A simple methodology for water quality monitoring

G. R. Pearce, M Ramzan Chaudhry and S Ghulam
(KAR Project R6662)

HR Wallingford in collaboration with International Waterlogging and Salinity Research Institute, Lahore

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Executive Summary

The water resources of many countries are rapidly becoming insufficient to meet the growing demands for agricultural, industrial and municipal supplies. At the same time these resources are being polluted by the activities of man particularly in city areas. Irrigation is the major water user accounting on average for about 70% of the usage in the world and considerably more in some developing countries. At present, water resource managers are mainly concerned about whether the quantity of available water is sufficient to meet supply needs and water quality is a secondary consideration. However, given the rapidly increasing demand for water and the fragility of this essential natural resource there is an urgent need for water managers to become quickly aware of water quality trends in their supplies.

The methodology proposed in this project and used in an initial case-study has been developed to provide a simple, appropriate and relatively inexpensive means by which water resource departments can collect their own data about locally important parameters and draw their own conclusions. The methodology is appropriate because it uses a field-kit approach and reduces the dependence on central laboratories for information. In most countries laboratories are expensive to run and have difficulty in retaining qualified staff. Moreover, there are many logistical problems that make it difficult to supply samples to laboratories and to receive back the resulting analyses. Central laboratories have an important role to play, but are constrained in their ability to provide sufficient monitored information that would enable water resource departments to include a reasonable level of water quality management in their operations. The approach of this methodology, in giving those water resource departments a method to obtain information directly themselves, shows promise.

The main objective of this study was to develop a new field methodology in monitoring water pollution trends in a main open water distribution system. A case-study was carried out to demonstrate the use of the methodology in the example of the highly significant levels of municipal and industrial effluent on the River Ravi as it passes through Lahore. In order to do this, a simple water quality monitoring programme was initiated at four selected sites around Lahore, Pakistan. The sites were selected to permit the quality of water to be assessed before entering the city and after leaving it.

The project demonstrated how the data can be collected and indicates the type of beneficial information that can be obtained for water resource managers when the data are processed and analyzed. Results from the monitoring carried out over an initial year are presented and although constrained by teething problems, can be used to give an initial indication of pollution trends now affecting the area surrounding the city of Lahore.

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Part I

The Water Quality Monitoring Methodology

1. INTRODUCTION – THE NEED FOR WATER QUALITY MONITORING

A simplified technical procedure for monitoring and assessing water quality/pollution problems in main water distribution networks has been developed. The technique has been developed for use by Irrigation Departments and Water Resource Managers in regions where conventional laboratory-based water quality monitoring is too expensive, too slow or is focussed on other issues. The Water Quality Monitoring (WQM) strategy utilises low-cost, portable instrumentation that can largely be used by non-specialist technical staff, and reduces the need for costly laboratory analysis. The instrumentation comprises recently developed field-kits that can provide, with few exceptions, acceptably accurate determinations of the range of pollutants found in rivers, canals and water distribution networks.

With decreasing amounts of water resources available, declining levels of water quality as pollution increases and increasing burden due to growth of population, there is an urgent need for the authorities responsible for the distribution of water resources to become aware of the growing importance of water quality in the management of their resources. Salinity has long been recognised as a potential major problem, but with the growth in population and development there has been a large increase in municipal and industrial pollution of water. These pollutants, and their related environmental impacts, have remained largely unmeasured and ignored in many developing countries even though there appears to be an awareness of the problem. As a result it is difficult to enforce pollution controls on industrial and municipal effluents, and pollution sources such as factories have been able to ignore the water quality problems they cause.

For most developing countries there is very little treatment of municipal or industrial wastewater. The rivers and canals are the water treatment system. While there is sufficient water to adequately dilute the pollution, the rivers will carry out natural remediation.

The danger is that in a situation where water pollution may be steadily increasing, unless an effort is made to build up records, and understanding of the processes and trends, the changeover from tolerable conditions to intolerable conditions may come as a sudden event. Unless the controlling authorities understand the local water quality processes and are monitoring how pollution trends are developing, the associated problems may arrive too suddenly for remedial action to be taken.

The most effective actions to control potential problems are those carried out when the problems are still quite small. If pollution is allowed to grow unchecked, the result may be sudden loss of aquatic ecosystem and profound effects on downstream users. An example of this is that the waters may suddenly become anaerobic – this might happen during summer low-flows if the amount of municipal wastewater effluent continues to increase.

The WQM methodology has recently been developed to provide those concerned with water quality, environment agencies, water supply authorities, irrigation departments etc. with a means to set up their own WQM programmes. In the past it has been extremely difficult for them to do this due to their lack of financial and technical resources. Instead they have been largely dependent on sophisticated central laboratories. However the disadvantage of such laboratories is:

(i) high expense to set up,
(ii) high cost and difficulty of retaining the qualified technical staff needed to run it,
(iii) difficulty in preserving samples when they are transported from field sites over long distances and in hot conditions,
(iv) delays in processing the samples may mean that several weeks elapse before the results are reported – such information cannot therefore be fed back to the field sites for management interventions.

This report outlines a new WQM technique that provides simple and relatively inexpensive water quality data with acceptable accuracy. The costs of maintaining an expensive laboratory and specialist staff are avoided, and the technique gives relevant data directly to the people that need it – the field staff on the spot and the direct managers of the water distribution system.

Part II of this report describes some fieldwork, recently carried out in Pakistan on the River Ravi System near Lahore, to test the WQM approach. The fieldwork has been carried out by the international Waterlogging and Salinity Research Institute (IWASRI) in collaboration with HR Wallingford, UK. Co-operation and specialist advice has also been obtained from the Punjab Government's Environmental Protection Department (EPD) and its Irrigation Department (Irrigation Research Institute, IRI). Assistance in laboratory analysis was provided by the Institute of Environmental Engineering and Research at the University of Engineering and Technology (UET) in Lahore and by the Soil Fertility Institute of the Ministry of Agriculture.

Part III contains the conclusions and recommendations.

2. WATER QUALITY MONITORING METHODOLOGY

The WQM methodology is an appropriate technical procedure for monitoring and assessing water quality and pollution problems in the large-scale water distribution networks that are found, for instance, in major irrigation systems. The strategy utilises low-cost, field-kit instrumentation that can be used by non-specialist technical staff, and substantially reduces the need for expensive and time-consuming laboratory analysis.

The methodology is now feasible as the major advances made over the last 10 to 15 years by instrument manufacturers have enabled a range of analytical procedures, some complex, to be adapted into field-kit technologies. Table 1 summarises the current situation about the wide availability of field-kits. All the major parameters utilised in normal environmental analysis can now be measured using the field-kit approach. The major exceptions are Biochemical Oxygen Demand (BOD) and Total Organic Carbon content (TOC) – both of which require detailed, prescribed laboratory procedures.

The WQM procedure is portrayed overleaf, and is repeated in Figure 1. The first step is for concerned departments or managers to identify which environmental problems are of prime concern and which locations are affected. They should then call in a local environmental expert to advise on which are the main potential pollutants and how often they should be measured (continuously, daily, weekly, fortnightly, monthly or continuously).

At each chosen site, there will need to be a preliminary site survey in order to check the choice of parameter to be measured, to check the logistics of how the measurements will be carried out and to ensure that all the needed parameters have been identified. In doing this it is important to define whether the objective is to build up understanding of how the water quality parameter varies (trend monitoring) or whether to carry out regular surveillance that will enable any serious pollution incident to be identified and dealt with. Equally, the WQM programme to be set up might comprise both objectives, or it might focus on other separate, more specialised needs (see Table 2) such as preliminary surveys, emergency surveys, impact surveys or modelling surveys (Chapman, 1996).

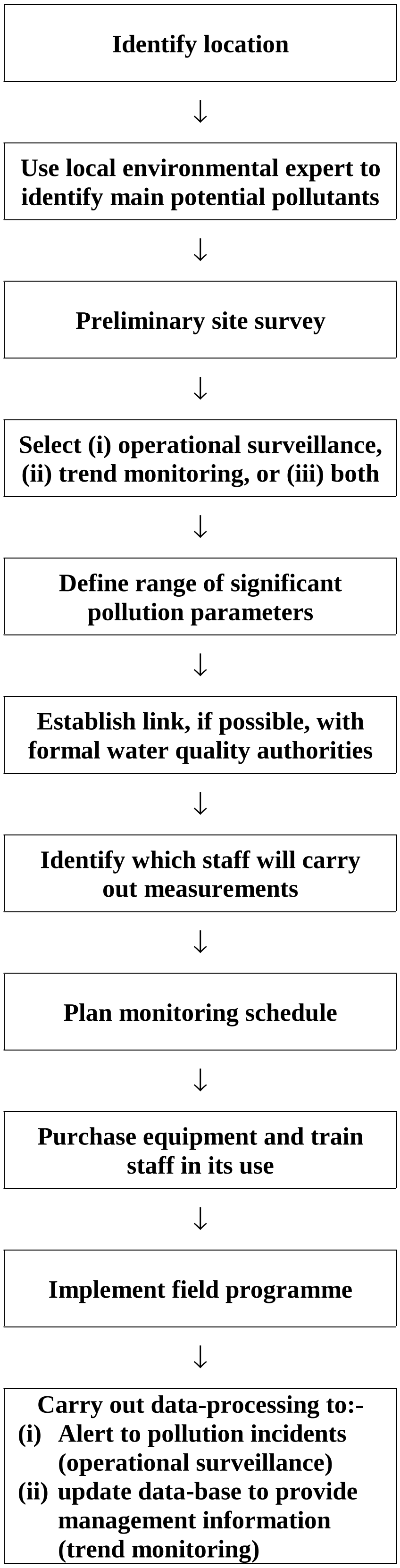
Since the locations chosen for investigation may also be of particular concern to other agencies with formal interest in water quality monitoring, such as Pollution Control Authorities, Public Health Departments and Universities, there should be an investigation of whether the WQM procedure to be established can be linked to any existing programmes. Not only would this assist in the planning of the WQM procedure, but the information from other programmes could be used to check and counter-check the results being obtained.

Facilitating such a link might entail ensuring that weekly measurements at a particular location were scheduled so that they coincided once a month, say, with sampling programmes from other authorities.

The next consideration of the implementing department is to identify which staff will carry out the monitoring. This has implications for the provision of transport if the staff concerned do not already have it, and for the provision of the basic training that may be needed so that staff have adequate minimum technical standards. One possible strategy would be to utilise departmental staff who are already visiting certain locations for other reasons (such as checking on the need for maintenance at key water control structures, or collecting water flow data). The advantage of doing this is that these staff would be in a position to react immediately if a water quality problem was found and could move immediately to control the pollution.

Their own awareness of the importance of water quality considerations would also be increase. This is an important benefit, since irrigation departments traditionally have been concerned only with how much water is available and have paid little or no attention to how much water quality is being affected – despite growing public awareness of pollution problems, particularly in developing countries.

The Water Quality Monitoring Procedure



An alternative strategy for meeting staffing requirements would be to take on new staff for the purpose, or to hire in additional staff on a temporary, contractual basis. This would be advantageous if special, additional funding was available that could include additional staffing as well as the capital costs for the equipment needed.

Choice of what the WQM information is to be used for will strongly guide the preparation of the schedule for water quality monitoring. The implementing department will need to decide how often the measurements are to be made. This will necessarily be a balance between the availability of staff to carry out the monitoring and the amount of information needed to show and establish water quality trends. In almost all cases of setting up monitoring locations, provision will need to be made for taking or obtaining flow discharge rates.

Another important factor to consider at this stage is the processing of the data. Normally it should be entered on to a computer database.

Purchase of equipment will depend on what parameters are needed to be measured. Given the wide range of field-kit instruments available and the wide range of manufacturers, it is beyond the scope of this report to list out the types of field-kit available to each parameter. However, since cost will be a fundamental consideration, the prices of purchasing various field-kits, and of regularly using them, are presented in Table 3. This information is based on a market survey carried out in the UK in early 1998. The table is intended to give outline indicative costs, and local information on obtaining the required field-kits will probably reveal considerable variation in price.

At this point in the planning procedure it would be a good idea to compare the estimated costs of deploying field-kits for the WQM procedure with the cost of sending samples to the local environmental laboratory. Table 4 presents a summary of costs entailed in sending samples to a commercial laboratory for various water quality tests. Inevitably these are relatively expensive, not only because of the associated costs of buying sophisticated instruments and retaining highly trained staff, but also because the costs were obtained from UK sources. In a developing country, the costs would be expected to be less than those tabulated but would still be relatively expensive compared to the costs of field-kit determinations.

Indicative costs show that a basic collection of WQM field-kits will cost about £5,000 ($8,500) and that the two other major costs will be:- (i) supplying minimum laboratory facilities (such as the availability of distilled water and cleaning facilities) and (ii) the provision of transport. Comparison (Table 5) of the relative costs of sending a water sample to a laboratory, with the cost of making the analysis at site with a field-kit, shows a very large difference. For the determinands considered, analysis was very much less expensive using the field-kits.

Training of staff to be utilised can be organised by sending them on training courses set up as part of the deployment of the WQM project, or they could receive training from the local agents supplying the equipment, or they could attend general courses. A simple approach would be on-the-job training, since the techniques are relatively easy to sued. Interpretation of the collected data is a more challenging task, and some staff will need to be responsible for processing the measurements made, archiving it and running analysis procedures. This in turn will need to be combined with flow data so that correct interpretation, albeit approximate, can be made and the overall trends in water quality variation, if that is to be the objective of the exercise, can be identified.

With all the foregoing points dealt with, the WQM procedure is ready for implementation. A key point is that the preparation and implementation are not necessarily extensive pieces of work. The whole point of applying this procedure is that it is simple to set up and that it gives useful information quickly and inexpensively. Field data, once it starts to come in, can either be used for immediate tactical response to the present water quality situation or to pollution incidents. It can be used in conjunction with water flow information for strategic management of the deployment of water resources. For example, water quality data could be used;

(i) to indicate that salinity levels were adequate/acceptable after the receipt of saline tubewell water or drainwater into the system, or

(ii) for identifying whether microbiological problems were building up following the injection of water from the drainage system, or

(iii) for identifying long-term, year-by-year gradual change in water quality parameters - so that remedial measures can be planned and introduced before a critical pollution load situation is reached.

3. OBJECTIVES OF THE STUDY

The aim of the project has been to pilot develop an appropriate, pragmatic methodology for monitoring water pollution trends in surface water distribution systems. The methodology is based on the wide range of water quality monitoring field kits that have recently been developed.

The technique is intended to be of particular use in areas where return flows from municipal, industrial and agricultural sectors are threatening the reliability of water quality for the multi-purpose uses of downstream users. Such users mainly comprise irrigation systems, but they inevitably contain many towns, villages and even cities who are receiving both the water and the pollution in it. In situations such as this, there is a strong need for trend data to be collected so that problems can be identified and appropriate solutions implemented.

The main objectives of the WQM methodology are to provide water resource departments with the means to receive data for themselves on water quality trends in irrigation waters; and to create awareness about the growing importance of water quality in the people responsible for distribution and managing irrigation water. However, the technique could be utilised in many other situations, such as spot-tests on water sources used for domestic supply.

The study also aimed to try out the methodology in a typical representative situation and to ascertain any practical difficulties. The River Ravi system at Lahore was selected for this purpose (see Part II for discussion).

4. WATER RESOURCES POLLUTION PROBLEMS OF DEVELOPING COUNTRIES

Sufficient water resources of adequate quality are essential for sustainable agricultural development. Increasingly, in many parts of the world, as municipal and industrial demands for freshwater increase and discharges go unchecked, the quality of the water remaining available for irrigated agriculture is deteriorating. As a consequence crop yields are being affected and, in some cases, human health is being threatened (e.g. by contamination of crops with pathogenic organisms and or toxic substances).

The causes of pollution in water resources are many and varied (see Table 6). Some of the most common causes, which occur at local, regional and international levels, include:

- **Salinization** of surface waters and groundwaters due to factors such as repeated reuse, saline intrusion and the salt load that inevitably arises from agricultural drainage.

- **Organic wastes** introduced into water bodies from sewerage discharges and agro-industrial effluents.

- **Pathogenic micro-organisms** usually emanating from sewerage discharges that predominantly are completely untreated.

- **Eutrophication** of surface waters arising as a result of both diffuse and point sources of nutrient inputs (i.e. leachate from excessive applications of nitrate fertilizers, or runoff from animal feed-lots).

- **Agrochemical contamination** of surface water and groundwater by pesticides and degraded by-products.

- **Industrial effluents** discharged, often untreated, containing a wide range of toxic substances.

The relevance of the particular water quality problems to irrigation, and other users of water are summarised in Table 1. It should be noted that out of all of mankind's uses of water, irrigation is relatively tolerant with respect to most pollutants. However, the water supplied to an irrigation scheme is not just used for irrigation, the local communities and industries may also make use of it, especially if groundwater is unavailable or of unacceptable quality.

If effective action is to be initiated to combat the threat to agricultural production and human health posed by the various forms of pollution described, then information on current water quality and on general trends is essential. Historically, however, the management of irrigation and drainage systems has been undertaken by engineers more concerned with delivering water of sufficient quantity than water of acceptable quality.

Although there are some signs of change, the level of environmental awareness in irrigation departments is still very low. Consequently water quality monitoring in irrigation systems is often inadequate or completely lacking. Given the rapidly increasing importance given to the environmental aspects concerning the use of water resources, there is an urgent need:

1. to increase substantially the amount of information being collected,
2. to improve the reliability of data collection,
3. to provide rational, appropriate standardised methods for processing the data,
4. to extend widely the dissemination of information to water resource departments at both operational and managerial levels.

5. USE OF WATER QUALITY MONITORING (WQM) METHODOLOGY

5.1 Selection of parameters

The application of a WQM programme to a certain location requires the selection of the water quality parameters that will be monitored, with due regard to the objectives of the programme. The main aim of the proposed strategy is to identify whether water resources are of sufficient quality for irrigated agriculture. However, it is recognised that the water distributed via irrigation canals may, in many developing countries, be used for domestic consumption in rural communities that do not have access to groundwater. Thus public health parameters will inevitably also be required in WQM programmes, and will in most situations be the highest priority group in the range of parameters considered for monitoring.

Irrigation of crops presents a possible health risk to both cultivators and consumers if the water is contaminated with pathogenic organisms or toxic substances (see Table 1). Moreover, excessive levels of various inorganic ions may adversely affect soil quality and thereby reduce the potential for crop growth.

Agricultural activities may also impact on water quality – a particular concern is the re-use of drainage water is to irrigate crops. Thus, for example, organic matter and inorganic matter (from land husbandry) and agrochemicals (i.e. pesticides and fertilisers) may enter both surface waters and groundwaters as a result of run-off and/or percolation. Additionally, irrigation may also lead to the salinization of receiving water bodies. There is, therefore, a wide range of parameters to be included in a WQM programme, especially if industrial pollutants are present. If the water is also being utilised for other purposes, such as domestic supply, then the range becomes larger and the allowable concentrations become much more challenging.

The suggested list of key water quality parameters for inclusion in a WQM programme is presented in Table 1. The list of maximum allowable concentrations for different uses of water are listed in Table 7. This gives the recommendations by a number of international authorities for a wide range of water quality parameters. The table is reproduced from Chapman (1996).

How the parameters are selected for monitoring depends on local conditions. For example, trace elements need only be measured when they are introduced by main activities or occur naturally at higher concentrations. Similarly, because of the great variety of pesticides available, specific compounds should only be monitored if they are being used in the region. Consequently, before a monitoring programme is initiated at any given site a preliminary site survey is needed, under the guidance of a local environmental expert, to define the range of significant parameters that will need to be monitored on a regular basis.

5.2 Selection of instrumentation and technology for WQM procedure

Conventionally, water samples are sent to a laboratory for analysis. Laboratory methods, such as those described in the British Standards Series BS 6068 and the "Blue Book" (Methods for the examination of waters and associated materials, HMSO, London) are still centrally important to such analysis. Many different countries have their standards for laboratory procedures. However, for most of the parameters listed as being of interest to water quality monitoring, a field-kit is available (see Table 1). Table 8 gives indication of the range and accuracy of some WQM field kit instruments used in the field-testing. This section provides a review of the main field-kits that are now available.

5.2.1 Colour photometer kits

The colour photometer is an extremely versatile instrument that can be used for measuring a wide range of parameters – especially metal and inorganic ions. It works by passing light of a characteristic colour through a water sample and measuring how much is absorbed. The sample has to be pretreated according to the parameter to be measured, by adding certain reagent tablets to a predetermined volume so that the sample is adjusted to give a standard response to the absorption of the light. The photometer works by passing light through a test-tube containing the conditioned sample and through a coloured filter onto a photocell. The photometer display shows the percentage of light transmitted. This is compared to the 100% transmittance obtained using a pure water sample as a reference. The percentage is then converted to the concentration of the target parameter using standard empirical tables.

