Department for International Development
1 Palace Street
London
SW1E 5HE

Identifying Sustainable Options for the Mitigation of Diffuse Agricultural Pollution

Final Report

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Mott MacDonald
Demeter House
Station Road
Cambridge CB1 2RS
UK
Tel : 44 (0)1223 463500
Fax : 44 (0)1223 461007

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International Team

- Simon Howarth – Team Leader, Mott MacDonald
- Helen Steward – Team Leader MM (until June 2004)
- Simon Turner – Agriculturist (ADAS)
- Geraldine Terry – Livelihoods (MM)
- Sean Murphy – Economics (MM)
- Lucinda Edes – until June 2004
- Christian Smillie – until January 2005
- Caroline Meilhac – until November 2005
- Christopher Thomas

National Team – Egypt (DRI)

- Ashraf El-Sayed – Water Quality Specialist/ Environmentalist
- Adel Abdel Rasheed – Water Quality Specialist
- Ibrahim Lashin - Agriculturist
- Mai Mai - Livelihoods

National Team – Sri Lanka (IWMI)

- Rebecca Tharma - Ecologist
- Thushara Abeysekera - Chemist
- K Jinapala – Livelihoods Specialist
- P Someratne – Livelihoods/Agriculture
- Alexandra Clemett – Livelihoods Adviser
- Premachandra – Field Assistant

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Abbreviations, glossary and acronyms

Anicut – diversion weir (SL), also known as *amuna*
Ara – small natural stream drainage channel (Sri Lanka) – typically with very large seasonal variations in flow
ASD – Agrarian Services Department (SL)
BOD – Biological oxygen demand
COD - chemical oxygen demand
Chena – shifting cultivation (SL)
DO – Dissolved oxygen
DOA – Department of agriculture
DPSIR – Drivers, pressures, state, impact and responses
DRI – Drainage Research Institute
DS – Divisional Secretary (SL)
EC – Electrical Conductivity
EEAA Egyptian Environmental Affairs authority
FAO – Food and agriculture organisation
Feddan - unit of area (approx 1 acre or 0.4 ha)
FFS – Farmers field school
FGD – focus group discussion
FID – Fayoum Irrigation Department
FO - Farmer Organisation
GN – *Grama Niladari* (unit of local government in Sri Lanka)
GOE – Government of Egypt
GOSL – Government of Sri Lanka
ID – Irrigation Department
IPM – Intergrated pest management
IWMI – International Water Management Institute
Kalapuwa – lagoon (SL)
Maha – wet season (November - March) (SL)
Markaz – district (Egypt)
MALR – Ministry of Agriculture and Land Reclamation
MASL – Mahaveli Authority of Sri Lanka
MWRI - National Water Resources and Irrigation
NWRC - National Water Resources Centre
NWSDB – National Water Supply and Drainage Board (SL)
OFC - Other field crops (other than rice) (SL)
Omda – village headman (Egypt)
Oya - river (SL)
PBDAC – Principal Bank for Development and Credit
RBMC – Right bank main canal
SL - Sri Lanka
TDS - total dissolved solids
Wewa - tank (SL)
WHO - World Health Organisation
Yala - dry season (April – Sept) (SL)

Executive Summary

Background

The degradation of water resources is an increasing problem world-wide, but most countries have given greatest emphasis to controlling point source pollution from homes and industry. However, water pollution from agriculture is becoming a major concern with increasingly intensive agricultural practices and use of agro-chemicals (Ongley, 1996). Due to its diffuse nature, it is more difficult and time-consuming than point source pollution, both to study and to control. Thus, although there have been many studies across the world on surface water pollution, its relationship with agricultural practices and resulting impacts on livelihood strategies and the environment are less well understood. In consequence, relatively little effort has been put into developing mitigation measures.

Objectives

The objective of this project was to investigate agricultural pollution of water in two large-scale irrigation schemes, in order to:

- understand the causes of diffuse pollution;
- analyse the impacts that this has on water quality;
- assess the effect on livelihoods, (especially the livelihoods of the poor); and
- propose solutions where appropriate.

