk management documents and personal judgement to familiarise himself/herself with the programme and identify the target populations needs.
- **The risk communicator selects** the main consumption information by considering the following:
  - Frequency of consumption of fish from a specific water body or water bodies.
  - The human health benefits from eating fish.
  - Chemicals of specific concern and their human health effects.
  - The adverse health effects of eating contaminated freshwater fish.
  - Reducing fish consumption risk by cleaning and cooking methods.
  - Identification of the safer fish species or size of fish or the water bodies that have the lowest contamination.
- **The risk communicator selects** the style of presenting the information by considering the following:
  - A combination of text tables and diagrams or graphics is the most effective.
  - Using a cajoling tone and not a commanding tone.
  - Assessing whether qualitative or quantitative information is the most suitable for the target group.
  - Determining what the education level of the target group is, for example, will they be able to read the information.
- **The risk communicator selects** the most appropriate dissemination mechanism by considering the following:
  - Mass media types: for example, talks on the local radio stations and on television (for example *50/50Pprogramme on SABC*).
  - Specialised media types for example brochures, posters, fact sheets, newsletters, fishing regulation articles in newspapers and in fishing and outdoor magazines.
  - Interpersonal contacts during meetings of non-governmental organisations, town councils, fishing clubs and catchment forum meetings or during contacts with the staff of the DWAF and other governmental organisations (the Department of Health, Provincial Environmental, Nature Conservation and Tourism Departments) responsible for information transfer in the area of interest.
- **The risk communicator** selects the most appropriate time for information change by considering the following:
  - Information exchange should be done throughout the year to stimulate public awareness and keep up compliance.
  - Target specific times of the year, for example the beginning of spring when fishing generally starts and the summer period when fishing is most intensive.
  - Holidays (especially during summer time) or days when fishing competitions are held.

As resources become more available the risk communicator should expand the specific programme, for example by obtaining detailed information needs from the target group or by producing additional and more detailed information. In South Africa the risk communication related to the consumption of contaminated freshwater fish should be managed and implemented by DWAFin collaboration with other governmental organisations (the Department of Health, Provincial Environmental, Nature conservation and Tourism Departments, local governmental structures), CMA's non-governmental organisations (NGO's) and the local community in the region.

Step 10: Evaluation and review of programme

It is vital to formally review all aspects of the programme. Specific attention must be given to the following:

- Re-assessment of the fish contaminant data obtained during the follow-up surveys.
- Re-assessment of the risk assessment process as new information may be available and as new data is obtained.
- Re-assessment of the risk management programme to determine whether the programme was and still is effective.
- Re-assessment of the risk communication initiatives to determine whether the objectives of the communication strategy were reached.

The review must also consider the objectives, activities and remedial actions that have been taken by other programmes, especially those related to catchment management and the river health programmes of DWAF. This review will enable the risk manager to adapt the programme as required, thereby achieving the goals of reducing the health risk to the consumers of freshwater fish and contributing to the effective management of catchments.

Conclusions

If this methodology is accepted by the authorities it should provide guidance to governmental authorities at national or provincial level and project managers for the collection of data and information as well as for the assessment, management and communication of the health risks associated with the consumption of freshwater fish. The basic requirements are highlighted, as limited resources (financial, infrastructure and skilled personnel) in South Africa would curtail the possibility of undertaking detailed assessments as undertaken by the US EPA. Nevertheless, by applying the proposed methodology, sound comparable assessments, based on risk assessment methodology, can be made regarding the human health risk associated with the consumption of freshwater fish in South Africa. People responsible for these assessments would also be able

to compare their data and information with other studies in the world, especially that of the United States of America.

These surveys will also identify areas in the aquatic system where aquatic life and especially fish have unacceptably high chemical contaminant levels due to anthropogenic activities in the catchment. This information can be used in catchment management programmes and thereby contribute to the general management of the catchments. Thus, by following and implementing the proposed methodology a major contribution would be made to the protection of the consumers of freshwater fish as well as ensuring that the fish populations are fit for present and future human consumption. This would in turn contribute to the ultimate goal of protection the freshwater aquatic environment. As DWAFis the custodian of freshwater systems in South Africa, it is envisaged that the monitoring of chemical contaminant levels in fish according to the proposed methodology would be implemented and managed by the Department in collaboration with other governmental organisations organisations (the Department of Health, Provincial Environmental, Nature conservation and Tourism Departments, local governmental structures) and CMA's. It must be stressed that for the methodology to be effectively implement a multidisciplinary team approach must be followed.

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