Laboratory spectrophotometers work on the same principle but instead of simple optical filters, use monochromatic light sources in which the light wavelength can be adjusted to best suit the parameter of interest.

5.2.2 Electrometric probes

Electrometric probes measure ionic activity across a membrane in their sensor for a wide range of physical and chemical parameter (e.g. EC, DO, pH as well as specific ions). They work by relating ionic concentrations to electric current flow across the membrane. Ion selective electrodes work in a similar manner and are tuned to be specific to particular inorganic ions such as nitrate, ammonium and chloride. They are available as individual ion sensors or multi-parameter devices.

5.2.3 Enzyme Linked Immuno Sorbent Assay (ELISA)

This technique, which was originally developed to help diagnose human medical conditions, has been adapted to provide a relatively simple, fast and inexpensive screening field-test for a variety of pesticides and other complex organic pollutants. The basis of the test is to precondition sample tubes with enzymes linked to the pesticide of interest. When the sample is introduced into the tube, the preconditioner bonds only with molecules of the target pesticide. The process comprises immunological and enzyme chemistry steps that result in a quantifiable colour change that is proportional to the pesticide's concentration. The technique works down to very low concentrations (ppb) and is complete portable.

5.2.4 Anode stripping voltammetry

Although heavy metals and other non-metal elements can be measured using a colour photometer, the technique works well only at significant concentrations. However, the presence of these elements even at very low (trace) concentrations may be highly important. Traditionally these parameters are measured using atomic absorption spectrophotometry (AAS) and gas chromatography (GC) techniques that are suitable only for use in the laboratory. AAS is used for determining trace elements in water samples (also in sediments and biological tissues – when dissolved in acid).

Anode Stripping Voltammetry (ASV) is a process that has recently been extended so that it can be used in a portable instrument to measure a number of target heavy metals. The process works by introducing a precisely measured sample into a preconditioning, acidifying agent. The larger the concentration of the target heavy metal, the more of the acid is neutralised. The solution immerses a pair of electrodes, and proceeds to strip away the conducting surface from the anodic electrode. By consideration of the rate of change of the current across the electrodes, the extent of the anodic stripping can be determined. From the pattern of current change the concentration of the target heavy metal can be determined. The technology and chemical processes have been packaged into a single portable instrument (e.g. Metalizer 3000) that features single-use disposable sample phials, also internal processor to quantify the time signature of the stripping process.

5.2.5 Microbiological analysis

Because water-borne diseases are the most significant dangers due to pollution of water, the analysis of microbiological contamination is likely to be the highest priority variable to be assessed in most locations. This is because if the water is used for human consumption, micro-organisms such as bacteria, viruses and helminths can have profound effects, even if present only in small concentrations.

Microbiological analysis has historically involved collecting samples and refrigerating them in order to preserve them long enough to return them to the laboratory. This can give misleading results because the microbiological population starts to change as soon as the sample is removed from its natural environment.

The laboratory process comprises introducing the samples onto growth media then incubating them in Petri dishes so that each bacteria can develop into a visible colony.

Portable systems are now available comprising membrane filtration unit and battery-powered incubator. Because the system is portable, incubation can be started on site immediately. This avoids inherent accuracies due to transportation, delay and higher temperature that can become large in the context of the difficult conditions prevalent in some developing countries. The system can be set to measure the concentrations of either total coliforms or faecal coliforms. The method comprises passing a 100ml sample through a filter paper that collects the individual bacteria. The filter paper is placed on a growth medium and incubated for 16 hours. Counting the visible colonies gives the number of bacteria per 100ml. Because the coliform concentration can reach millions per 100 ml there is a need for dilution, plus proportional correction, to limit the colonies to be counted to a reasonable number.

In some cases, such as rivers, canals and drains with high sediment loads, it can be difficult or even impossible to pass the water sample through the filter. The filter becomes clogged up and the measured concentration of micro-organisms is made inaccurate by the excess material on the surface of the filter and by the high pressure required to force the sample to pass through. In such circumstances the problem can be satisfactorily avoided by careful prefiltration of a larger sample, and by the use of alternative indicator species. Growth of e.coli or total coliforms on a laurelsulphate medium is widely utilised, but measurement of streptococcus concentration can give a more realistic indication of significant presence of microbiological pollution.

5.2.6 Flow record analysis

A vital component of any WQM assessment is to evaluate how much water is represented by the water quality parameters measured. Without this it is not possible to examine the overall balance of pollutant movement. Normally, the sampling point for the study would be selected to be a location where the flow could be easily determined, such as a barrage or cross-regulator where the measurements will normally be monitored anyway. It would also be possible to choose a gauging point at a structure where the stage/ discharge (Q/h) relationship is known, or even at a suitable site where a Q/h relationship would have to be established (such as the effluent proceeding along a main drain).

Discharge measurements are necessary for determining the flow balance or the pollutant mass balance, and are required for any further calculations (such as water quality models). It is assumed that the Irrigation Department or Water Resources Department carrying out the WQM procedure would be monitoring flow and discharge rates as a matter of course.

5.2.7 Data-processing

It is most important to prepare a process for collecting the information coming from the network of deployed WQM instruments and from any other sources that may be relevant and available. The data-processing system will archive the data and provide a mechanism for integrating the information into a coherent structure so that Management Information (e.g. about pollution incidents identified, and trends recognised) is produced that can be fed back to both senior and local management.

At a basic level, simple spreadsheets can be used. Above them data-processing increases in sophistication and complexity up to state-of-the-art water quality mathematical models. The emphasis should be on choosing a system that is simple to use by the staff involved, and which provides appropriate information. There are strong reasons, from the point of view of involving and maintaining staff interest, for processing the data manually and hand-drawing the graphs depicting water quality variation as it builds up over the course of the monitoring programme.

5.2.8 Role of environmental laboratories

The purpose of the WQM procedure is to extend the range of pollution monitoring, not to replace or undercut existing laboratories. The WQM procedure enables a wide range of locations to be monitored using instrumentation of limited accuracy, but is capable of identifying and quantifying trends.

Serious pollution incidents will of course need proper investigation by the environmental authorities. The WQM procedure can aid the early recognition of such problems.

Secondly, for the WQM approach to retain its value, the data collected will need to be cross-checked by a reputable laboratory at regular intervals. The interval would vary from monthly to annual, depending on circumstance.

Thirdly, it is hoped that the WQM approach can help to extend the outreach of the environmental laboratories, by providing a mechanism that enables the laboratories to receive information about water quality problems (albeit approximate) that they otherwise would have no knowledge about.

6. REVIEW OF WQM PARAMETERS

The water quality parameters of main interest have been listed and introduced in Table 1. The following section gives brief guidance on the environmental problems indicated by the parameters.

6.1 Salinity

Salinity has profound effects on the sustainability of irrigated agriculture, on the productivity of crops, and on the fertility of land resources.

It is normally taken as the total dissolved concentration of major inorganic ions in the water (Rhoades, 1992). These include for instance sodium, calcium, magnesium, potassium, bicarbonate, sulphate and chloride ions. Although each type of ion can be considered separately, it is usual to assess their combined effect by estimating their total presence on a mass basis, and thus deriving the Total Dissolved Solids (TDS) concentration – either in mg/litre or $mmol_c$/litre. Without a laboratory, direct estimation of TDS is difficult to carry out. However Electrical Conductivity (EC) is widely used as a practical index of salinity, and can be conveniently measured in the field (or in the laboratory) using an EC meter. The units now conventionally used for EC are dS/m (deciSiemen per metre); these are directly equivalent to the old, commonly used millimhos/cm.

The relationship between TDS and EC is approximate but consistent. This is because EC is lightly affected by variation in the composition of ions in the water. Although the composition remains the same for a given water source, and depends largely on the nature of the source catchment, it can vary from source to source. Generally speaking, EC's in dS/m can be approximately converted to TDS by multiplying by 700. The factor can be defined more explicitly for each given location. The relationship is temperature dependent, and EC determinations have to be temperature-compensated to a standard reference of 25°C.

The basis of the widespread use of EC as an easy to measure indicator of salinity is that plants respond primarily to total salt concentration rather than to the presence of particular types of salts.

The standard guidance (Ayers and Westcot, 1985) for the acceptable limit of salinity in irrigation water is an EC of 3 dS/m (approximately equivalent to a TDS of 2000mg/l), with the recommendation that water less than 0.7dS/m (459mg/l) can be used without restriction.

This guideline has been widely judged to be conservative since saline waters can successfully be used for irrigation. More recent guidelines (Rhoades, 1992) have classified saline waters used for irrigation as:-

Water Class	EC	TDS
Non-saline	<0.7 dS/m	<500 mg/l
Slightly saline	0.7-2 dS/m	500-1500 mg/l
Moderately saline	2-10 dS/m	1500-7000 mg/l
Highly saline	10-25 dS/m	7000-15000 mg/l
Very highly saline	25-45 dS/m	15000-35000 mg/l
Brine	> 45 dS/m	> 35000 mg/l

The importance of the local situation should not be under-emphasised. The actual effect of irrigating with saline water depends on the nature of the local soils and on the sensitivity of the crops being grown. In some situations it is possible to cultivate crops successfully using highly saline waters, in others using only slightly saline waters may result in salinisation.

With respect to public health considerations for human consumption of salt-affected water, the USA/Canada recommend 500mg/l as a maximum limit of acceptability, the WHO recommend 1000mg/l. In fact, since salinity is such a noticeable taste local people will inevitably exercise choice, if they have it.

6.2 Temperature

Temperature strongly influences microbial processes (e.g. organic matter breakdown) and other processes that occur in the water system.

Heated industrial wastewaters lower the dissolved oxygen level, with detrimental effect on aquatic life.

6.3 Dissolved oxygen

Dissolved oxygen (DO) Oxygen is an important element in water quality control. Its presence is essential to maintain biological life within a system and the effect of a waste discharge on a river is largely determined by the oxygen balance of the system. Oxygen is only slightly soluble in water and its solubility will decrease as temperature increases. Clean surface waters are normally saturated with DO, but such DO can be rapidly removed by the oxygen demand of organic wastes.. The measurement of DO provides a broad indicator of water quality. Changes in DO concentrations can be an early indicator of changing conditions in the water body. DO concentrations in unpolluted waters are normally about 8-10 mg/l (at 25^{o}C). Concentrations below 5mg/l adversely affect aquatic life, and concentrations below 2 mg/l will cause fish kills. DO is not appropriate for assessing groundwaters because there is no opportunity for the water to establish an equilibrium with atmospheric oxygen.

Oxygen Demand (OD) Organic compounds are generally unstable and may be oxidised biologically or chemically to stable, relatively inert end products such as $C)_2$, NO_3, H_2O. An indication of the organic content of a waste can be obtained by measuring the amount of oxygen required for its stabilisation.

Biochemical Oxygen Demand (BOD) – is the measure of the oxygen required by micro-organisms whilst breaking down organic matter. BOD is normally measured over a period of 5 days, and shows how much oxygen is needed by the water to completely oxidise its organic pollution load. DO, on the other hand, gives an indication of how much oxygen is present and thus shows how much the oxygen is being utilised. BOD measurements are carried out in a laboratory.

Chemical oxygen demand (COD) is the amount of oxygen consumed by organic matter as determined by chemical oxidation using a boiling solution of potassium dichromate and concentrated suophuric acid. Typically the COD is larger than the BOD.

6.4 Nitrates

Nitrates are normally present in all natural, drinking and wastewaters. As well as natural drainage, particularly from igneous rock areas, nitrates enter water bodies from the breakdown of vegetation, the use of chemical fertilizers and the oxidation of nitrogen compounds. Significant amounts of nitrate also enter from animal feed-lots, from domestic wastewaters and from industrial effluents. Nitrate is an important parameter to test for, particularly with respect to drinking supplies. Consumption of water with excessive nitrate content may be responsible for methaemoglobinaemia (blue baby syndrome) in bottle-fed infants.

The influence of human activities can increase nitrate concentrations up to about 1 mg/l (NO_3-N) and in some circumstances to as much as 5 mg/l. In cases of extreme pollution, such as urban wastewater outfall drains, nitrate concentrations may be as high as 200 mg/l (NO_3-N). The EU (see Table 7) has set a recommended maximum of 5.7 mg/l N (i.e.25 mg/l NO_3-N), and an absolute maximum of 11.3 mg/l N (50 mg/l NO_3-N) for the nitrate content of drinking water. In general, a rising nitrate concentration in groundwater is a warning sign of pollution.

6.5 Nitrites

Nitrites are found in natural waters as an intermediate stage in the nitrogen cycle, and are formed in water either by the oxidation of ammonia or the reduction of nitrates. Thus biochemical processes can cause a rapid change in nitrite concentrations. In natural waters, nitrites are normally present only in low concentrations (0.1 – 0.5 mg/l). However, higher concentrations may be present in sewage and wastewaters. Nitrites are harmful to aquatic life. The nitrite test is used for pollution control in wastewaters, and for monitoring drinking and agricultural waters.

Nitrite concentrations in freshwaters are usually very low, rarely higher than 0.1mg/l (NO_2-N). High nitrite concentrations are generally indicative of industrial effluents or organic pollution. The WHO guideline for drinking standards is 3 mg/l (N), which is equivalent to 1mg/l (NO_2-N).

6.6 Ammonia

Ammonia occurs in water as a breakdown product of nitrogenous material. It is also found in domestic effluent and certain industrial wastewaters such as pulp and paper factories. At high concentrations ammonia is harmful to fish and other forms of aquatic life. Unpolluted waters contain low amounts of ammonia – less than 0.1 mg/l (NH_3-N). Typical river waters contain ammonia in the range 0.1-3 mg/l (NH_3-N). Higher concentrations indicate pollution from sewage industry or fertilizer run-off.

6.7 Phosphates

Phosphate is an essential nutrient for all living organisms. However, when phosphate levels rise above natural levels due to the activities of man, entrophication of water bodies can occur. Phosphates are extensively used in detergents and washing powders, also in food processing industries and industrial water treatment processes.

Phosphates can enter water-courses through a variety of routes – particularly via domestic and industrial effluent and from agricultural land run-off. Phosphate is an important control test for natural and drinking waters. Whilst phosphates are not considered harmful for human consumption, they do exhibit a widespread and complex effect on the natural environment.

Phosphate levels can vary widely over the year due to seasonal take-up by plants. The levels vary from 0.001 mg/l (PO_4-P) in unpolluted waters to 200 mg/l (PO_4-P) in enclosed saline water bodies.

6.8 Boron

Boron is an abundant natural element essential at trace concentrations for plant growth. Some plants are highly sensitive to variations in this concentration. For this reason, there is a need to check in supplied waters that the boron concentration is sufficient. This would particularly be the case downstream of industrial processes where borates are widely used. Average concentrations in surface water are normally less than 0.1 mg/l, and rarely exceed 1.5 mg/l. For irrigation purposes, current guidelines recommend maximum concentrations of 0.5 mg/l for sensitive crops and 6 mg/l for tolerant crops.

6.9 Chromium

Chromium is a heavy metal present in certain industrial wastewaters, such as those from tanning, plating and coating industries. Chromium is widely distributed, and occurs in its hexavalent form as chromates and dichromates or in its trivalent form as chromium salts. In water supplies, hexavalent chromium (chromium VI) is particularly undesirable since it is a Class I carcinogen. Chromium III is relatively inert but is still rated as a Class III carcinogen and should be avoided. Because of its carcinogenity, the WHO have established a guideline value of 0.05 mg/l for a drinking water standard that is unlikely to give rise to significant health risks. However, this is under continuing review.

6.10 Heavy metals

Heavy metals such as Cadmium, Zinc, Copper, Lead may be toxic to aquatic organisms if present at high concentrations. Health risks are principally caused by the consumption of affected fish etc., but they can also be created by absorption in crops irrigated with wastewaters. Bioaccumulation in the aquatic environment is principally due to organic metallic compounds.

The heavy metals can be carried as aqueous salts in the water body, but most of the ions are adsorbed onto sediment particles. Although there is an equilibrium between the two forms, it is possible for heavy metals to be accumulated where sediment is deposited.

6.11 Coliforms

Measurement of the faecal coliform concentration gives an indication of the relative presence of sewage in the water, and likelihood of the presence of associated viruses, more harmful bacteria and other dangerous microorganisms (all of which are difficult to measure individually). In raw sewage concentrations of faecal coliforms (as E coli) can vary between 1-50 million / 100 ml. Sewage treatment would reduce these levels but such processes are not widely deployed in Developing Countries especially in rural areas. Instead use is made of night soil, latrines and the natural self-purification processes that occur in rivers and water bodies.

An alternative parameter is to measure the concentration of total coliforms. This indicates the presence of wastewater and excreta from other sources such as animals, farms, run-off from land fills and rubbish dumps. Typical concentrations of total coliforms in raw sewage vary from 10-100 million coliforms / 100 ml.

A third approach that can be used is to streptococcus bacteria as the indicator.

The removal of the coliforms, and other microbiological organisms depends on the oxygen level of the receiving water and a number of other physical factors such as temperature, turbidity and exposure to sunlight.

Water bodies in areas of high population density can have counts of up to 10 million coliforms/100ml. At the other extreme, the WHO recommendation for drinking water is that there should not be any coliforms present.

Irrigation of crops with wastewater needs to be carried out carefully since as well as the risk to irrigation labourers, there is a risk that the crop products will be contaminated by the bacteria and other micro-organisms. Irrigation should cease several days before harvesting to encourage complete die-off.

6.12 Pesticides

Normally pesticides quickly adsorb to soil particles and are immobilised from leaching to the groundwater (except for some water-soluble types). However, if soil particles enter the river system due to soil erosion run-off during heavy rainfall (monsoon), the attached pesticides can enter the water system. Despite widespread use, it is not likely that significant amounts of pesticide pollution are being introduced in this way; and those that are, are heavily diluted. A bigger pollution risk is location-specific incidents such as operator mishandling.

The main classes of pesticide are: organo-chlorines (OC), organo-phosphates (OP), carbamates, triazines and chlorphenols. Monitoring is difficult, because there are so many types, and many have breakdown by-products. Internationally there is some uncertainty on what are permissible concentrations in drinking water, and whether any detectable concentration is permissible. The present limit is 0.001 mg/l. Representative concentrations in water bodies are indicated to be (Chapman, 1996): OC 0.00001 – 0.001 mg/l; OP 0.001 – 0.01 mg/l.

6.13 Suspended sediments

Suspended solids are the main mechanism by which pollutants such as pesticides and heavy metals are transported. These pollutants can attach to bonding sites on the sediment particles, and are carried by them suspended in the water. The pollutants can be released at any stage if and when the chemical equilibrium changes – such as change in acidity or temperature. The solids may also cause pollution directly, depending on their nature, if they are deposited and undergo decomposition.

Part II

Pakistan Case Study of the methodology

1. WATER POLLUTION IN PAKISTAN

Water pollution is a serious issue in Pakistan. It is estimated (Saleemi, 1993) that approximately 16,000 cubic metres of wastewater are discharged daily into water bodies from the industrial sector. This corresponds to a BOD loading of 20,000 tonnes. Municipal pollution of the water system is dominated the large amount of human sewage that directly enters the system. It is estimated this amounts to 50% of the 2M tonnes of excreta produced each year in the cities. Significant amounts of industrial and domestic effluent are received in all the country's major rivers and also in most streams and drains. According to the EPD (1995) water pollution is assuming serious levels, particularly around Pakistan's major urban centres. A recent environmental profile of Pakistan indicates that about 40% of deaths are related to waterborne diseases.

Industries such as tanneries, canneries and slaughter houses and domestic sewage are responsible for the addition of bacterial contamination to water bodies. EPA Punjab studies show that the values of total coliform as MPN/100 ml in sewage range from 27×10^8 to 56×10^{12} against the water quality guideline of 1000 for agricultural irrigation use. Table 9 comprises data from an EPA spot-check on various industrial effluents with Pakistan national standards of water quality, and demonstrates that serious pollution is occurring.

There has been a large increase in the use of biocides and fertilizers in Pakistan during recent years. For instance in 1990-91, the use of chemical fertilizers rose to 2 million tonnes, and the importation of biocides rose to 10.5 million tonnes.

2. USE OF WQM PROCEDURES AT LAHORE, PAKISTAN

The irrigation system around Lahore city in Pakistan (see Figure 2) was an appropriate situation to test the WQM method. This is because water progressing down two main waterways passes through the urban area and picks up a wide range of municipal, industrial and agro-chemical pollutants before being collected together and discharged into the nearby river Ravi.