The study has been undertaken in two contrasting environments - in Sri Lanka and Egypt - where climate, water management systems, agriculture and livelihoods differ in key respects. These were chosen to help ensure that broader conclusions can be drawn which will be applicable more widely than just in the case study sites. It is not suggested that findings from two sites will cover all of the wide range of possible causes and impacts of pollution, but they are contrasted in order to draw more general conclusions.

Methods and limitations of the study

There were five linked components to the study:

- Background studies – literature review and institutional assessments to plan and place fieldwork in context so that findings could be extrapolated more widely than just the case study sites;
- Water quality – routine programme of water quality monitoring in 12 locations in each study site covering a wide range of parameters including the main agricultural pollutants (suspended sediments, nutrients, pesticides, metals) which we compared with relevant national and international standards for drinking water, agriculture, fisheries and ambient waters. The water quality studies were supported by analyses of fish and sediments;
- Agriculture – review of policies and practices at national and local level to evaluate both current pressures on the environment and future trends in the pressures, by compilation of secondary data and statistics, key informant interviews, field observations and questionnaire survey of sample farmers;

- Livelihoods – assessment of the role of water in livelihoods and the impact of deteriorating water quality on these uses, by compilation of secondary data, group discussions using PRA techniques, questionnaires on specific issues, and key informant interviews; and
- Impacts and mitigation measures – synthesis of the impacts of water pollution on livelihoods and the environment, and recommendation of appropriate methods to mitigate these.

The main immediate limitation of the study related to the monitoring of pesticides, which is a complex task, given that the various chemicals volatilise, adsorb to sediments, dissolve in water and decay in different ways and rates. Concentrations are extremely small and are at or beyond the limits of current laboratory techniques. We cannot assume that negative results mean that pesticides are not being lost to the environment. However, we can draw some qualified conclusions by considering likely decay rates and dilution factors.

There is also a lack of knowledge of the health and other environmental effects of pesticides and their breakdown products

Selection of study sites

The two case study countries were selected to have:

- Contrasting agro-ecological environments;
- Locally recognised problem of agro-chemical pollution;
- Large-scale irrigation and drainage systems with many characteristics common to their region; and
- Established links with local partners willing to collaborate on the study.

On this basis Egypt and Sri Lanka were chosen and, within these countries, we selected Wadi Rayan, in the Fayoum and Kachchigal *ara* in the southern dry zone, on the grounds that they had

- Existing surface water quality problems which can be (almost) completely attributed to agricultural pollution (as opposed to domestic/municipal or industrial)[1].
- Likely existence of socio-economic and ecological impacts[2].
- Ease of accessibility with no significant security or logistical issues.
- Scale of study manageable within project budget and timeframe (realistic catchment size).
- Availability of existing information.

Within each site, we selected a number of sampling points for water quality monitoring and related areas for detailed studies of livelihoods and agricultural practices.

[1] this in practice meant that peri-urban irrigation schemes (which are often where a high proportion of input-intensive crops, such as vegetables, are grown) were excluded. Whilst this might be regarded as a weakness of the study, the more rural schemes selected are more representative of irrigated agriculture as a whole.

[2] It will be seen later that the measured impacts were later found to be less than the popular perception

Wadi Rayan (Fayoum): Egypt

Wadi Rayan drainage catchment comprises the western part of the Fayoum depression - a very fertile area of intensive agriculture in the western desert 90 km south of Cairo. This area has virtually no rainfall and is reliant solely on irrigation from the Nile – water is diverted at the Assiut barrage some 250 km further south. The depression is below sea level and has no outfall: all drainage water flows into lakes (Qarun and Rayan) from which water is only lost by seepage or evaporation – they are thus becoming increasingly saline and polluted. Irrigation has been practised for millennia, but only became perennial in the 20th Century when a modern irrigation and drainage network was constructed. Wadi Rayan was an adjacent dry depression which was linked to the Fayoum by construction of the Wadi Rayan drain in the 1970s – previously all drainage was to Qarun. There is about 175,000 ha irrigated land and a population of 1.75 million, 60% of whom work in agriculture. The detailed study area is in Ibshaway district in the extreme west of the basin, an essentially rural area where least impact from Fayoum city and other municipal areas can be expected.