Two sites were selected upstream - one on the River Ravi and one on the BRBD Canal - both at the point at which the canal passes under the river by means of a syphon. Two sites were selected downstream - one at the downstream end of one of the minor canals leading off the BRBD Canal, ie at Thokar Niaz Baig. The other was selected to be at the Baloki Headworks on the River Ravi 40 Km below Lahore. This is a key point in the system, as all the wastewater from the Lahore metropolitan and suburban areas is accumulated here and is included in the major diversion of water at the barrage to the main irrigation areas to the South of Lahore. These areas include the Lower Bari Doab and the Fordwah East Siddiqui Commands. Also the water is received by a large number of towns and villages.

The water quality data has been collected using field kits specifically chosen for local pollutants and analyzed using the HYQUAL PC database system. The methodology can be used by staff who have basic technical training and does not require a specialist to carry out the bulk of the data collection and data analysis.

The specific objectives of the field work at Lahore were to:

1. Install the field-kit monitoring (WQM) methodology and assess the suitability of the range of field techniques employed.
2. Examine the results obtained and evaluate their reliability and usefulness.
3. Assess the effectiveness of the database system used and comment on its applicability.
4. Use the results to demonstrate a spot check analysis of the present situation in Lahore.

The four sites selected for field monitoring were:-

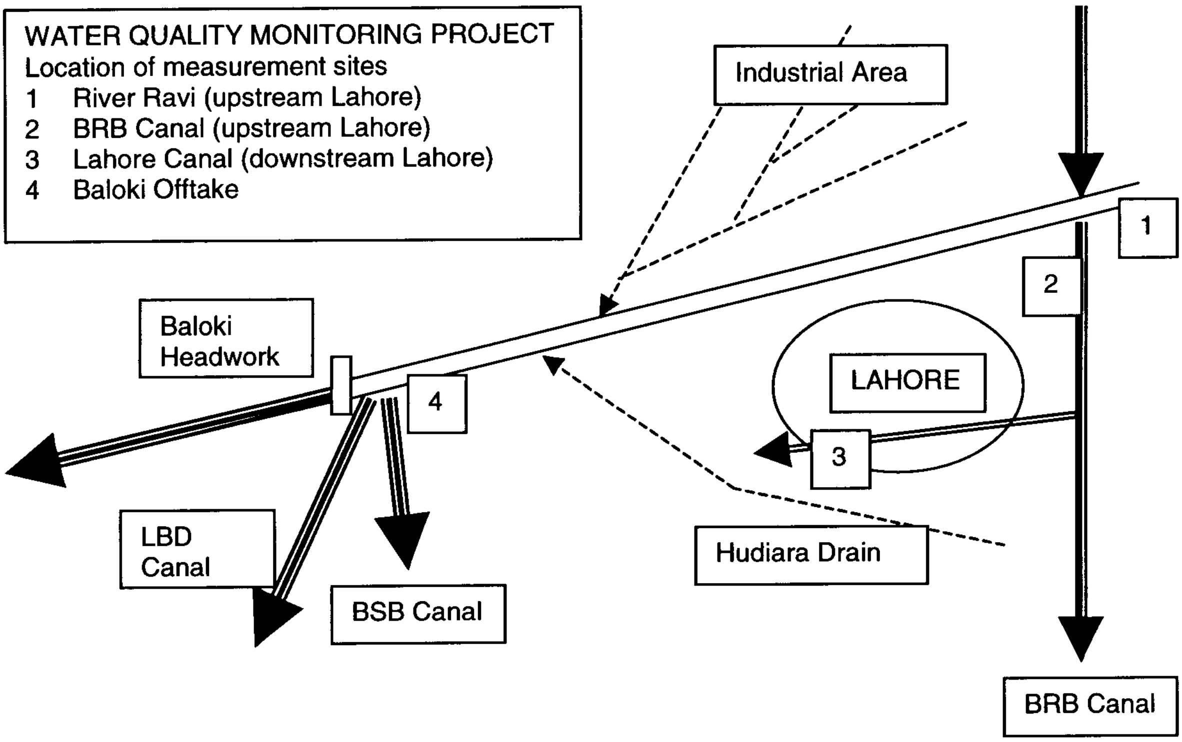
(1) River Ravi at the Ravi Syphon site upstream of Lahore (and its pollution sources);
(2) BRBD Canal (Bambanwala Ravi Badian Debalpur) at Ravi Syphon. This site was on the link canal bringing water to the Ravi area from the adjacent River Chenab:
(3) Lahore Canal at Thokar Niaz Beg. This site was on a canal distributing water to an agricultural area downstream of Lahore but which passed through the centre of the city and consequently picked up pollution;
(4) River Ravi at Baloki Headworks. This was the site at which the Ravi water is redistributed to the downstream major irrigation areas. At this point the Ravi has received substantial inflows from major water transfer link canals connecting the Chenab and the Jhelum Rivers. It also has received all the wastewater from Lahore.

The following schematic diagram which illustrates how the four sites relate to the system, is also reproduced at Figure 3.

WATER QUALITY MONITORING PROJECT

RIVER RAVI, LAHORE, PAKISTAN

LOCATION OF MONITORING SITES



Use of the WQM procedure involved selecting the key pollution parameters that were significant for the given situation. A local environmental expert was consulted for advice on the parameters of most concern. For each of the four sites, field kits to measure predefined appropriate parameters were deployed. Checks were made on their relative accuracy using a local environmental laboratory.

The main advantages of the WQM field kit approach, as compared to sending samples to a centralised laboratory were:

1) The field kits were completely portable and consisted of hand-held instruments that were easy to use, even in remote areas.
2) Each kit was a self-contained system that could be used by a single operator.
3) The kits could be used either in the laboratory or in the field.
4) The kits were not inexpensive, but did represent a large saving both in start-up and running costs, compared to the cost of setting up a conventional laboratory and retaining expert staff to run it.
5) As results were available immediately, a considerable amount of time in waiting for lab results was saved.
6) Since the samples did not need to be carried back to a central laboratory, there was no sample degradation. (Sample degradation can especially affect bacterial counts, dissolved oxygen, conductivity and many of the chemical tests. Therefore these kits actually gain in terms of potential accuracy in this respect.)

The field methods used in the field testing comprised:

- Photometer
- Incubator (for bacterial tests)
- Conductivity meter
- Dissolved Oxygen meter.
- ETG ASV Metalyser

Photometric analysis

A portable, precision colorimetric photometer (Paqualab) was used to measure a number of inorganic ion concentrations. As advised by the local environmental consultant to the project, the parameters monitored in this way were nitrate, nitrite, phosphate, ammonia, boron and the heavy metal chromium.

Microbiological concentration analysis

A membrane filtration system and portable, battery-powered incubator (Paqualab) were used to assess microbiological quality. Because the incubator was portable, sample incubation was started on site. The system used could either be set to indicate faecal coliform concentrations, or total coliform concentrations. The method comprised taking a 100ml sample and passing it (by vacuum induction) into through a filter. The filter paper was then placed in a petri dish on a preprepared laurel sulphate growth medium. At the end of a 16 hour incubation period at 37°C, each single bacteria had multiplied up to a visible colony. Counting the number of colonies thus gave the number of bacteria in the original sample. Dilution, followed by due proportional correction, was needed for high concentrations so as to limit the number of colonies to be counted.

Electrical conductivity

EC was measured using a standard EC meter (Paqualab) with temperature compensation and integral indication of water temperature.

Dissolved oxygen (DO)

A portable DO meter was used to measure the concentration of oxygen at the sampling sites.

Heavy metals

A state-of-the-art portable analyser (ETG ASV Metalyser) was used to test for the presence of certain heavy metals. The device utilised a system called anode stripping voltammetry to identify the target heavy metal and to nullify interference from other trace metals that might have been present. The metalyzer comprised an analyzer and disposable sensors, and was capable of calculating the total concentration of certain heavy metals at trace concentrations to parts per billion (ppb).

Flow records

The four sample sites were selected to be close to standard gauging sites so that a continuous flow record could be obtained. The magnitudes of the flows were important to the dilution of pollutants.

Processing of WQM data

The HYQUAL water quality database software was used to store and process field information, and to analyse the data with the help of tabular and graphical reports.

3. RESULTS OF FIELD TESTING AND DISCUSSION

3.1 Flow rates

The flow rates recorded over the course of the monitoring are shown in Figure 4. This gives the month by month variation of the flows at the four monitoring locations. The magnitude of the flow and the degree to which varies over the year have important effects on water quality.

The Ravi River upstream of Lahore can be seen to provide a relatively low base flow characteristic of approximately 50 cumecs over most of the year. This is consistent with the diversion of the Ravi waters for irrigation in nearby India. However during the August monsoon period the Ravi flow increases by a factor of 30. This provides a significant flushing effect on the system but it also has the potential to introduce stored pollutants that would otherwise have remained in place. In particular there is potential for disturbed soil sediments to bring with them adsorbed pollutants such as biocides. However the dilution effect is such that these pollutants are not significant.

On the same graph (Figure 4a), it can be seen that throughout the year the waters of the Ravi are considerably increased by the time the river reaches the Baloki Headworks. The increase is approximately 500 cumecs and remains consistent, even over the monsoon period. This is indicative that there is a strict control and management of the waters that are added to the Ravi at Lahore. Principally, the added waters are from the Upper Chenab Link Canal and the Qadirabad Barrage Link Canal (also transferring water from the River Chenab). However there is also a significant contribution made from the drainage channels of the City of Lahore. Although it can be seen that the wastewater outputs are quite small, cumulatively they comprise a significant volume of added water; but their real significance is in the concentrated nature of the pollution contained in them. This pollution is considerably diluted by the link canals by the time the waters reach Baloki. It should be noted that the objective of this exercise was not to define the pollutants added by Lahore, but to go about assessing the effect of this pollution on the waters by the time it is diverted at Baloki to reach the downstream irrigation areas. Such information is of growing importance to irrigation authorities responsible for managing the distribution of water.

January is the one month of the year when no external waters were added to the Ravi. This is when the Pakistan national canal network is closed for annual desilting and essential maintenance of structures. During this critical time the dilution effect is lost and the river is particularly susceptible to high pollution levels.

The flow rates in the canal systems are straightforward, and both show the complete reduction of flow during the January closure period. The data records consulted show, that for the whole period of January, there is completely no flow. It is curious that there is no transition stage as the canal volumes draw down and then refill. This could be expected to take place over a number of days.

The BRBD Canal is a small link canal bringing Chenab water to irrigate the Central Bari Doab Command. The Lahore Canal is a distributary of the BRBD and fulfills recreational and domestic purposes in the centre of Lahore before passing out of the city to bring irrigation water to a relatively small sub-command area in the Raiwind area.

3.2 Electrical conductivity

The Electrical Conductivity (Figure 5) of the River Ravi at both sites remains well within irrigation requirements of 3dS/m throughout the year and could even be described as being of good quality (with respect to salinity). Figure 5a shows a substantial increase in downstream Ravi EC at Baloki during January. This reflects that the salt load is more or less unchanged, but that the dilution from the link canals is not occurring. Using salt as an indicator in this instance shows that the Ravi salinity is emanating in the base load from India.

EC in the canal system can be seen to remain in good condition throughout the year (See Figure 5b).

3.3 Temperature

Water temperature at all sites (Figure 6) increased gradually, but substantially over the 6 months from December leading to summer. During this period both the canal and river systems increased by about 15°C from just over 10°C to just below 30°C. It should be noted that micro-organisms such as bacteria and pathogens are able to proliferate at a much faster rate at higher temperatures.

3.4 Dissolved Oxygen (DO)

By the above criteria, the collected data (Figure 7) seems to show that the DO situation throughout the whole system was already quite badly affected by pollution. The low readings measured at Baloki are indicative of other evidence; such as fish are becoming rare, whereas in previous years they were quite plentiful. This can largely be attributed to the large amounts of sewage that are being added to the system and the large amounts of dissolved oxygen used in the processes of natural remediation to oxidise this organic matter.

This evidence seems also to suggest that there are high organic loads in the canal system, indicative of widespread sewage pollution.

It is suspected that the relatively high readings of DO at the beginning of the monitoring period may have been caused by operational error in not allowing the DO meter to stabilise fully. Confirmatory readings should be carried out. High DO readings would suggest that the organic load is either not so great, or more probably that because of the lower water temperature the oxidation reaction is taking place considerably slower.

3.5 Nitrate

The fact that the nitrate concentrations measured during the monitoring are so much lower than expected levels, raises a question about the accuracy of the nitrate photometer test. The high sediment load may have influenced the photometer readings. The evidence (see Figure 8a) taken at face value indicates that nitrate levels rise and fall by a factor of three during the course of the year cycle from a high of approximately 0.5mg/l (NO_3-N) in January when dilution is low to a level of just under 0.2 mg/l (NO_3-N) for the rest of the year. It would seem that the levels in the canal system stay relatively low throughout the year again at just about 0.2mg/l (NO_3-N).

3.6 Nitrite

Nitrite levels measured in both the river and canal system (See Figures 9a and 9b) indicate quite low, acceptable values. The occasional high points may be spurious, due to use of the equipment at the lower end of its measuring range.

3.7 Ammonia

Ammonia levels recorded in the river system (see Figure 10a) ranged from 0.1 to 1 mg/l (NH_3-N), The site downstream of Lahore was consistently higher, but both the ammonia concentrations measured at both sites were of acceptable level. Concentrations measured at the canal sites (see Figure 10b) were typically 0.2 mg/l (NH_3-N) throughout the year and were also of low concern.

3.8 Phosphates

The phosphate levels measured at all four sites (see Figures 11a and 11b) were all in the range 0.1 to 1 mg/l (PO_4-P) over the year and did not show any seasonal variability.

3.9 Boron

Monitored data on boron concentrations (see Figures 12a and 12b) was started later in the project, and shows that in both the river and canal systems the boron concentrations were acceptable initially in the 0.5 to 1.0 mg/l range during the first half of the year, but then reduced to 0.5mg/l and below.

3.10 Chromium

During this monitoring programme, chromium was measured using the photometer method in terms of chromiumVI (CrVI), chromium III (CrIII) and total chromium content.

Chromium VI concentrations in the River Ravi system and in the Lahore Canal system were found to be at the 0.5mg/l level generally throughout the year (see Figures 13a and 13b). Apart from an unusual reading from the Ravi Syphon site in January, CrVI levels appear to be consistently higher at the Baloki Headworks than at the Ravi Syphon - possibly indicating a slight impact of Cr VI from the industries in Lahore.

Chromium III levels (see Figures 14a and 14b) were also found to be in accord with drinking water standards, and showed consistent levels during the monitoring period.

Measurements of total chromium content (using separate tests) agreed with the characteristics established for the two above specific Cr states (see Figures 15a and 15b).

3.11 Heavy metals

The metalyzer system did not find significant detectable concentrations of at any of the four sites during the whole period of monitoring. The possible reasons for this are:-

(i) The level of heavy pollution from the Lahore area was very low.

(ii) There was sufficient dilution from the waters added to the Ravi to dilute heavy metals in Lahore's effluents down to a non-detectable level.

(iii) Heavy metals emanating from Lahore were adsorbed onto heavier sediment particles and accumulated as deposits on the river bed rather than passing down through system on suspended sediments.

(iv) The relatively untested field kit system was not able to strip the target heavy metals from the suspended sediments to which they were adsorbed and was thus unable to detect them. Normally 90% of the heavy metals are in the sediment-adsorbed phase.

3.12 Faecal coliform

Faecal coliforms proved to be a demanding parameter to measure in the field, mainly because of the requirement to utilise proper laboratory facilities to prepare the petri dishes and other equipment prior to each field trip. Further problems were encountered in the form of sediment clogging of the filter membrane used to isolate the coliforms in the taken sample. Also it proved difficult to regularly prepare the glassware needed to dilute samples down to manageable concentrations. Sorting out these problems took quite some time for the field team to sort out, with the result that it was only late in the programme that more reliable assessments of coliform concentrations became possible. A considerable number of data were recorded by the team as "unaccountable" - this means that the level was so high that the coliform count could not be made. In order to improve the evaluation of the available data, these records were interpreted as having a count of at least a 1000 organisms.

(These data are interpreted in Figures 16a and 16b). Given the measurements made by other workers at Baloki, it can be seen that this estimate is extremely conservative. Their evaluations mention counts of the order of 1,000,000 coliforms per 100ml.

It is unfortunate that more reliable data could not be collected about the coliform concentrations as this appears to have been a key indicator in understanding the pollution characteristics emanating from Lahore. However, had the monitoring phase continued into a second phase the difficulties in carrying out the analytical work could have been resolved and a reliable set of coliform counts could have been built up.

The latter part of the monitoring phase did indicate that the coliform counts at Baloki were of medium significance, and that the readings were slightly higher than those readings from the upstream site at the Ravi Syphon. This indicates two key points. (i) It seems that the river and the added water from the link canals is moderately successful in remediating the bacteria derived from the large sewage disposal into the Ravi at Lahore. Actually the river has 40 Km in which the natural processes of solarization and oxidation can take place. (ii) The low DO levels in the river may well be explained by the large-scale utilisation of dissolved oxygen by the river's biochemical processes to deal with pollution.

4. LABORATORY CROSS-CHECKS

Table A2 gives data collected during 3 spot-checks carried out during the monitoring phase of the case-study. The spot-checks were carried out in collaboration with two separate organisations. At the same time that measurements were made using the WQM field-kits, water samples were collected and returned to the laboratory for analysis.

Comparison of the data indicates that although close correspondence was not achieved, there was sufficient tie-up between the two approaches to have confidence that the WQM method was capable of giving reliable indicative results.
The difference between the DO measurements was unacceptably large. The WQM determinations were found to be incorrectly executed (the DO probe was not being given sufficient time to adjust to the water condition). In fact these particular cross-checks served the purpose of identifying the mistake being made in the DO meter technique and enabled corrective measures to be made.

The difference between the two sets of faecal coliform measurements was also found to be unacceptable. Again this cross-check exercise enabled the problem in technique to be rectified:- (1) clogging of the filter by the high sediment load, and (2) insufficient dilution of the filtrate to enable the bacterial colonies to be separately identified and counted. In the latter part of the monitoring phase, the method used for determining faecal coliform concentration was corrected, however the local staff still had a problem with limited access to suitable laboratory support facilities.

It is important to recognise that the accuracy achieved in these determinations is largely influenced by factors such as operator skill, standard of field-kit preparation and how representative the sampling location is of its surroundings. The actual accuracies of the field-kits provided by the respective manufacturers (see Table 8)_ provide an ultimate target for potential accuracy by uses of the WQM methodology.

Part III

Conclusions and Recommendations

1. CONCLUSIONS

1.1 Application of the WQM methodology in a real situation case-study

The WQM methodology described in the preceding sections, was applied to a typical situation identified in Lahore, Pakistan. Details of this application were presented in Part II.

The case-study demonstrated the feasibility of setting up the WQM methodology and encouraging local water organisations to take it up and apply it. It also helped to identify the difficulties faced by such organisations in carrying out this work. Even though the procedure is formulated with the intention of reducing the difficulty and expense of carrying out water quality monitoring, it does not completely resolve such problems. For the technique to function successfully, there will need to be, in any future applications, provision of sufficient resource so that needs such as logistic requirements and training programmes, are adequately catered for.

1.2 Role for WQM Methodology

The Water Quality Monitoring methodology is a consistent and appropriate strategy that managers in the water resource departments of developing countries can use in preparing water quality monitoring programmes, in irrigated agriculture areas.

Such managers are increasingly required to deal with water quality problems, either as water is delivered into their project area or as it leaves and proceeds to the next downstream user area. Until recently, they have had only to concentrate on water quantities. However the increased need to use lower quality water, the increased use of agrochemicals and the increased awareness of environmental impacts are all impelling irrigation management authorities to pay greater attention to water quality issues. Furthermore, they are increasingly required to show responsibility for the quality of water they pass on to further users downstream.

Very little water quality information is available to them. With the rapid deteriorations taking place at present in the quality of water resources, there is a strong imperative to implement monitoring programmes that can quickly provide information on at least the basic trends.

In trying to carry out environmental monitoring, water departments face a number of problems:-

- The instrumentation commonly specified by environmental authorities is generally sophisticated and expensive. Because of the large variety of pollution parameters a wide range of instrumentation is needed. In order to use this instrumentation and to provide the tactical support needed a cadre of specialists is needed.

- The samples have to be collected from remote areas and returned to central laboratory. This inevitably creates errors due to degeneration of the samples. It also means that there is a time delay introduced, as the samples may take several weeks to be processed. The release of the information can therefore be considerably delayed, it is unlikely to reach the people in the area where the sample was taken, and as such there is no possibility for the water authorities to make a prompt tactical response to any pollution detected.

- The Environmental authorities where they do exist, are often overwhelmed by urgent needs and although they have much data, may not make it readily available.

- Little is known about the exact needs of local managers.

The management authorities of water resource and irrigation systems are quite separate from the environmental authorities and if they are to understand the water quality trends in their own water delivery systems, and identify for themselves current pollution trends, so they can use their water more effectively, then they need access to more targeted information. In this respect they need steps for themselves to implement action. Furthermore they need to harness the information by processing it so that the results can be used in a useful and appropriate way.

The WQM Methodology presented in this report can be used by irrigation and water resource managers in conjunction with local environmental pollution experts. The strategy enables results, obtained using simple, field-kit techniques, to be readily understood, and their significance compared with national and international standards. The results are also available "on-the-spot", so the departmental team-members who take the measurements can assess their significance straight away and take any appropriate action immediately.

Use of the WQM methodology and the associated data-processing procedures will help Irrigation and Water Resource Departments to build up their own understanding of their pollution problems. It will instill knowledge of national and international water quality standards, and act as a training tool for local staff.

1.3 Assessment of WQM Methodology

Suitability

In general terms, the WQM Methodology was found to work adequately in principle. When field-tested on the Lahore case-study it produced useful data with minimal input by the local technical staff involved. Certain tactical difficulties were encountered at various times, such as restricted availability of transport and particular laboratory facilities, but were overcome during the testing period. Within a short time inexperienced staff became conversant with the requirements of the WQM methodology and were in a position to undertake reliable regular monitoring.

Field visits

In order for the WQM methodology to work effectively, visits to the field sites need to be reliable and regular. Even a relatively inexpensive water quality monitoring technique such as the one proposed requires commitment and an adequate level of resources to be made available, which may be a constraint in the difficult financial situation faced by Pakistan and many other developing countries.

Ease of carrying out tests

One of the main lessons learnt was that on-the-spot tests were easy to do if they involved simple and quick procedures. Those that required significant time, such as the colour development procedures needed for the photometer tests, and other slightly complicated procedures proved difficult to complete adequately within the compressed schedule of a regular visiting schedule. The tests that can be most effectively carried out are those that simply involve inserting a probe into the water and reading the display. These include basic measurements such as EC, DO, pH, temperature and heavy metals concentration.

It was also shown that for the methodology to operate effectively, facilities were needed in addition to the instrumentation and direct support equipment provided. These comprised electricity for battery recharge, distilled water and facilities to clean the instrument glassware and the microbiological equipment.

With these points in mind, the methodology could be improved in some applications, if some of the longer duration tests were completed back at base. This would only be possible for transportable samples. This, if called for, would be a pragmatic response to practical difficulties faced in D.C.'s, and would not negate the WQM approach. The advantage of this improvement would be to decouple the rush to visit sites and complete the field programme, from the more important objective of working through the analytical procedures in an accurate and consistent manner. The methodology could also be improved if the organisation executing the WQM study had basic wet laboratory facilities available.

Biological indicators

The study was not able to evaluate the use of biological indicators. Using the response of organisms living in the water for indication of water pollutant trends has the benefit of the integrating nature of the organisms moving through large amounts of water. It would also be valuable to investigate other similar procedures that could possibly have been utilised, e.g. colilert tests, pollutant selective electrodes, etc.

Use of water flow records

The water discharge characteristic is a parameter that adds significantly to the understanding of water quality processes. It enables observed variations in water quality parameters to be rationalised. For this reason it is recommended that sampling sites should be established, as far as possible, at existing flow gauging sites, especially since these are inevitably located at key control and surveillance points within the system.

Predefinition of water quality variables to be monitored

It is important to define what answers are needed before commencing on the study and purchasing the equipment needed. To a certain extent some parameters such as EC and DO will always be important for a given situation. The definition of the parameters needed should involve a local environmental expert who will be able to identify the pollution parameters that should be selected for the purposes of the study. For the study at Lahore, extensive preparatory discussion and work was carried out with officials from the Punjab Government's Environmental Protection Department.

Groundwater monitoring

Groundwater resources are of prime interest in the provision of water supplies, especially because of growing shortages in water resources. The WQM methodology is suitable for the analysis of groundwater quality (with the exception of Dissolved Oxygen content – see Section 6.3).

1.4 Lessons learned

Lahore case-study field-test

The WQM methodology functioned reasonably well, given the difficulties of carrying out the measurements. The information obtained in the initial one-year period gave an approximate indication of information so that the main processes and water quality priorities relevant to the water system at Lahore. Although the measurement programme was significantly constrained by the difficulties faced by the local monitoring team in reading the sampling points at regular intervals and by the lack of back-up laboratory facilities, the technique standard improved through the monitoring phase. By the end of the phase the counterpart staff had improved their understanding of how the WQM techniques should be used, and would have been in a good position to provide higher standard data if the monitoring exercise had been part of a longterm programme. With the limited information collected, it is possible to see that sewage disposal is a dominant issue both in terms of the high bacteriological content in the river and the high inherent risk of passing on disease. It can also be seen that the oxygen levels are low as the river tries to deal with the high pollution load that has been introduced into it.

The data also showed that water quality problems, particularly for industrial pollution, were less severe than expected. This shows that the dilution effects on which the river system has relied are still valid. However, to understand the process and to identify the long-term trends therein, there is an urgent need for a systematic water quality monitoring programme to be initiated. This should be in conjunction with the existing data acquisition programmes carried out on flow.

<u>Issues to be resolved</u>

1. Measurements of suspended sediment (TSS) should have been included in the list of parameters to be monitored in this field-test. TSS has a strong effect in constraining the growth of aquatic plants and related eco-systems, as well as in the transport of adsorbed heavy metals and pesticides. The information is also of interest in understanding sediment deposition and soil erosion processes in the catchment. However, the measurement of TSS is a laboratory technique, and the related portable technique using a turbidity meter is difficult to use at the high sediment concentrations encountered in the Ravi system.

2. In order for the WQM methodology to be fully effective, the field visit programme needs to have a reliable visit programme with a project vehicle assigned. This may be a problem for departments in Developing Countries that have severe constraints on available transport. An alternative approach, but potentially of higher net expense, would be to deploy a field-kit set at each site.

3. There is a need for a PC computer system to be provided so the data-base can be effectively used. The HYQUAL system performed adequately and seemed to have most of the flexibility required. However a major shortcoming was its inability to allow the user to visualise flows. Also keying in data was an intensive operation.

4. Interaction with local environmental experts is important if the WQM methodology is to be successfully employed.

2. RECOMMENDATIONS

2.1 Demand for WQM

There is growing awareness of increasing levels of pollution and consequent reduction of water quality in rivers and water distribution systems. This is a global trend that is taking place against a backdrop of declining reserves of water. The awareness appears to permeate all levels of society. In western countries there are strict and effective mechanisms already in place to monitor and control the problem. Why is this not the case in Developing Countries?

The answer seems to be in the availability and prioritisation of suitable resources. This is a profound problem in the governmental agencies of many Developing Countries since they are strong influenced from a professional point-of-view to favour the high technology approach used in developed countries, and this approach is both very expensive to set up and very demanding to maintain. D.C. governments have been able to set up Environmental Laboratories or Authorities using a range of financing opportunities when they have become available.

The immediate difficulty faced by such bodies is the high running cost of maintaining sophisticated instrumentation and retaining highly qualified staff. The more chronic problems are the scale of the environmental pollution faced, the large call on their services for just a few of these pollution problems and the lack of compliance and regulatory enforcement which makes it difficult for any progress to be made.

Water is a pivotal issue in all Developing Countries, and is one of the first resources to be affected by pollution problems. But the authorities responsible for managing and distributing the water are not the same as those responsible for environmental monitoring. They tend to be powerful departments and are focused on domestic issues such as ensuring that water distribution policies are carried out. Dealing with water pollution problems is not really one of their objectives, and the responsibility is left to the relatively weak environmental protection authorities. This means that water departments generally have not developed water pollution monitoring capability.

Thus although everyone may be convinced about the existence of water pollution problems, and the need to introduce controls, little effective action is taking place and little is likely to happen. The staff in water departments are as aware as anyone else of the problems, which in some countries are quite profound and critical. What appears to be required in order to improve the rapidly declining situation is either major investment to make environmental authorities more effective, or to introduce some inexpensive environmental monitoring techniques that can be implemented within water departments and provide information about water quality trends (albeit not as accurately as professional laboratories).

The main recommendation of this report is to propose the Water Quality Monitoring Methodology as an appropriate and relatively inexpensive mechanism that can enable a series of simple water quality data to be collected, and a quick, reasonably reliable understanding of local water quality trends to be made.

During the course of the case-study field-testing, interest in utilising the technique was shown by responsible organisations in WAPDA, by the Punjab Irrigation Department and by the provincial EPAs (Environmental Protection Agencies) who saw the WQM methodology as a means to improve their functioning above and beyond their existing resources. In the preparatory phase of this project, discussions were held with Irrigation Departments in India (Tamil Nadu and Gujerat), Egypt and South Africa. All expressed their interest in utilising the WQM methodology. In India the technique was seen as means to improve the outreach of the existing Pollution Control Boards. In Egypt the Operations Department of the Ministry of Public Works and Water Resources could see an application for them in real-time monitoring of main drains prior to their water being recycled at Reuse Pumping Stations. This could be integrated into the sophisticated system that is to be introduced as the NWRC Environmental Quality Laboratory. In South Africa, although a conventional sophisticated system is in existence there is a need to provide monitoring facilities to local government in the widespread rural areas. This need is particularly underlined by the recent Water Act legislation which requires local communities to be empowered with responsibility for the use and safe disposal of water resources. It is anticipated that the situation in South Africa reflects a move towards greater self-regulations at local level throughout the other countries in the region. Applications can be envisaged in many other countries with a range of different environmental problems, but with a requirement for practical, inexpensive procedures in place of impossibly demanding sophisticated techniques. These would include Eastern Europe and the Former Soviet Union as well as the conventional list of less developed countries.

2.2 Implementation of WQM Methodology

Agencies, or authorities, considering to monitor water quality will need to examine a number of internal factors:

(i) **Economics** – the cost of establishing the WQM field-kit methodology is considerably less expensive that settling up and running a conventional water quality laboratory;

(ii) **Accuracy** – the WQM methodology gives lower accuracies and will not be sufficient for legal enforcement of polluters, but it will give sufficient information about whether or not a certain type of pollution is occurring at a location and what the trend is.

(iii) **Reliability** – the certainty of WQM methodology results will never be as complete as laboratory determinations, however whether or not samples are regularly taken becomes an internal matter for the executing department, it is not dependent on staff from another department.

(iv) **Communications** – The WQM methodology gives results immediately on-the-spot and these are available to local management. The communications associated with laboratory analysis are notoriously difficult, due to the time taken to send to the laboratory, the possible delay by he laboratory in processing the batch and the time taken to send the results back. Additionally the lab results do not necessarily go to the staff that were responsible for collecting the sample and this engenders a lack of interest in the point of the measurement.

(v) **Data-processing/decision-making** Staff with on-the-spot measurements can intercede immediately to help deal with pollution problems just observed. At a higher level it is important that the data collected is not just stored but is also processed. This will enable essential information such as whether a certain parameter meets legal requirements, or whether a long-term or seasonal trend is discernible. The graphical out put of such information to senior management can lead to informed decisions being made in advance of, and avoiding, pollution crisis situations.

Implementation of water quality monitoring also involves consideration of factors external to the executing authority. Certainly there are considerable social, economic and health benefits to be gained by a water department that introduces such a programme. Additionally, the spin-off from the programme can be to promote greater awareness of pollution and public health issues amongst the local population, who may themselves be contributing to the problem.

2.3 Strategies for using the WQM Methodology

(i) WQM alone

At the lowest level the WQM approach can be launched in isolation, with the objective of providing the executing department with simple facts. This will provide simple, but approximate overview of the local situation. However, the full cost of setting up and running a laboratory, or of expensive processing by a commercial laboratory, are obviated.

(ii) WQM plus occasional link to laboratory

In order to transform the above results into information that is considerably more reliable, it will be necessary for the WQM programme to establish a link with a local, capable environmental laboratory. As well as providing the necessary cross-checking of results the laboratory can also contribute the expert guidance needed to plan out the programme and to help in checking that the correct conclusions are drawn.

(iii) WQM plus laboratory

A logical progression of the WQM approach is for the programme (or programmes) set up to act as an outreach for the environmental laboratory, especially if it is functioning under restricted conditions. In this way the physical monitoring would act as a surveillance network for the laboratory, and provides indication of trends and the location of serious problems which the laboratory had better get involved in. This would enable the laboratory to avoid mundane monitoring and focus its specialist staff on the priority pollution problems.

2.4 Needs for further work

As described in this report, the WQM methodology is ready to be applied. In particular it is intended for use in helping Irrigation and Water Departments to start to quantify the water quality processes taking place within the water resources in their jurisdiction. Thus it could be utilised within existing departmental structures or introduced as part of technical co-operation projects.

It can be adapted to meet the requirements of other water users, e.g. groundwater abstraction and water supply. However in this circumstance the achievable accuracies and applicability would need to be checked in order to make sure that the information was of acceptable standard. In particular, the water quality standards for drinking water are quite demanding in many respects, and the technique could be used only for approximate assurance of acceptability.

It is important to point out, in conclusion, that the WQM methodology has only become feasible thanks to the development of portable field-kits. There is high expectation that the series of improvements will continue in the future, with the result that field-kits may become more accurate, less expensive, more reliable and suitable for use with an increased range of parameters. Furthermore it is also reasonable to look to progress in other related fields to help in this advance. In particular the use of biological macro-organisms and micro-organisms for water quality monitoring is seen as a promising approach that would be virtually free as well as being available to wide sections of local communities.

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Tables

Table 1 Environmental parameters significant to water quality

Environmental parameter	Description	Principal sources	Importance to irrigation	Importance to Water Supply	Importance to Eco-system	Field-kit available?
General variables						
Total dissolved solids Electrical conductivity	(TDS) Concentration of solids soluble in water (mg/l) EC is an easily measured indicator of salinity (dS/m)	Rock and soil leachate	✓✓✓	✓	✓	EC meter
Dissolved oxygen (DO)	Concentration of oxygen present - low levels indicate high organic pollution	Percentage reduction of DO indicates the degree of organic pollution	✓	✓	✓✓✓	DO probes
Acidity (pH)	Acidity or alkalinity of water depends on the hydrogen ion activity.	Natural balance can be altered by effluents	✓✓	✓	✓✓	pH meter
Total suspended solids	TSS is the concentration of suspended sediment, algae etc.	Erodibility of catchment soils	-	✓✓✓	✓✓✓	✗
Turbidity	Cloudiness is a highly sensitive indicator of the effects of TSS, algae, bubbles, etc. – Important indicator for acceptability of drinking water	Algal growth indicates excess nutrients	-	✓✓	✓✓	Turbidity meter
Temperature	Effects the rate of biochemical processes in the water body	Climate is the strongest effect, but hot springs or industrial thermal discharges (e.g. cooling water)	-	-	✓✓✓	Temp probe-thermometer
Nutrients						
Ammonia Nitrates/nitrites Phosphates	High levels of nutrients promote algal plant growth in water bodies, which may cause oxygen depletion as the result of respiration and decay processes of fast growing plant populations	Excess application of fertilisers and runoff from animal feed-lots	- - -	✓ ✓✓✓ -	✓✓✓ ✓✓ -	Colour photometer
Organic matter						
BOD	Biochemical oxygen demand – the amount of bio-degradable matter is measured by the amount of water needed to complete its oxidation	Total organic matter measured above and below a sewage or industrial discharge can indicate the degree of pollution caused	-	✓✓	✓✓✓	✗
COD	Chemical oxygen demand gives a measure of the amount of organic material by means of a strong oxidising agent		-	-	✓✓	✗
TOC	Total organic carbon content is the organic material present, measured by direct analysis of the carbon		-	✓	-	✗

Table 1 (continued)

Environmental parameter	Description	Principal sources	Importance to irrigation	Importance to Water Supply	Importance to Eco-system	Field-kit available?
Major Ions						
Sodium Magnesioum Calcium Chloride Sulphate	Excess quantities of major ions are responsible for salinization of soils. Sodium is particularly dangerous when used to irrigate heavy clay soils since it reduces the stability of the soil particles and causes physical degradation (sodicity). Calcium and magnesioum counteract sodicity	Rock and soil leachates	✓✓✓ - ✓ ✓✓✓ 	✓ ✓ - ✓ ✓	- - - - -	Colour photometer
Carbonates	Carbonates and bicarbonates influence alkalinity and sodicity		✓	✓	-	
Trace elements	Trace elements can be selectively toxic to animal and plant life if there is an excess (or shortfall) of them compared to normal background concentrations	Trace elements originate from weathering of rocks and soil, but can be increased by sewage, industrial and mining effluents. They can also be increased by removal of natural elimination processes				
Heavy metals: Copper, Lead, Cadmium, Chromium, Mercury, etc.	Accumulation in the food chain causes hazard at all levels in the eco-system		✓	✓✓✓	✓✓	ASV for heavy metals and
Non-metals: Boron, Arsenic, Fluoride	Certain elements can have direct toxic effects, such as arsenic. Others consumed over period of time cause illnesses such as cancers.		✓✓ ✓	✓ ✓✓	✓ ✓✓	Colour photometer
Simple organic contaminants						
Hydrocarbons	Oil and petroleum compounds (800 identified) are major pollutants responsible for ecological damage	Industrial effluents and tanker spills	✓	✓✓	✓	✕
Phenols	Phenols have direct toxic effects on aquatic organisms and reduce oxygen availability	Industrial effluents	-	✓✓	✓✓	✓
Surfactants	Detergents are the principal surfactant and their foam enables pathogens to concentrate and reduces aeration and therefore slows self-purification	Industrial and household wastewaters	-	✓	✓	✓

Table 1 (Continued)

Environmental parameter	Description	Principal sources	Importance to irrigation	Importance to Water Supply	Importance to Eco-system	Field-kit available?
Complex organic contaminants						
Pesticides	Any detectable concentration indicates pollution. Over 10,000 different forms are known to exist. Some are biodegradable and safe, others are persistent and profoundly unsafe	Mishandling of agrochemicals and mobilisation of soil particles during rain	-	✓✓	✓✓	ELISA kit
PCBs	Polychlorinated biphenyls are a persistent and accumulating pollutant	Industrial effluents	-	✓✓	✓✓	ELISA kit
Microbiological organisms						
Coliform bacteria	Bacteria originating in the gut, can in raw sewage contain 10-100 million bacteria per 100ml	Sewage and animals wastes	✓✓✓	✓✓✓	-	Portable incubator
Pathogens	Viruses and other dangerous bacteria occur in very much smaller frequencies, but finding coliforms gives warning that they may be present. Other pathogenic or debilitating organisms that can occur include helminths and parasitical worms	Sewage and animal wastes, and interaction of parasitical cycle	✓✓	✓✓✓	-	✗
Cyanobacterial toxins	Cyanobacteria such as blue-green algae release toxins which during population explosions reach dangerous levels	Result of high nutrient loads	-	✓	✓✓	✗
Other						
Radio-nuclides	Hazardous and bio-accumulating	Nuclear industry effluents, also occasionally due to natural causes	✓	✓✓✓	✓	Geiger meter

Includes information from Chapman (1996) Tables 34.1 and 3.7

Table 2 Types of water quality assessments

OPERATION:	IDENTIFIES:
Background monitoring	Natural levels (reference for assessing impacts)
Preliminary surveys	Which parameters will need to be monitored
Emergency surveys	Rapid assessment following major incident
Impact surveys	Limited sampling near source
Modelling surveys	Intensive monitoring of real situation
Early warning surveillance	Continued acceptability check

Source: GEMS (1991)