There are two main cropping seasons: winter, when wheat, berseem (fodder) and beans are the main crops; and summer when maize, cotton and rice are grown. There is an intermediate season – known as *nili* – when maize and vegetables are grown. Vegetables can be grown throughout the year, and are an increasingly important cash crop. Fields are irrigated by gravity through a comprehensive network of surface channels to each field, and there is a sub-surface drainage system to remove excess water and control salinity. There is a shortage of water, so reuse of drainage water is important for irrigation – this is mainly constrained by salinity. Livestock are important, with most households having a few animals, and fodder crops (maize and berseem) need to be grown for this reason.

The canal network provides all water used in the Fayoum: in addition to irrigation, drinking water is taken from the canals and treated; the canals are used for bathing, washing and other domestic purposes (although this is discouraged because of the risk of catching schistosomiasis[3]); cattle are watered from the canals; fish are caught in canals (but this is now relatively rare). Sewage is nominally excluded from the canals (via septic tanks or trenches which are pumped and removed by tanker for treatment and disposal elsewhere), but some canals are used deliberately or otherwise for waste disposal and sanitation. Villages tend to be alongside canals and hence residents have access to canal water[4] for all purposes; the surface drains are more remote from villages, more deeply incised making access more difficult, and too saline to be a favoured source of water.

Landholdings are small, with 50% owning less than 0.4ha and agriculture highly dependent on manual labour – apart from plouging, which is mechanised. In the past the government sprayed cotton crops from the air, but this practice has been discontinued and chemicals are now applied by hand using knapsack sprayers. Fertiliser use is very high, one of the highest per unit area in the world, and pesticides are widely used on a variety of crops although farmers report that their use is declining due to growing awareness and restrictions.

[3] an endemic and serious (although now treatable) disease transmitted via contact with surface water, with certain species of snail acting as intermediate host. Environmental control of these snails through appropriate water management influences operation and maintenance of the canal system

[4] when they are flowing, but there is a closure for maintenance in January and some canals towards the tail of the system have an inadequate supply and may be dry for prolonged periods

Kachchigal *ara*: Sri Lanka

This is a small catchment of about 185 km^2, draining into Kalametiya – a lagoon along the south coast of Sri Lanka. It has been linked for the past 40 years to the adjacent and much larger Walawe basin, by construction of an inter-basin irrigation channel. The Kachchigala *ara* now acts effectively as a main drain for the Uda Walawe Right Bank irrigation system.

The upper third of the catchment (6,500 ha) is largely unirrigated and comprises scrub jungle with small areas of villages, *chena*[5] and small tanks irrigating perhaps 500 ha in total. The lower two-thirds (12,000 ha) is intensively farmed, although the actual crop area only covers about 7,000 ha. Paddy is the dominant crop covering about 70% of the land, with bananas being the other main crop (600 ha), vegetables are grown on about 200 ha (3% of the cultivated area) and a variety of permanent crops (including coconut, cashews, jackfruit and others) totalling around 1,200 ha are also grown.

The canal system serves many purposes apart from irrigation – canals and tanks may be used as raw water sources of drinking water for many people; they are used directly for many household purposes such as washing and bathing; livestock (particularly buffalo) wallow in the channels; and many people fish in canals, tanks or drains although only a very small number rely on fishing as the main source of livelihoods. The Kalametiya lagoon supports more important fisheries, but one which has declined drastically since construction of the irrigation system and fewer than 100 households depend on this now. This decline is largely due to the increase of freshwater flows and sediment into the previously brackish lagoon, but many other aspects of pollution and changes in water management are believed to have had an impact.

Drinking water supply is a major local concern. Groundwater is used for drinking in some areas, but this has a high fluoride content and is not suitable for direct consumption. There are some piped water supplies (derived from canals, tanks or groundwater), and other people depend on deliveries by tanker. Village tanks are common raw water sources for drinking water schemes, as well as for a multitude of other uses. It should be noted, however, that they are partially filled by drainage water and thus influenced by upstream agricultural practices.