Table 3 Summary of field kit costs

Determinand	Field Kit	Purchase Cost	Training Needs	Special Requirements	Cost per sample
General Determinands					
Dissolved Oxygen (DO)	DO/Temp. Meter	£380	None	None	£0.10
	Photometer*	£500	Low	Dist. Water/Batteries	£2.00
pH	PH/Temp. Meter*	£210	None	None	£0.10
	Photometer	£500	Low	Dist. Water/Batteries	£0.10
Turbidity	Turbidity Meter*	£500	None	None	£0.10
Micro-Organisms					
Total and Faecal Coliforms	ELE Paqualab Incubator and MFU*	£1,030	Low	Dist. Water/Batteries	£0.50
	MUG Reagent Tubes Incubator + UV lamp	£700	Low	Batteries	
Ions					
Electrical Conductivity	Conductivity/ Temp. Meter*	£250	None	None	
Sulphate, Nitrite, Nitrate, Phosphate, Ammonia, Chloride	Photometer*	£500	Low	Dist. Water/Batteries	£0.15-0.40
	Reagent & Colour Chart	-	Minimal	Distilled Water	£0.30
Pesticides					
Organochlorines#	Immunoassay Test With Photometer	£1,400	Low	Dist. Water/Batteries Protective Clothing	£10.00
Carbamates, Organ-ophosphorous#	Non-immunoassay Test with Photometer	£1,400	Low	Dist. Water/Batteries Protective Clothing	£10.00
Triazines#	Immunoassay Test With Photometer	£1,400	Low	Dist. Water/Batteries Protective Clothing	£10.00
Exotics					
Total Petroleum Hydrocarbons (TPH), Polychlorinated Biphenyl (PCB), Polycyclic Aromatic Hydrocarbons (PAH)	Immunoassay Test With Photometer	£1,400	Some – Sampling Handling	Protective Clothing Calibrations Distilled Water	£25.00
Phenols	Photometer*	£500	Low	Dist. Water/Batteries	£1.00
	Reagent, Colour Chart	£25	Minimal	Distilled Water	£8.00
Detergents (anionic)	Reagent, Colour Chart	-	Low	Distilled Water	£8.00
Trace Metals					
Boron, Cadmium, Chromium (III, VI), Copper, Lead, Zinc	Photometer*	£500	Low	Dist. Water/Batteries	£0.45-0.55
	Reagent, Colour Chart	-	Minimal	Distilled Water	
Cadmium, Copper, Zinc, Lead	ETG Metalyzer	US$4,200	Minimal	Mains Recharge	US$15.00
Copper Lead	Scanning Analyser Stripping voltammetry)	£1,650	Minimal	Mains Recharge	£4.50
Mercury	Voltammetric/Polar-Ographic Analyser**	DM25,000	Medium**	Some pre-treatment may be needed	

Table 4 Summary of commercial laboratory costs

Determinand	Laboratory test	Cost per Sample*
General Determinands Biochemical Oxygen Demand	Potentiometry	£4.00
Dissolved Oxygen (DO)	Titrimetry	£4.00
PH	PH Meter	£0.50
Turbidity	Turbidity Meter	£1.50
Micro-Organisms Total and Faecal Coliforms	Most Probable Number/Membrane Filtration	£8.00
Ions Electrical Conductivity	Potentiometry	£0.50
Sulphate Nitrite Nitrate Phosphorus Ammoniacal Nitrogen Chlorine	Colorimetry	£8.50
Pesticides Organochlorine Pesticides	Gas Chromatography/Mass Spectrometry	£50.00
Exotics Detergents, NVM, Phenols	Colorimetry/Gravimetry	£43.00
Trace Metals Boron Copper Chromium III Cadmium Zinc Lead	Inductively Couple Plasma	£12.00
Chromium VI	Colorimetry	
Mercury	Cold Vapour Atomic Fluorescence	£11.50

Notes:
These approximate costs are based on the assumption that there are 10 sampling sites, with samples collected on a monthly basis.
Sources:
Severn Trent Laboratories, Water Quality Centre, North-West Laboratories.

Table 5 Comparison of testing costs for selected determinands

a) Determinand: Dissolved Oxygen

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	DO/Temp Meter	£380	None	Batteries Distilled Water	£0.10
	Photometer*	£500	Low	Batteries	£2.00
Laboratory Instrument	Dissolved Oxygen Meter		None	Should be Measured On-Site	
Commercial Laboratory	Titrimetry	-	-	-	£4.00

b) Determinand: Total and Faecal Coliforms

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	ELE Paqualab Incubator and MFU*	£1,030	Low	Distilled Water Batteries Serial Dilutions	£0.50
	MUG Reagent Tubes, Incubator + UV Lamp	£700	Low	?	
Laboratory Instrument					
Commercial Laboratory	Most Probable Number/Membrane Filtration	-	-	-	£8.00

c) Determinand: Ions (Sulphate, Nitrite, Nitrate, Phosphate, Ammonia, Chloride)

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	Photometer	£500	Low	Dist. Water/Batteries	£0.50
	Reagent & Colour Chart	-	Minimal	Distilled Water	£0.30
Laboratory Instrument					
Commercial Laboratory	Colorimetry	-	-	-	£8.50

Table 5 (continued)

d) Determinand: Organochlorine Pesticides

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	Immunoassay Test with Photometer	£500	Low	Dist. Water/Batteries	£10.00
Laboratory Instrument					
Commercial Laboratory	Gas Chromatography/ Mass Spectrometry	-	-	-	£50.00

e) Determinand: Detergents (Anionic)

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	Reagent, Colour Chart	-	Low	Distilled Water	£8.00
Laboratory Instrument					
Commercial Laboratory	Colorimetry/Gravimetry	-	-	-	£43.00

f) Determinand: Trace Metals (Boron, Cadmium, Chromium (III and VI), Copper, Lead, Zinc)

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	Photometer*	£500	Low	Distilled Water/Batteries	£0.45-0.55
	Reagent, Colour Chart	-	Minimal	Distilled Water	£0.45-0.55
	ETG Mtalyzer (Cd, Cu, Zn, Pb only	US$4,200	Minimal	Mains Recharge	US$15.00
	Scanning Analyser (Cu, Pb only)	£1,650	Minimal	Mains Recharge	£4.40
Laboratory Instrument					
Commercial Laboratory	Inductively Coupled Plasma/Colorimetry	-	-	-	£12.00

g) Determinand: Mercury

	Method	Purchase Cost	Training Needs	Special Requirements	Cost per Sample
Field Kit	Voltammetric/Polar-ographic Analyzer**	DM25,000	Medium**	Some pretreatment may be needed	?
Laboratory Instrument					
Commercial Laboratory	Cold Vapour Atomic Fluorescence	-	-	-	£11.50

Table 6 Sources of main pollutants found in surface-waters

SOURCES

	Atmosphere	Point sources		Non-Point sources			Mixed sources	
Pollutants		**Sewage**	**Industrial effluents**	**Agricultural effluents**	**Dredging**	**Shipping**	**Urban wastes**	**Industrial wastes**
Bacteria/ Pathogens	-	xxx	-	xxx	-	x	xx	-
Nutrients	x	xxx	x	xxx	x	x	xx	-
Trace elements	xxx	xxx	xxx	x	xxx	xx	xxx	xxx
Biocides	xxx	x	-	xxx	xx	-	xx	x
Industrial pollutants	xxx	xxx	xxx	-	xxx	x	xx	xxx
Oils	-	-	xx	-	x	xxx	xx	x

(Adapted from Chapman, 1996)

Table 7 Examples of maximum allowable concentrations of selected water quality variables for different uses

Use	Drinking water					Fisheries and aquatic life		
	WHO[1]	**EU**	**Canada**	**USA**	**Russia**[2]	**EU**	**Canada**[1]	**Russia**
Variable								
Colour (TCU)	15	20 mg 1^{-1} Pt-Co	15	15				
Total dissolved solids ($mg1^{-1}$)	1,000		500	500				
Total suspended solids (mg 1^{-1})						25	10[(3)]	
Turbidity (NTU)	5	4 JTU	5	0.5-1.0				
PH	<8.0[4]	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5		6.0 - 9.0	6.5 - 9.0	
Dissolved oxygen (mg 1^{-1})					4.0	5.0 - 9.0	5.0 - 9.5	4.0[5] - 6.0[3]
Ammoniacal nitrogen (mg 1^{-1})					2.0	0.005 – 0.025	1.37 – 2.2[6,7]	0.05
Ammonium (mg 1^{-1})		0.5			2.0	0.04 – 1.0		0.5
Nitrate as N (mg 1^{-1})			10	10				
Nitrate (mg 1^{-1})	50	50			45			40
Nitrite as N (mg 1^{-1})			1.0					
Nitrite (mg 1^{-1})	3.0 (provisional)	0.1			3.0	0.01 – 0.03	0.06	0.08
Phosphorus (mg 1^{-1})		5.0						
BOD (mg 1^{-1} 0_2)					3.0	3.0 – 6.0		3.0
Sodium (mg 1^{-1})	200	150						120
Chloride (mg 1^{-1})	250	25[1]	250	250	350			300
Chlorine (mg l^{-1})	5.0						0.002	
Sulphate (mg 1^{-1})	250	250	500	250	500			100
Sulphide (mg 1^{-1})			0.05					
Fluoride (mg 1^{-1})	1.5	1.5	1.5	2.0	<1.5			0.75
Boron (mg 1^{-1})	0.3	1.0[1]	5.0		0.3			
Cyanide (mg 1^{-1})	0.7	0.5	0.2	0.2 (proposed)	0.07		0.005	0.05
Trace elements								
Aluminium ($mg1^{-1}$)	0.2	0.2			0.5		0.005-0.1[7]	
Arsenic (mg 1^{-1})	0.01 (provisional)	0.05	0.05	0.05	0.01		0.05	
Barium ($mg1^{-1}$)	0.7	0.1[1]	1.0	2.0	0.7			
Cadmium (mg 1^{-1})	0.003	0.005	0.005	0.005	0.003		0.0002-0.0018[8]	0.005
Chromium (mg 1^{-1})	0.05 (provisional)	0.05	0.05	0.1	0.05		0.02-0.002	0.02-0.005
Cobalt (mg 1^{-1})					0.1			0.01
Copper (mg 1^{-1})	2.0 (provisional)	0.1[1]-3.0[1]	1.0	1.0	2.0	0.005-0.112[8,9]	0.002-0.004[8]	0.001
Iron ($mg1^{-1}$)	0.3	0.2	0.3	0.3	0.3		0.3	0.1

Table 7 (Continued)

Use	Drinking water					Fisheries and aquatic life		
	WHO[1]	**EU**	**Canada**	**USA**	**Russia**[2]	**EU**	**Canada**[1]	**Russia**
Variable								
Lead (mgl^{-1})	0.01	0.05	0.05	0.015	0.01		0.001-0.007[7]	0.03
Manganese ($mg1^{-1}$)	0.5 (provisional)	0.05	0.05	0.05	0.5			0.01
Mercury ($mg1^{-1}$)	0.001	0.001	0.001	0.002	0.001		0.0001	0.00001
Nickel ($mg1^{-1}$)	0.02	0.05			0.02		0.025-0.15[8]	0.01
Selenium ($mg1^{-1}$)	0.01	0.01	0.01	0.05	0.01		0.001	0.0016
Zinc ($mg1^{-1}$)	3.0	0.01-5.0[1]	5.0	5.0	5.0	0.03-2.0[8,10]	0.03	0.01
Organic contaminants								
Oil and Petroleum products ($mg1^{-1}$)		0.01			0.1			0.05
Total pesticides ($\mu g1^{-1}$)		0.5	100					
Aldrin & dieldrin ($\mu g1^{-1}$)	0.03		0.7				0.004 (dieldrin)	
DDT ($\mu g1^{-1}$)	2.0		30.0				0.001	
Lindane ($\mu g1^{-1}$)	3		4.0		2.0			
Methoxychlor ($\mu g1^{-1}$)	30		100	100				
Benzena ($\mu g1^{-1}$)	10		5.0				300	
HCH=Hexachlorobenzene ($\mu g1^{-1}$)	0.01							
Pentachlorophenol ($\mu g1^{-1}$)	9 (provisional)			10	10			
Phenols ($\mu g1^{-1}$)		0.5	2.0		1.0		1.0	1.0
Detergents ($\mu g1^{-1}$)		0.2		0.5[12]	0.5			0.1
Microbiological variables								
Faecal coliforms (No. per 100 ml)	0	0	0		0			
Coliforms (No. per 100 ml)	0			1				

Reproduced from Chapman (1996) Table 4

WHO World Health Organisation
EU European Union
BOD Biochemical oxygen demand
TCU True colour units
NTU Nephelometric turbidity units
1 Guideline value
2 Some values not yet adopted but already applied
3 Above background concentrations of ≤100mg l^{-1}, or > 100 mg l^{-1}, respectively
4 For effective disinfection with chlorine
5 Lower level acceptable under ice cover
6 Total ammonia
7 Depending on pH
8 Depending on hardness
9 Dissolved only
10 Total zinc
11 For some groups values are also set for individual components
12 Foaming agents
13 For a single sample

Sources: Environment Canada, 1987
CEC, 1978, 1980
Committee for Fisheries, 1988
Gray, 1994
WHO, 1984a

Table 8 Potential range and accuracy of WQM field kit instrumentation

Parameter	Field kit	Range (Manufacturer's data)	Accuracy (Manufacturers data)
Temperature	Temperature probe	0 to 50 C^o	±0.5%
Electrical Conductivity	EC meter	0 to 20 dS/m 0 to dS/m	±1.5% ±0.5%
pH	pH meter	0 to 14.00 pH	±0.02 pH
Dissolved Oxygen	DO meter	0 to 19.9 mg/1	±2% fsd
Nitrite	Photometer	0 to 0.5 mg/1 0 to 1.6 mg/1	± 5%
Nitrate	Photometer	0 to 1 mg/1 0 to 20 mg/1	± 5%
Phosphorus	Photometer	0 to 4.0 mg/1	± 5%
Ammonia	Photometer	0 to 1.0 mg/1	± 5%
Chlorine	Photometer	0 to 5.0 mg/1	± 5%
Chromium	Photometer	0 to 1.0 mg/1	± 5%
Copper	Photometer	0 to 5.0 mg/1	± 5%
Nickel	Photometer	0 to 10 mg/1	± 5%
Iron	Photometer	0 to 5.0 mg/1	± 5%
Manganese	Photometer	0 to 0.030 mg/1	± 5%
Zinc	Photometer	0 to 4.0 mg/1	± 5%

Table 9 Comparison of Water Quality standards and observed effluents in Pakistan

	National * Effluent Standard	Observed ** Effluent range-textiles	Observed ** Effluent range-Leather tanning	Observed** Effluent range-electroplating
Dissolved solids mg/1	3500 (municipal) 500(irrigation)	910 - 7780	18400-34765	1150-3940
Suspended solids mg/1	150	50-1200	1040-1700	180-715
Acids/alkalis pH	6-10 (municipal 7-8.5 (irrigation)	4.1-12.4	3.5-12.5	2.4-10.4
Organic matter (as BOD5)	80	152-2150	1400-4900	
Liquids and floating solids 10 mg/1	10	5-50 (Ghee)		
Toxic elements mg/l	1		20-300	2-20
Oxidising/reducing Agents mg/1	1		50-500	
Pathogenic Organisms Cfu/100ml	0 municipal 1000 irrigation			

* Ref: National standards
* Ref: EPA (1995)

Table 10 Cross-check between WQM readings and laboratory analysis of samples

	River Ravi at upstream sampling point				River Ravi at downstream sampling point			
	Date: 17/3/97		Date: 9/4/97		Date: 18/3/97		Date 10/4/97	
	WQM	IEER	WQM	IEER	WQM	IEER	WQM	IEER
EC (dS/m)	291	305	234	180	344	290	269	255
Temperature (°C)	21.3	22.0	23.7	24.3	17.7	18.3	23.1	22.3
Ammonia (mg/l)	0.08	0.0	0.87	0.0	1.5	0.0	0.8	0.0
Nitrate (mg/l)	0.1	<1.0	0.03	<1.0	0.11	<1.0	0.04	<1.0
Phosphate (mg/l)	0.16	0.45	0.75	0.34	0.48	0.57	0.64	0.34
Dissolved oxygen (mg/l)	9.2	6.2	3.3	6.5	2.8	5.2	23.9	5.6
Faecal coliforms (cfm/100ml)	30	18x10^{3}	540	29x1^{3}	-	15x10^{3}	-	29x103
	Date: 1/1/97				Date 1/1/97			
	WQM	EPD			WQM	EPD		
EC (dS/m)	382	390			566	580		
pH	7.8	8.0			7.5	7.8		

WQM = WQM measurement by IWASRI
EIIR = Lab determination by Ins. Environmental Engineering and Research at UET Lahore
EPD = Lab determination by Punjab Environmental Protection Dept., Lahore.

Figures

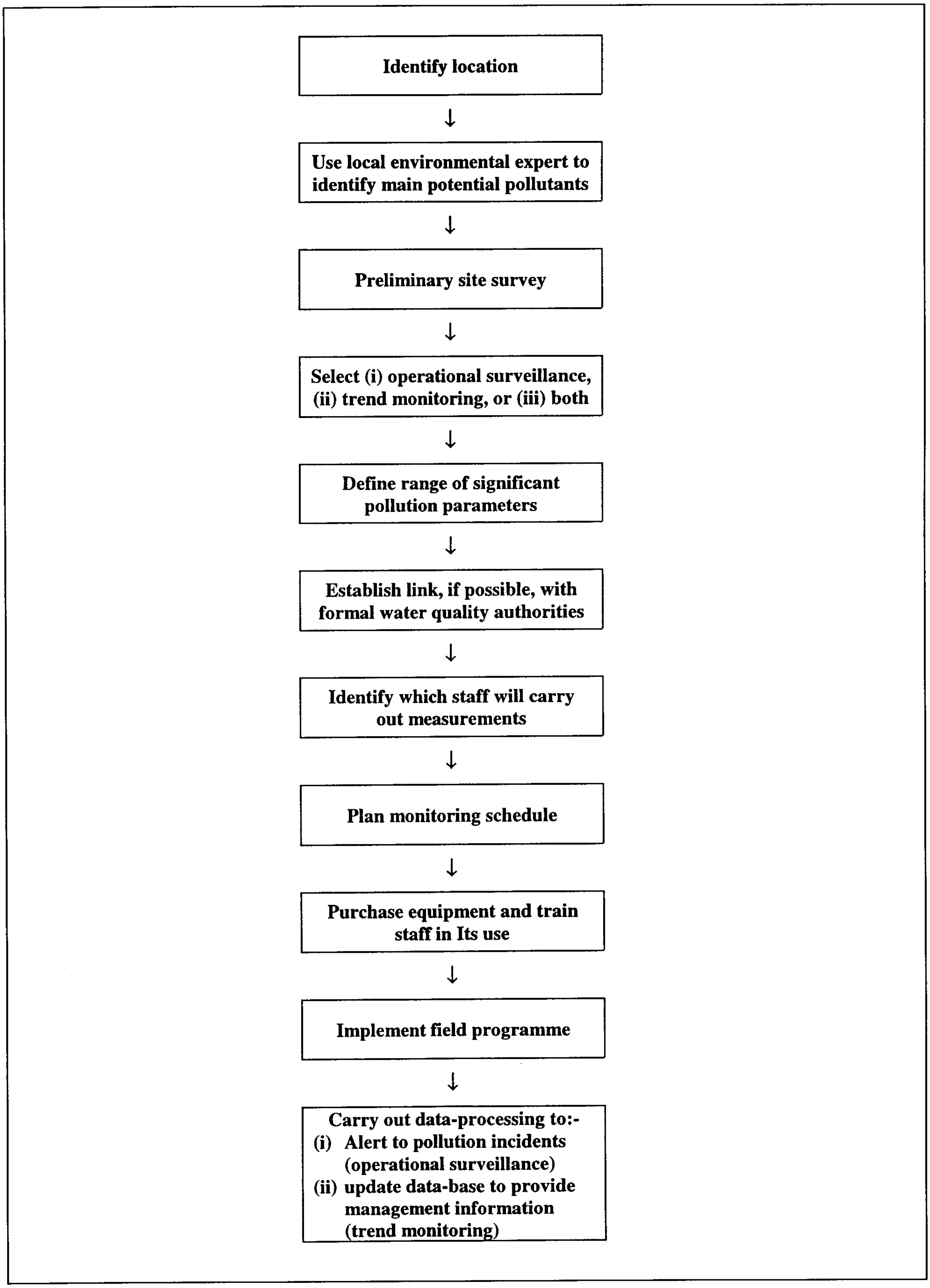


Figure 1 The Water Quality Monitoring Procedure

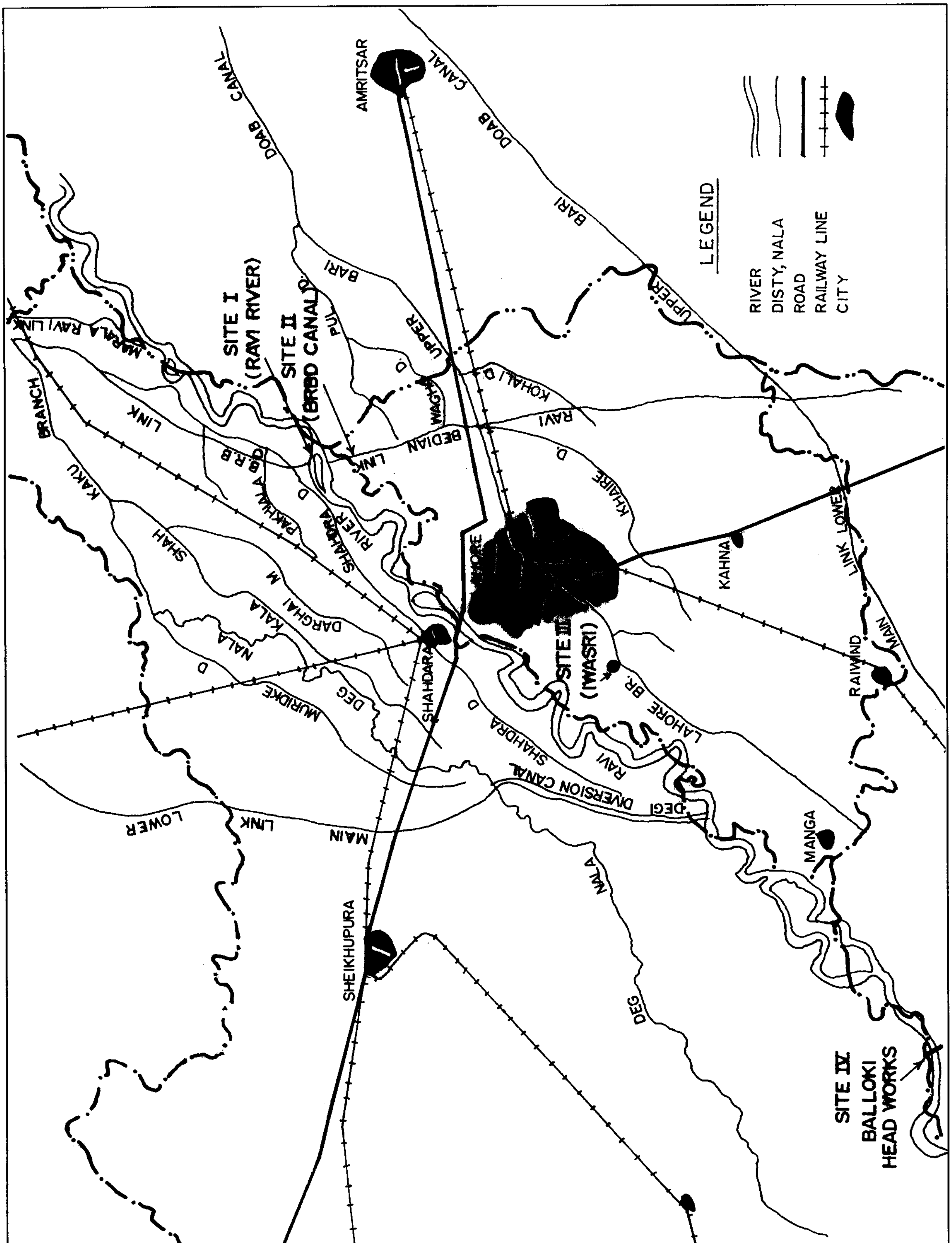
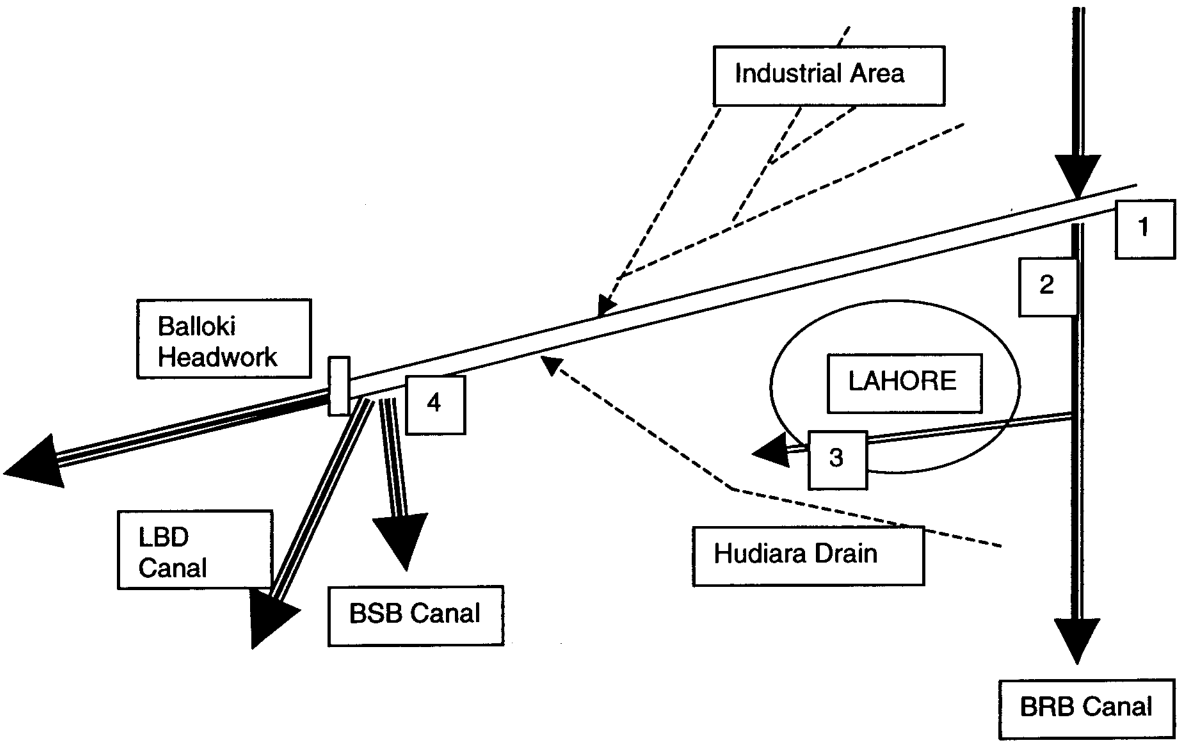


Figure 2 **Ravi system at Lahore**

WATER QUALITY MONITORING PROJECT

RIVER RAVI, LAHORE, PAKISTAN

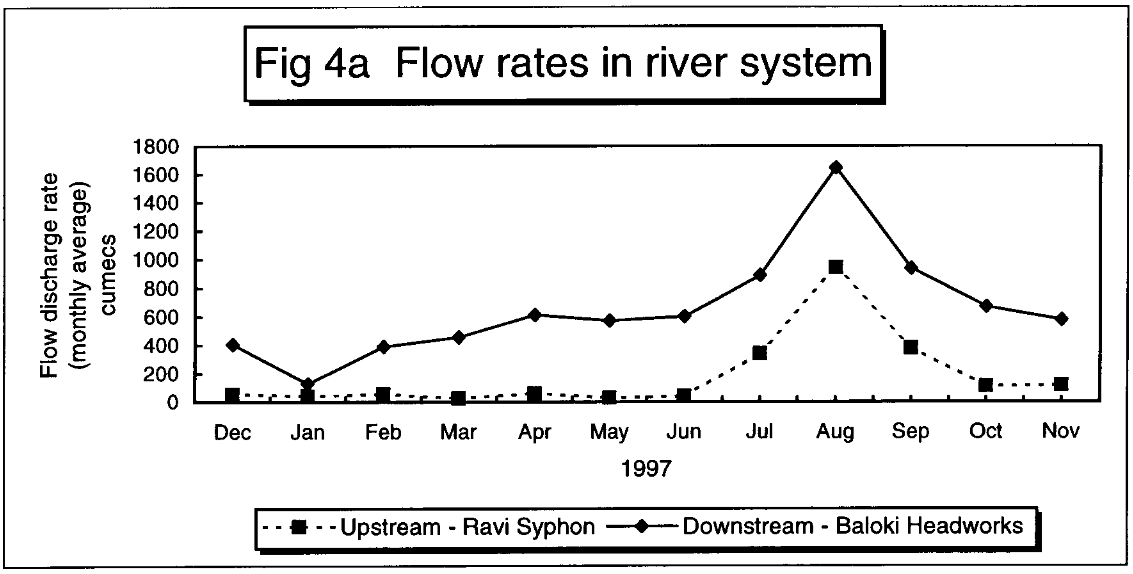
LOCATION OF MONITORING SITES



WATER QUALITY MONITORING PROJECT
Location of measurement sites

1 River Ravi (upstream Lahore)
2 BRB Canal (upstream Lahore)
3 Lahore Canal (downstream Lahore)
4 Baloki Offtake

Figure 3 Schematic diagram of Ravi system, upstram and downstream of Lahore



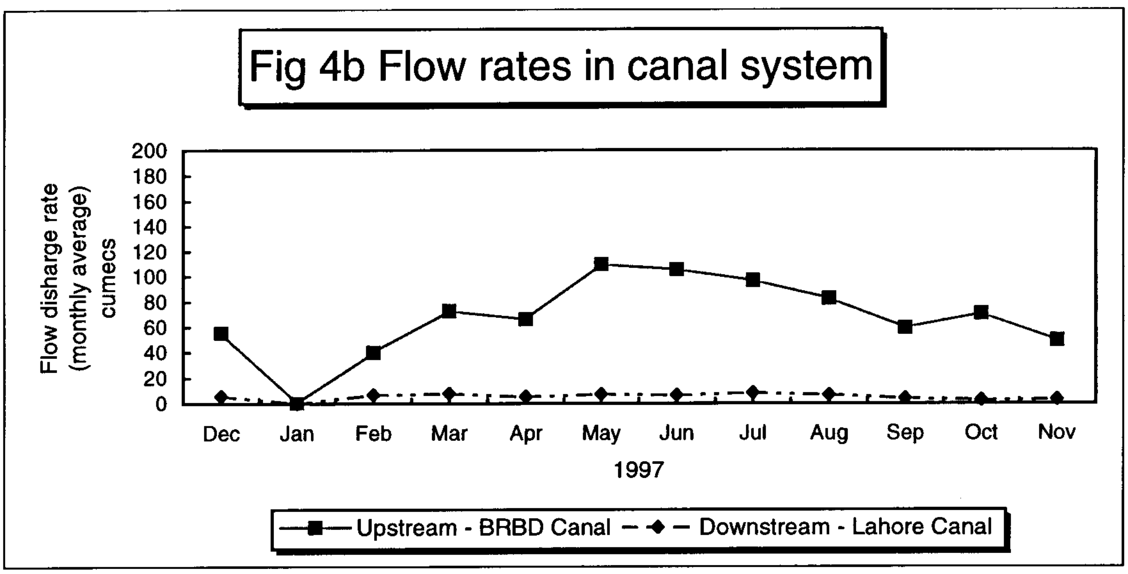
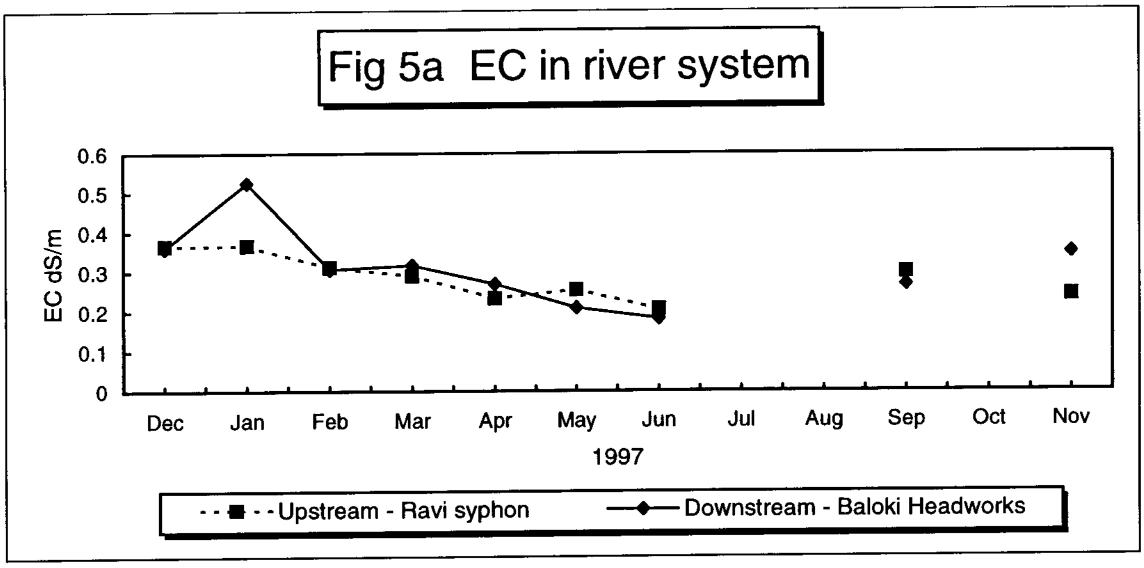


Figure 4 **Flow rates in river/canal system**



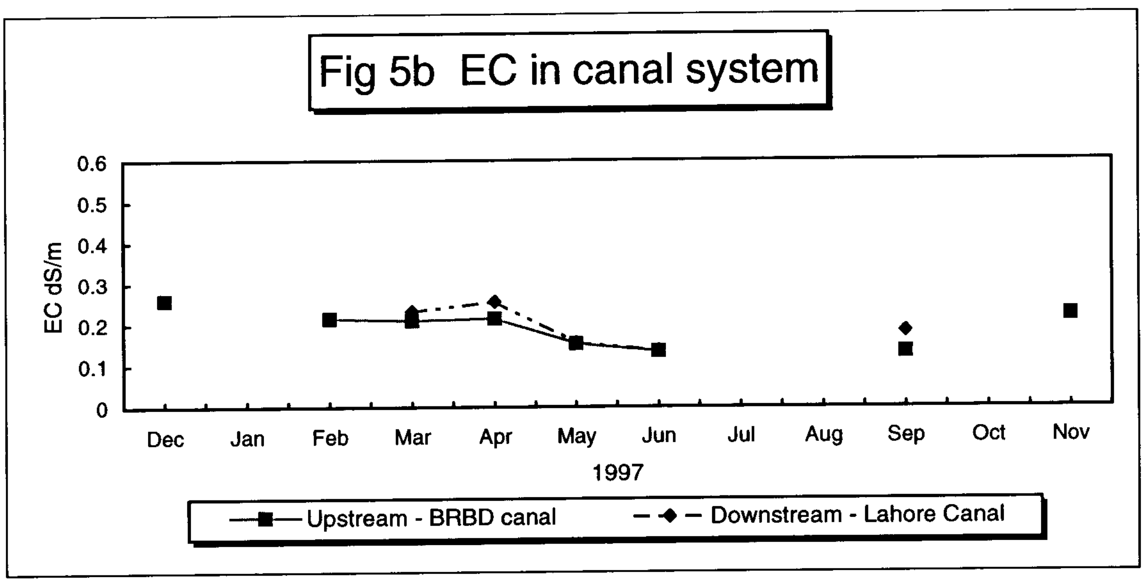
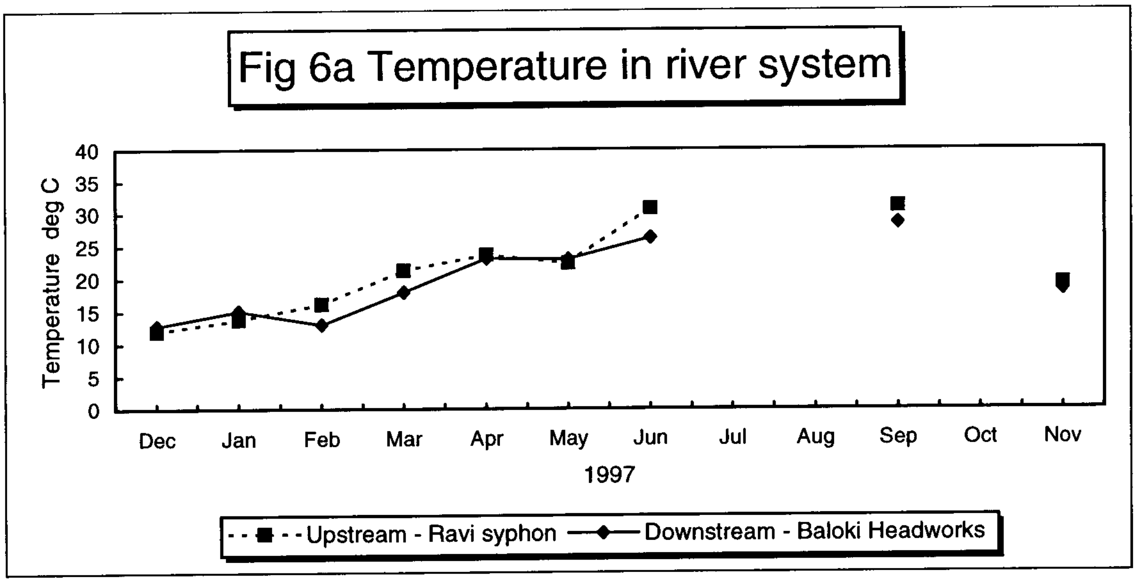


Figure 5 EC in river/canal system



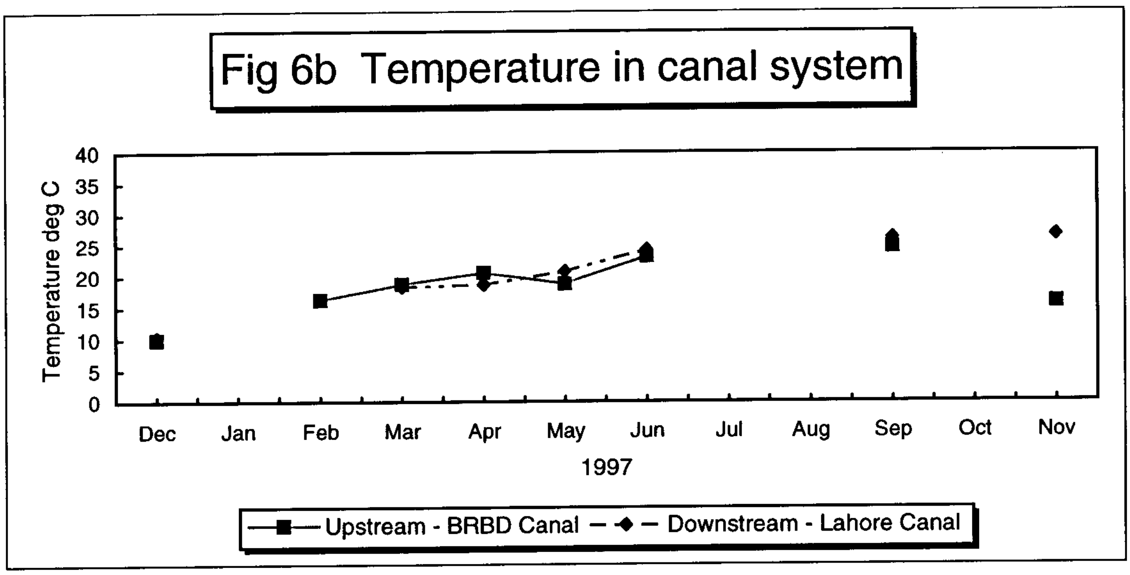
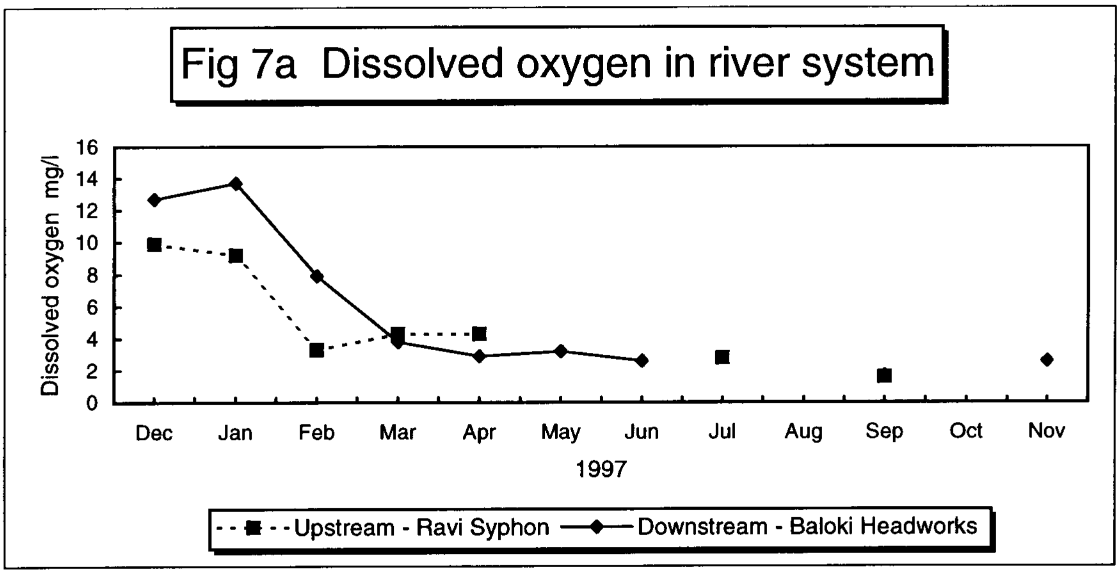