Landholdings are small – typically 1 ha per household – and are relatively uniform as the rights to use land[6] have only recently been allocated by the MASL[7], the agency responsible for development and management of the irrigation system. There is more variation in land under the small tanks, some of which is owned by temples and rented to farmers. Livestock are not widely kept, as there is little grazing land now, but were traditionally very important. The few who keep large herds now graze them in unirrigated land outside the study area. Agriculture is largely done by hand, with little mechanisation, but weed control is now mainly achieved by use of herbicides. Some insecticides are used on paddy and much larger quantities (per unit area) on vegetables. No pesticides are used on bananas or other permanent crops. Fertilisers are applied to all crops, although applications to rice appear to be well below government recommendations.

[5] shifting cultivation
[6] ownership of the land remains with the state, and individuals have no right to buy or sell this land
[7] Mahaweli Authority of Sri Lanka

Findings

Water quality

Water quality is generally good at the sites monitored, and within the appropriate national and international standards for each use for most parameters. The main exceptions are bacteriological quality and salinity. Canals are used for a variety of domestic purposes resulting in highly significant faecal contamination which will have an impact on human health (even if the canals are not used untreated as a source of drinking water).

Salinity of water in Egypt limits the scope for reuse - this rather than agro-chemicals is the limiting parameter for reuse. Nitrate levels are slightly elevated in some drains in Egypt, and there is the possibility that we did not detect the peaks due to the sparcity of the monitoring programme. However, this suggests more that there is scope for saving on fertiliser applications rather than that there is a significant problem in the environment. Pesticides were detected in some samples and locations, but at extremely low concentrations (below the limit of quantification). However, the sampling method means that there are probably substantially higher short-term local peaks in pesticide concentrations.

Irrigation can lead to accelerated soil erosion, and these sediments can be deposited in downstream areas causing loss of wetlands or flooding. Excess nutrients and pesticides may be bound to such sediments

Agriculture

Environmental considerations are less important than productivity factors in agricultural policy, but this is gradually changing. Water quality is now a key factor in Egyptian policy, although mainly for reasons of salinity control. Fertiliser use is still increasing in both countries, despite removal of subsidies in Egypt, and coupled with a change in cropping pattern this is leading to a growing pressure on the environment. Fertiliser use is much lower in Sri Lanka than in Egypt. This partly as a result of crop choice, as rice and bananas require lower quantities that the more demanding crops grown in Egypt, but also farmers consider the marginal returns to fertiliser too small to justify greater applications and hence yields are fairly low.

Pesticide use is not systematically recorded, and thus is difficult to evaluate. Such evidence that there is suggests a steady decline in use, with a gradual change to less toxic compounds. Both countries have effective systems for registering pesticides which are permitted for use, and both have banned many persistent organochlorine pesticides – although these are still detected in the environment[8]. Both have introduced programmes of integrated pest management which are helping in improving understanding of pesticides and the most effective ways of using them. These are important programmes but further work needs to be done to expand their scope and improve uptake.

[8] Despite some changes in uses and application methods, the presence of persistent (and therefore more easily monitored) pesticides in the environment is in an indication that modern less persistent pesticides may also be lost to the environment even if they cannot be detected

Livelihoods

Irrigation schemes in both areas provide the main source of water for most uses – which include agriculture, vegetable gardens, fisheries, livestock, domestic uses (bathing and washing clothes etc) and recreation. In both cases, water for drinking water schemes is taken from the canals but it is treated prior to distribution. Local people are sometimes concerned that the treatment is inadequate and there appear to be occasional problems, but the methods used are (if applied rigorously) adequate for the quality of water encountered (even allowing for the presence of pesticides in the canals). Canal water is used, largely by default, for purposes of environmental hygiene and therefore much sewage enters the canals and drains in an untreated form. This is the main cause of the bacteriological pollution noted earlier.

Impacts

The impact of water pollution depends on the uses to which the water is put. High salinity and a high incidence of schistosomiasis in Egypt limit the scope for reusing water for either agricultural or domestic purposes – although water is occasionally reused if the need is great enough. Agricultural pollution does not constrain or affect these uses. There is much greater reuse in Sri Lanka, where drainage effluent (either directly or via tanks) can easily be used for agriculture or domestic purposes, and where fishing in drains, tanks and lagoons is important for livelihoods (of a relatively small but impoverished proportion of the population).