Figure 6 **Temperature in river/canal system**



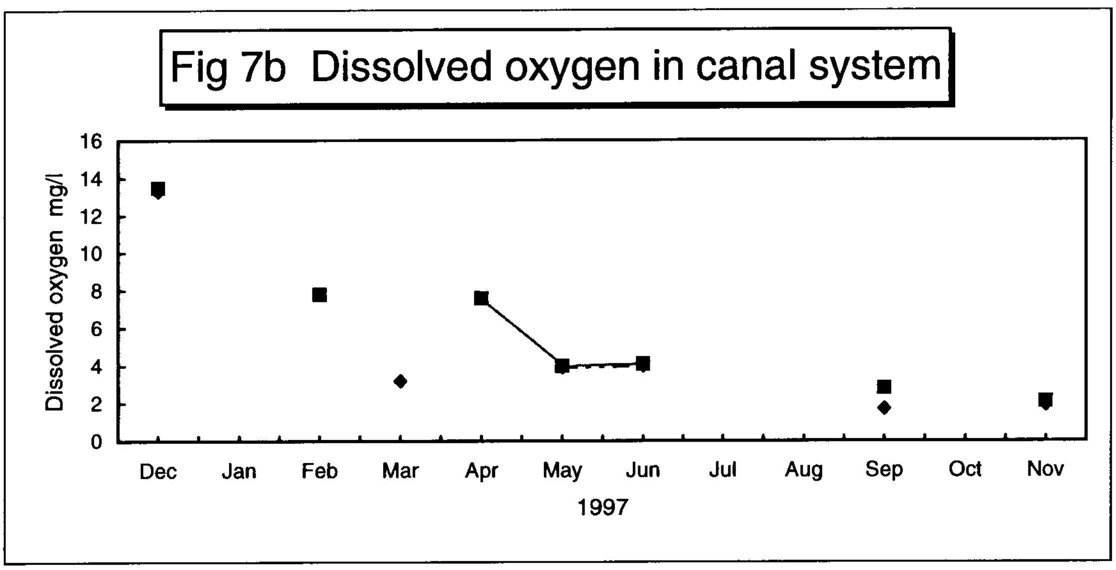
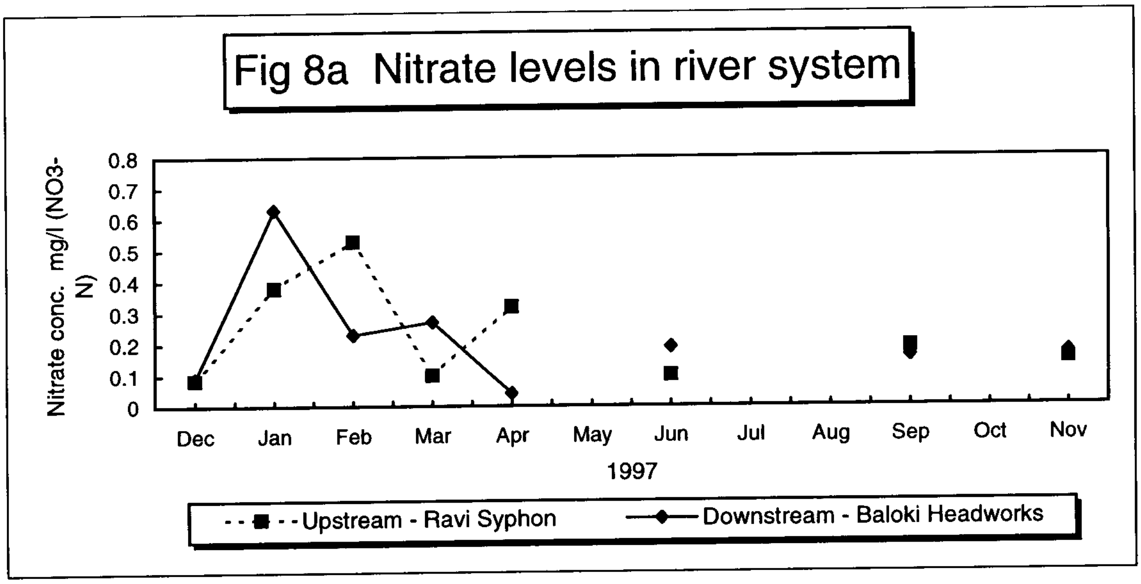


Figure 7 **Dissolved oxygen in river/canal system**



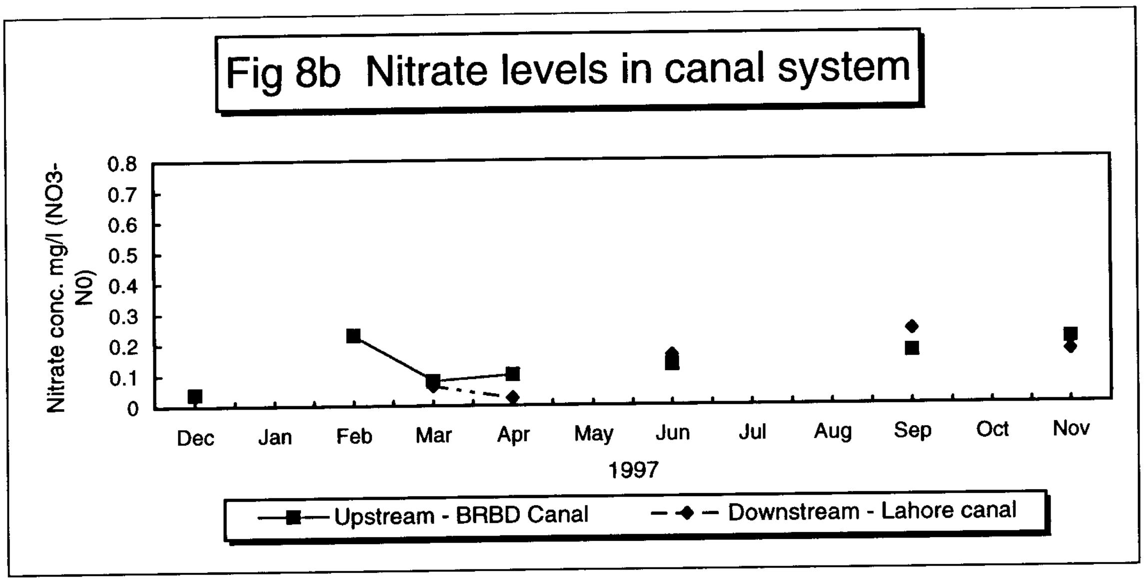
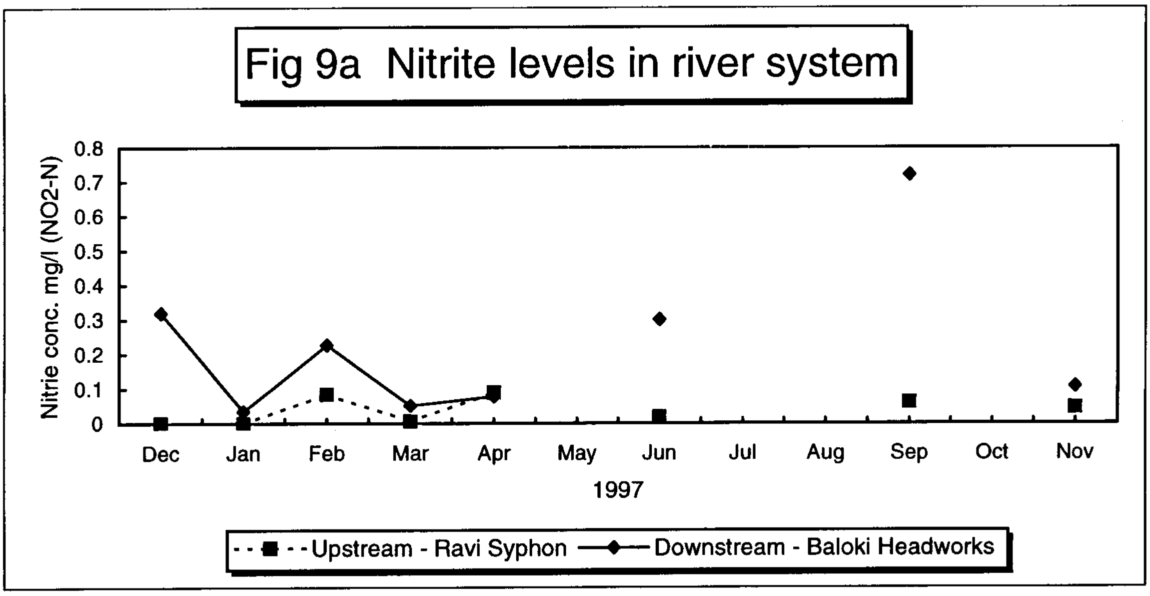


Figure 8 Nitrate levels in river/canal system



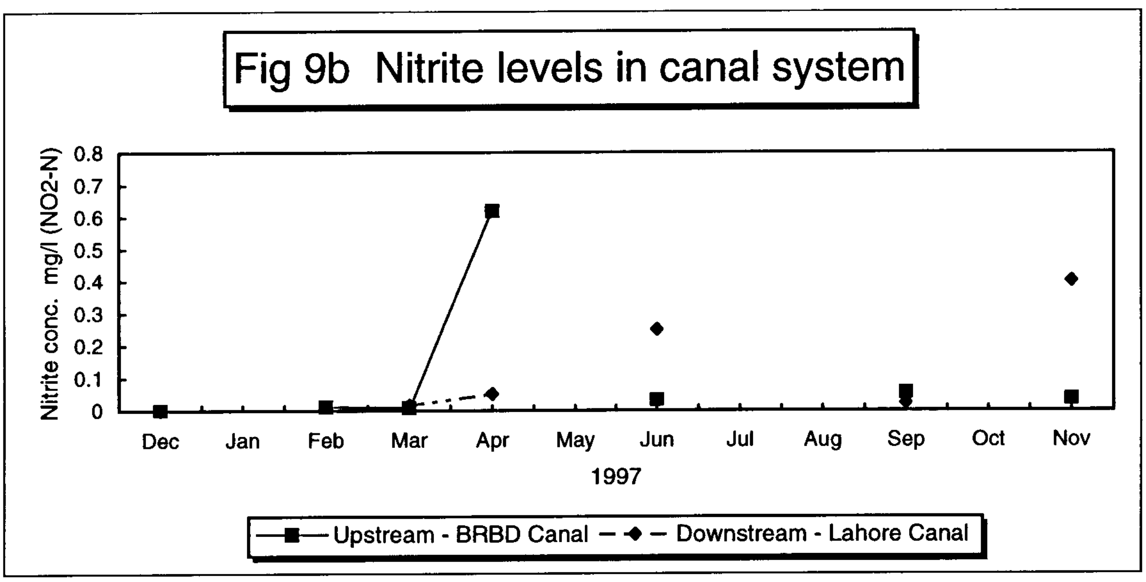
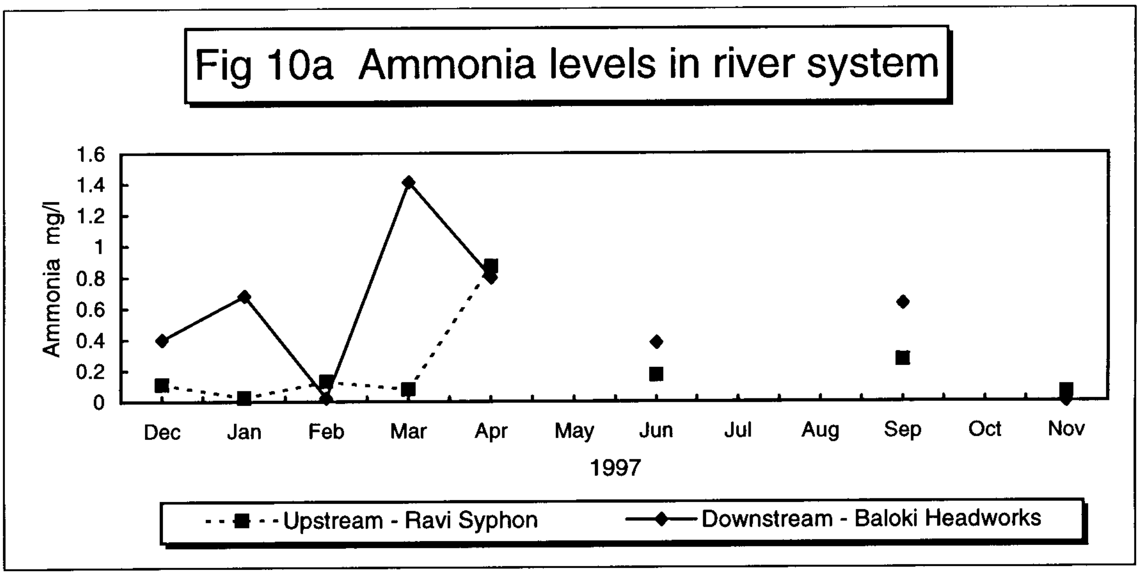


Figure 9 **Nitrite levels in river/canal system**



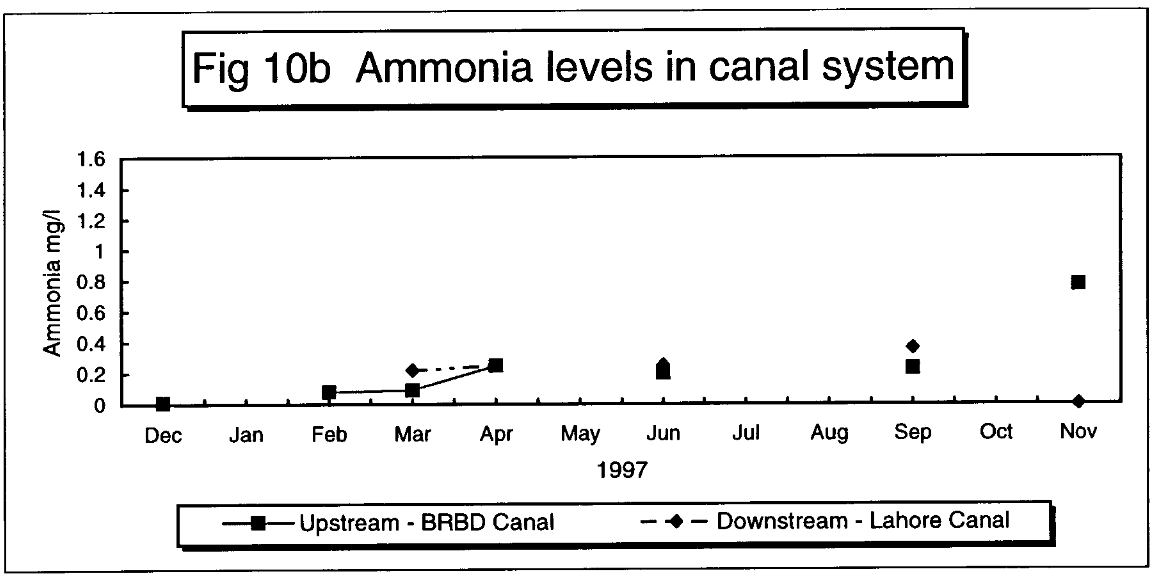
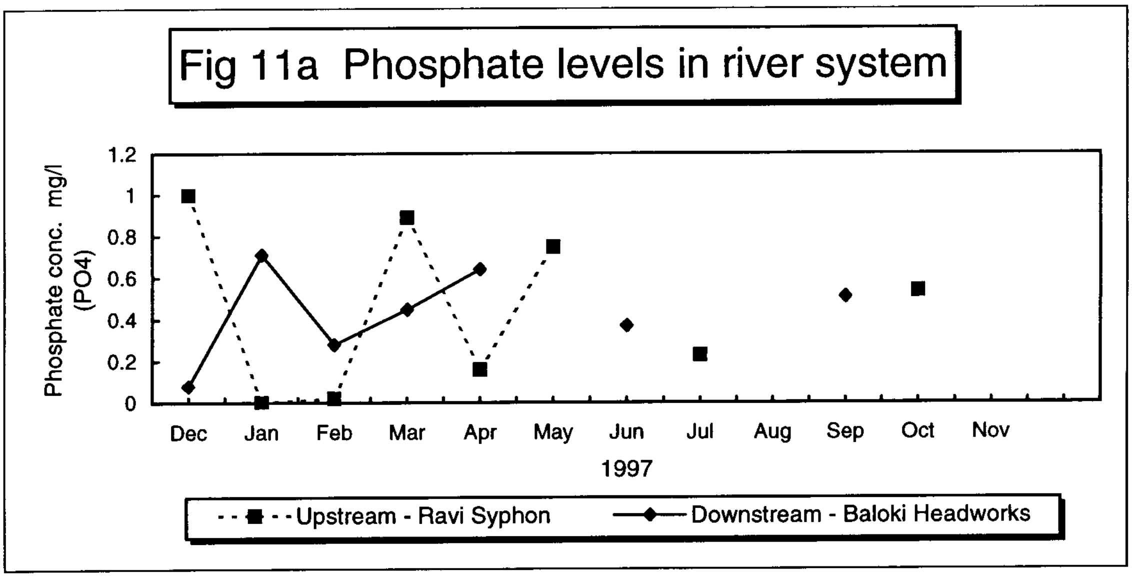


Figure 10 Ammonia levels in river/canal system



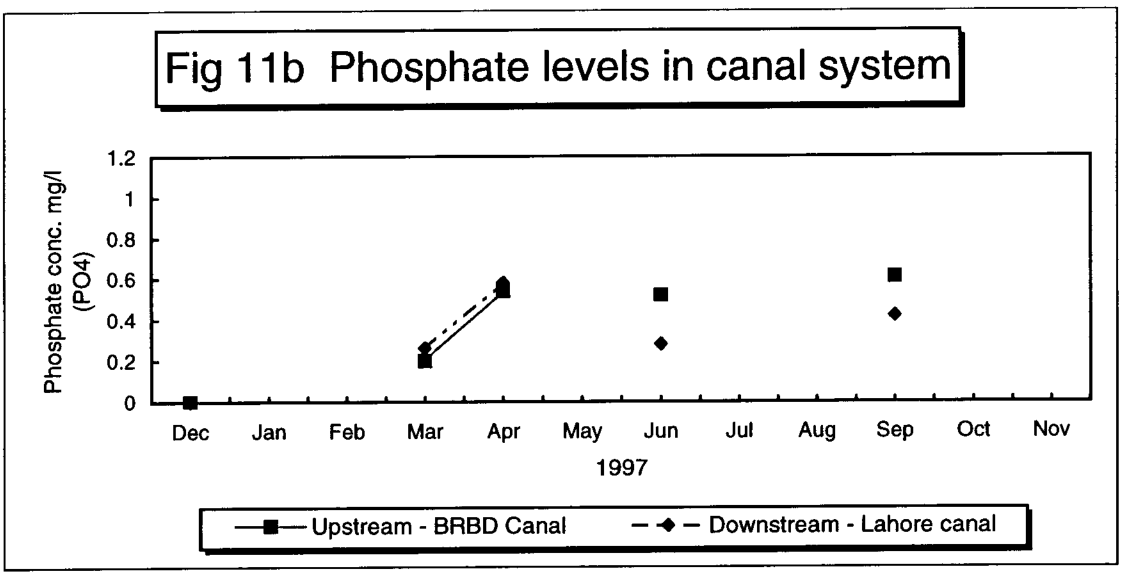
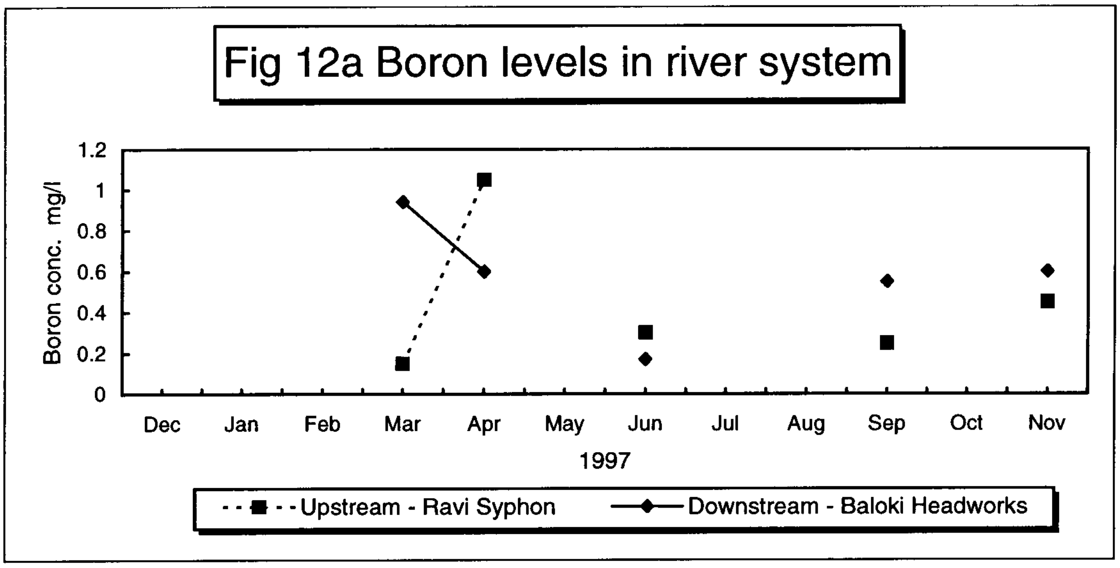