Agricultural pollution does not yet appear to have a significant impact on these uses. Pesticide concentrations are very low, because of dilution factors, and excess nutrients are believed locally to increase fish productivity. However, the detection of pesticides in water fish and sediments in any quantity is noteworthy, especially given the high dilution factors in a tropical catchment. The inevitable uncertainty, combined with observations of the Millenium Ecosystem Assessment suggest that cautious approach is necessary. The Millenium Assessment reported that there is an increasing risk of “potentially abrupt changes in ecosystems, with important consequences for human well-being. .. For example, once a threshold of nutrient loading is crossed, changes in freshwater and coastal ecosystems can be abrupt and extensive, creating harmful algal blooms (including blooms of toxic species) and sometimes leading to the formation of oxygen-depleted zones, killing all animal life[9].”

Since there are, on average, low concentrations of pollutants in most channels but short term peaks in minor drainage channels, it is likely that most damage will be to ecosystem health in these channels. This may in turn have a large impact further downstream. There is little evidence so far of eutrophication in the drains in study areas, but there is anecdotal evidence that this is exacerbating excess weed growth in drains elsewhere in the study countries which is causing problems of drain maintenance. However, the marginal impact of slightly elevated nitrate levels is probably very small (and unquantifiable). There is rather greater concern that there is eutrophication in the coastal lagoons, leading to excess weed growth, sedimentation and reduced fish populations. This is likely to be the case, but again is only one of several factors influencing lagoon fisheries.

[9] Ecosystems and Human Well-Being: Wetlands and Water Millennium Ecosystem Assessment, 2005. World Resources Institute, Washington, DC.

In the absence of observable significant impacts of agricultural pollution, it is difficult to recommend specific mitigation measures. However, there are many improvements in agricultural practices which would also reduce the risk of pollution: better timing of fertiliser applications, better techniques for using pesticides, reducing excess release of water to drains would all reduce the risk of pollution whislt at the same time improve agricultural productivity.

Misuse of pesticides, whether accidentally (eg poor application techniques[10]) or deliberately (eg for killing fish, making produce more attractive for markets, or suicide) is a very serious problem which is widely acknowledged in both countries. As well as contributing to pollution, such abuse is in itself a far greater risk to health and livelihoods than water pollution. This is being addressed by a range of measures such as the pesticide registration process and promotion of alternative pest control methods. However, these measures to control misuse of pesticides will also help further reduce water pollution.

Conclusions

We have not found any evidence of serious problems of water pollution arising from diffuse agricultural pollution. Pollution of water from sewage and from industrial sources is still the main problem in or adjacent to the study areas.

Irrigation leads to large changes in water flows in many channels (which may be positive or negative). These large hydrological changes have a major impact which makes it difficult to see the specific incremental impact of water quality changes. The potential risks of pesticide pollution are, however, serious both for the natural ecosystem and for human health. This makes it important to improve routine monitoring water quality and to reduce environmental exposure through all risks.

Livelihoods are not yet affected by agricultural aspects of water pollution in the case study sites. Agro-pollution would be a concern if water were used untreated for drinking, but bacteriological parameters would be more serious in short term. Improved water supply systems would be a priority in such situations, and the low concentrations of pesticides encountered would not present a problem for low cost treatment). Fisheries are the aspect of livelihoods which are the most likely to be affected.

Despite these generally positive findings, we still recommend caution and recognition of environmental issues when developing agricultural policy. It is possible to design measures to improve agricultural productivity which can be taken without adverse impacts on the environment. Better communication and understanding between the respective agencies is important for this.

Recommendations

Our recommendations are grouped in four categories

- Technical training
- Best management practices
- Legislation
- Monitoring and compliance

[10] for a number of reasons such as lack of knowledge or lack of appropriate protective clothing and equipment, and leading to direct contact, consumption or inhalation

Farmers have a growing knowledge and understanding of agrochemicals, but new products are continually being introduced and farmers have a patchy access to information – as a result their techniques are sub-optimal and sometimes dangerous. Traditional extension methods have not been very effective at reaching all farmers, but participatory methods such as farmers' field schools for integrated pest management are potentially very effective. However, uptake of these methods is still fairly weak and there is little dissemination of the knowledge to those who do not attend. Further work is needed to address the factors limiting this uptake, which are reported by Gutierrez and Waibel (nd)[11] to be due to an excessive focus on technical issues and a lack of attention to social and policy aspects. It is also important that women and children who directly involved in chemical applications are included in these programmes.

There are many aspects of agricultural management which could be improved to reduce water pollution without harming productivity – these include land management (restricting encroachment of drain and tank margins, irrigation practices to reduce soil loss); fertiliser application quantities and timing (particularly related to water management practices); pesticide application techniques (especially along drain margins, and for cleaning and disposal of equipment); and livestock husbandry and manure management. There will need to be further agricultural research before definitive recommendations can be made on issues such as modified fertiliser recommendations

Legislation is necessary before any water quality improvements can be enforced; this is generally in place in the study countries, although agricultural pollution is not specifically identified. Pesticide registration procedures need to be continually refined as new products are introduced, or new risks are identified.

Enforcement of water quality improvements is not possible until monitoring systems are improved. The costs and complexity of monitoring means that this needs to be a carefully targeted programme – focussing on key parameters and locations. In addition to water this programme should cover sediments, fish and invertebrates.

[11] http://www.spipm.cgiar.org/PDFs/SPIPM.%20First%20EPMR%20report,%202001.pdf

1 Introduction

1.1 Background

The degradation of water resources is an increasing problem world-wide, but most countries have given greatest emphasis to controlling point source pollution from homes and industry. However, water pollution from agriculture is becoming a major concern with increasingly intensive agricultural practices and use of agro-chemicals (Ongley, 1996). Due to its diffuse nature, it is more difficult and time-consuming than point source pollution, both to study and to control, and its relationship with agricultural practices and resulting impacts on livelihood strategies and the environment are less well understood. In consequence, relatively little effort has been put into developing mitigation measures

In many parts of the world, irrigation schemes have been designed and constructed with no consideration for controlling the quality of water returning to the river. With increasing intensity of agricultural production, use of many agrochemicals is increasing with resulting increases in the losses to the environment.These problems are exacerbated by over-abstraction from the river, causing artificially low flows downstream and hence high concentrations of agro-chemicals. This is a particular problem in developing countries where vast agricultural schemes have been developed and where large, mainly rural populations depend on downstream river systems for their livelihood. In a study into environmental flows in Zimbabwe (Mott MacDonald, 2004), problems of poor water quality due to upstream agriculture during very low flows were found to prevent rural communities from using river water. Similar agro-chemical derived water quality problems are known to occur in many countries and can affect health, water availability, fish catches, bank-side cultivation, irrigated crop production etc. among downstream communities. There is little awareness of how this pollution impacts on livelihoods downstream and thus limited incentive or knowledge to reduce such pollution.

Pollution processes and impacts are little understood or appreciated. Managers of irrigation schemes are more interested in the supply and delivery of water whilst agricultural extension services and agro-chemical suppliers are primarily interested in yield improvements and sales volumes respectively. Few have an interest in downstream drainage conditions or drainage pollution (with the possible exception of salinity) or the impact that this has on downstream users of drainage water.

1.2 Objectives of Study

The objective of this project was to investigate two case studies, to

- understand the causes of diffuse pollution;
- analyse the impacts that this has on water quality;
- assess the effect on livelihoods, (especially the livelihoods of the poor); and
- propose solutions (at both policy and local levels) where appropriate.

The study has been undertaken in two contrasting environments, in Sri Lanka and Egypt where climate, water management systems, agriculture and livelihoods differ in key respects. These were chosen to help ensure that broader conclusions can be drawn which will be applicable more widely than just in the case study sites. It is not suggested that findings from two sites will cover all of the wide range of possible causes and impacts of pollution, but they will be contrasted in order to draw

more general conclusions. The extent to which these are representative of other conditions or environments will be discussed in Section 3.1. Our methods were designed to improve local awareness of the problems caused by agricultural pollution, and the capacity in the case study countries to monitor water quality, agricultural pollution and livelihoods, and the inter-relations between these.