Figure 11 Phosphate levels in river/canal system



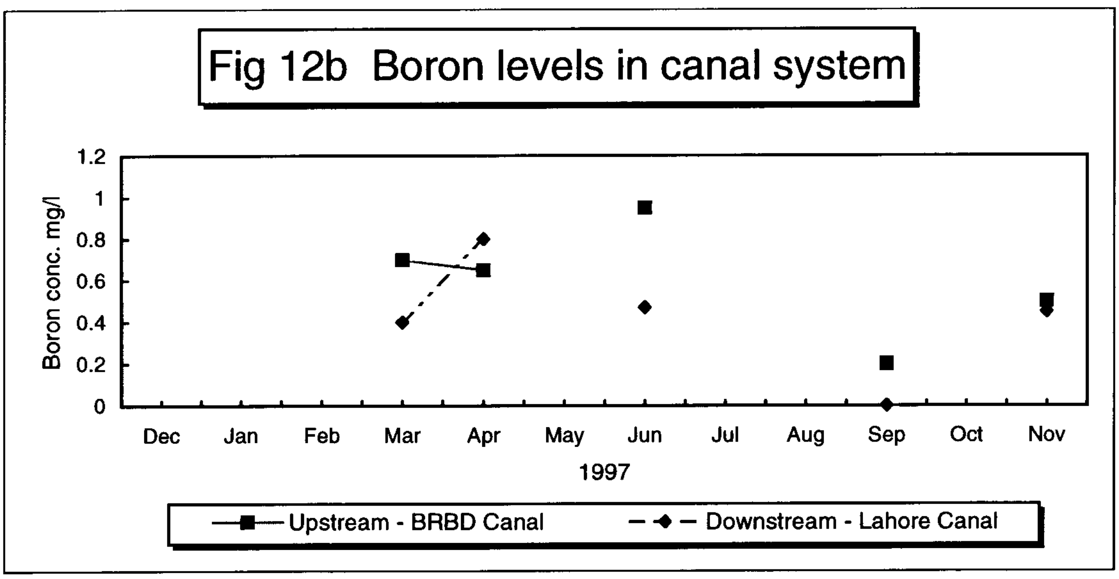
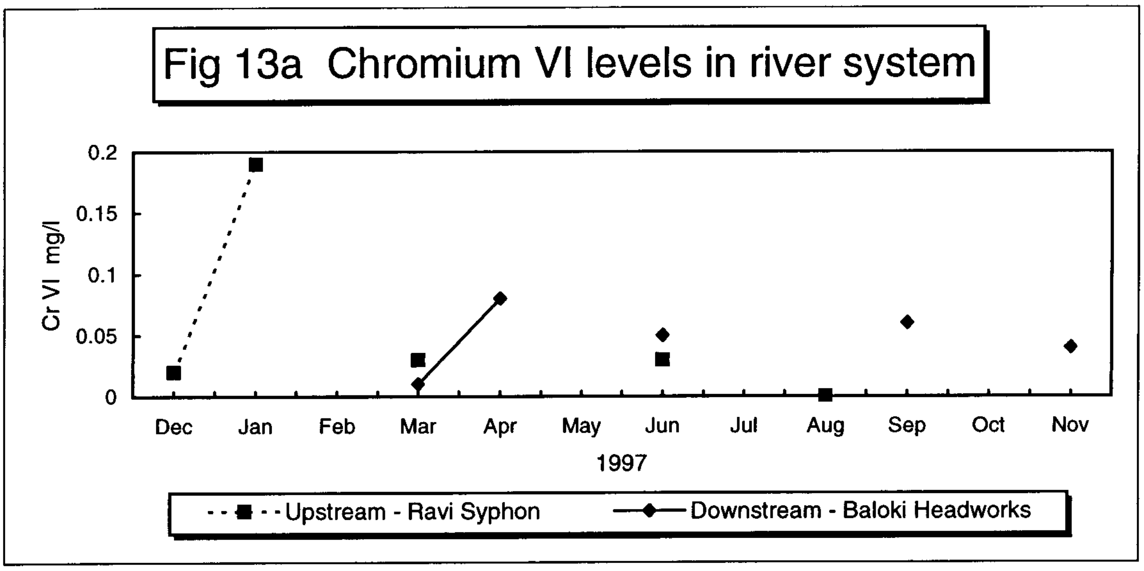


Figure 12 Boron levels in river/canal system



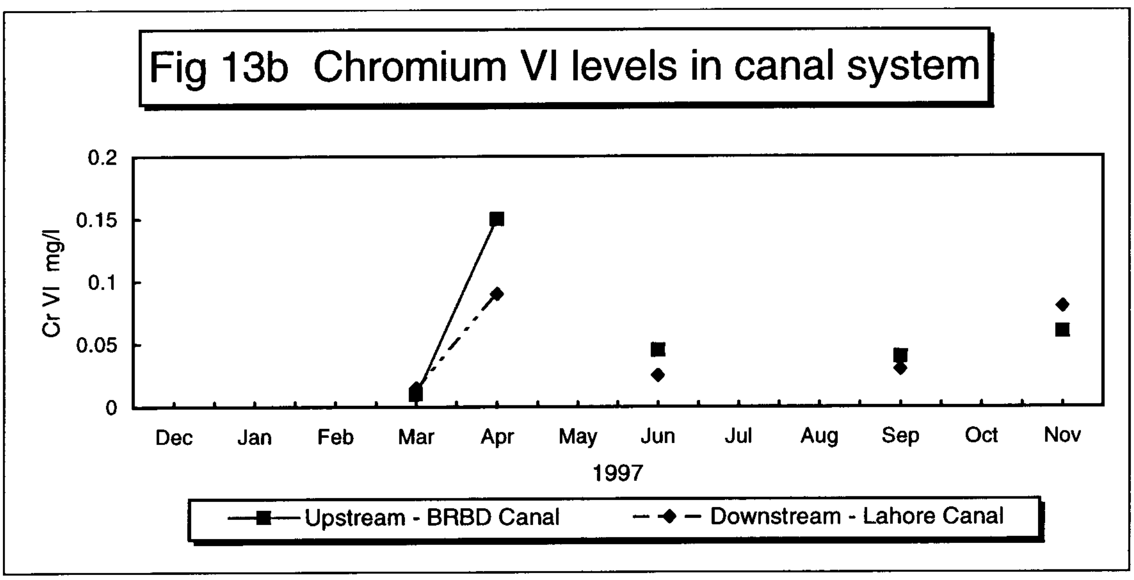
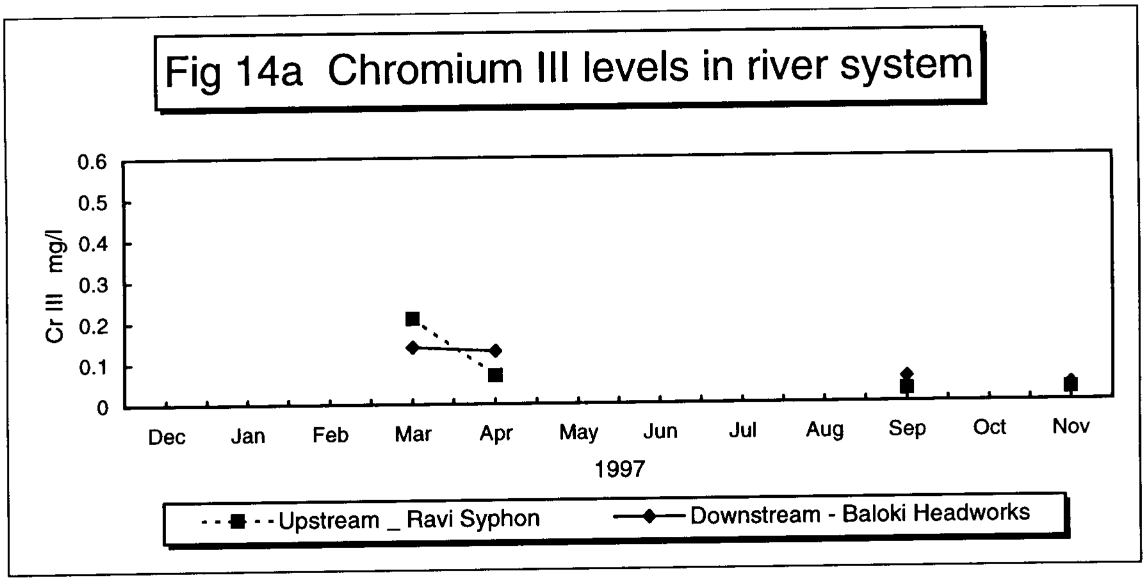


Figure 13 Chromium VI levels in river/canal system



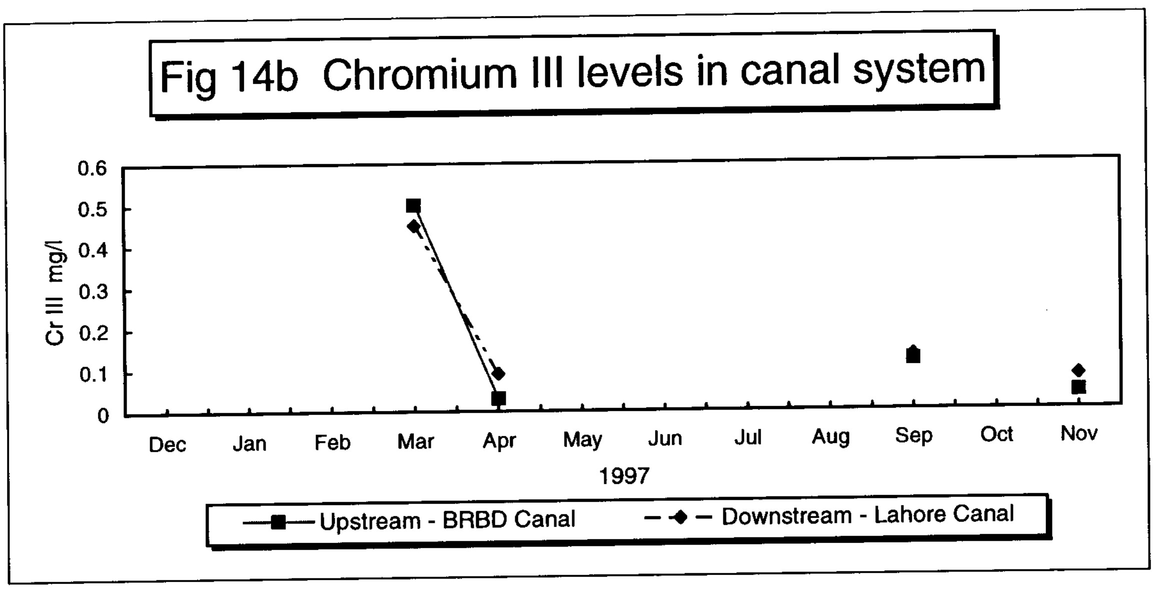
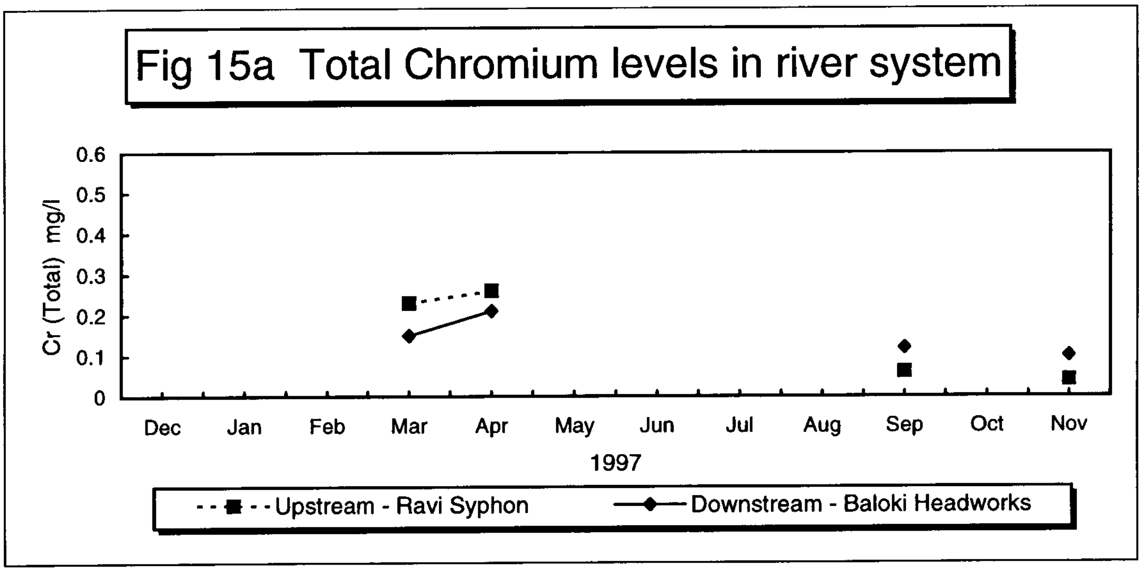


Figure 14 Chromium III levels in river/canal system



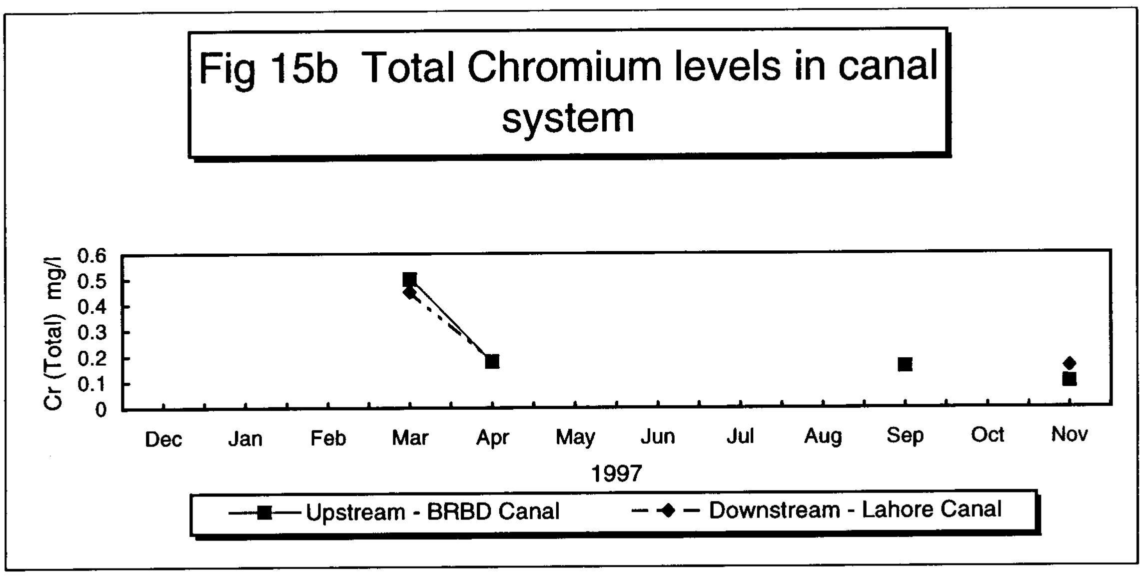
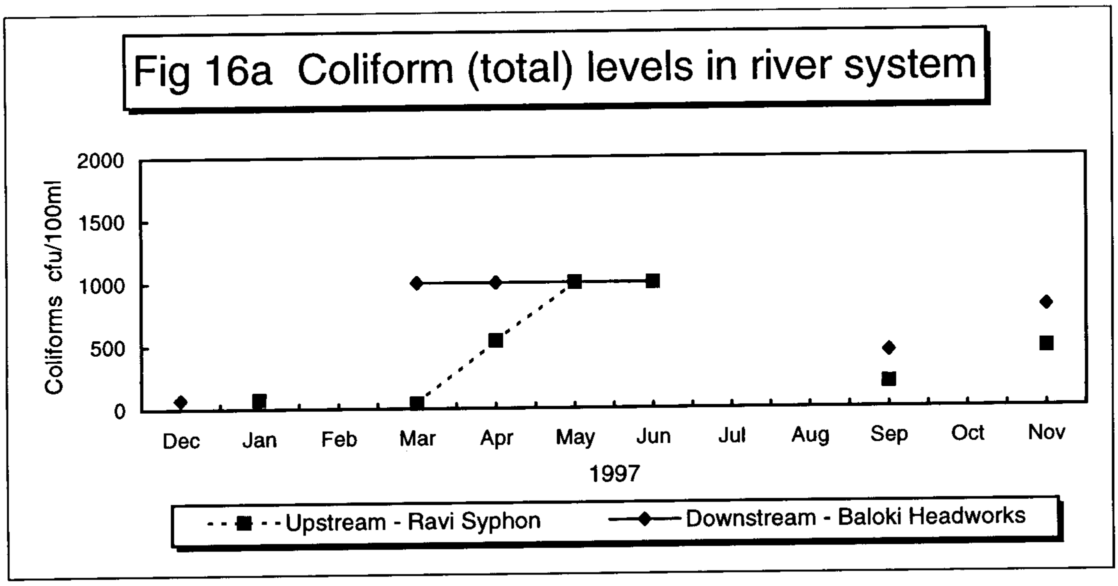


Figure 15 Total chromium levels in river/canal system



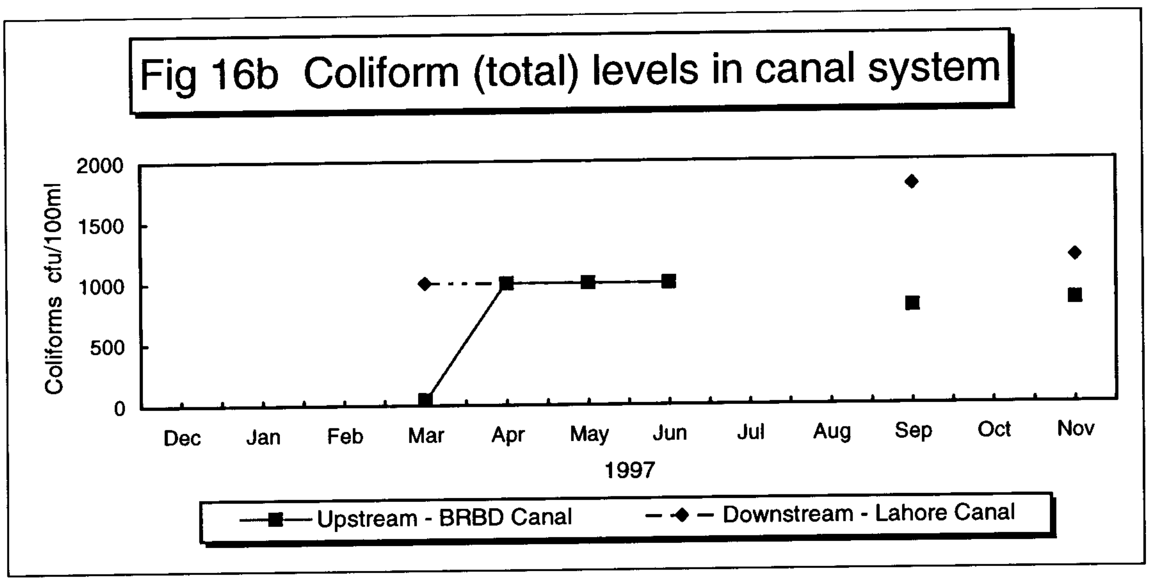


Figure 16 Coliform (total) levels in river/canal system

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