1.3 Goal, Purpose and Outputs of the study

GOAL: Combating degradation of water resources

PURPOSE: To improved the understanding of the impact of diffuse agricultural pollution from large scale irrigation on the river environment and on downstream livelihoods; and to identify solutions to mitigate these impacts.

OUTPUTS:

- Increased knowledge of the extent of agricultural pollution in each case study site.
- Improved understanding of downstream household livelihood strategies and the role that water plays as a productive asset.
- Improved local capacity to monitor water quality and agricultural pollution.
- Improved understanding of the socio-economic impact of agricultural pollution on downstream water users and on the environment.
- Improved awareness of impacts of agricultural pollution amongst all stakeholders.
- Recommended pollution reduction/mitigation options for each case study.

1.4 Structure of the report

This report synthesises the findings from two case studies, and is structured as follows:

- Introduction and background
  - Introduction (Chapter 1)
  - Review of literature and background to the problem, leading to refined statement of the research question (Chapter 2)
  - Description of methods we followed in selection and implementation of the case studies, and consideration of the limitations of these methods (Chapter 3)
- Description and analysis of the case studies, including institutional context, agricultural policies and practices, water quality and livelihoods
  - Egypt (Chapter 4)
  - Sri Lanka (Chapter 5)
  - Comparative analysis of case studies (Chapter 6)
- Impacts and options for mitigating impacts (Chapter 7)
- Conclusions and summary of recommendations (Chapter 8)

Additional supporting information and details on the individual case studies is presented in appendices

2 Background

2.1 Introduction

The central role of water on rural livelihoods in arid regions is widely recognised, and is discussed in the specific context of the two study areas in chapters 4 and 5 below. Irrigation systems provide the largest source of water in many of areas and, although agriculture is the dominant use, this water is used for many purposes – including domestic uses, livestock, fisheries and recreational uses as well as being important for the downstream environment. The impact of agricultural practices on water quality can thus have an indirect impact on many aspects of rural livelihoods.

According to Novotny (1999), there has been a worldwide shift since the 1950s from small family farms to larger, monocultural, intensively operated farm units, with a dramatic increase in yields, sustained by very significant increases in chemical fertilizers and pesticides. Irrigation return flows have thus become a pollution hazard – particularly in arid and semi-arid regions where there is less dilution or flushing by rain.

Irrigation management is the subject of extensive research and literature, but most attention has been given to managing the distribution of water, aiming to ensure the supply of a reliable and adequate quantity of water to all users. It is not surprising, given the difficulty even of ensuring this much, that water quality management has been given much less attention. Water quality is usually only a focus in places where there are large industrial or municipal point sources causing obvious contamination. Diffuse sources, largely of agricultural origin, have a much less apparent impact and are largely neglected. Furthermore, such pollution does not impact directly on the primary uses of irrigation systems: rather, it affects secondary users of canals, users of drainage waters, and those dependent on the river further downstream (who may all lack any formal right to this water).

The principal types of diffuse pollution derived from arable agriculture are agrochemical pollution, sedimentation as a result of soil erosion and salinisation due to inadequate drainage of irrigated lands. The focus of this research will be on pollution derived from agrochemicals, which can be sub-divided into three main groups: nutrients; biocides, and metals.

In this study we are interested in the impact of diffuse or 'non-point source' pollution on water quality and livelihoods. This refers to pollutants that have no obvious point of entry from land into watercourses. Agriculture is not the only human activity to cause such pollution; however it is generally regarded as the largest contributor of diffuse pollution, through the transfer of fertilisers, manures, pesticides and pathogens – particularly in countries where agricultural activity is dependent on irrigation water (Ongley, 1996). Irrigation water that is returned to freshwater sources (return flow) typically contains a variety of pollutants that can cause environmental and human health problems further downstream. Runoff of salts can lead to surface water salinisation, runoff of nutrients and pesticides can result in ecological toxicity problems and trace elements also pose a threat to human health (Ongley, 1996).

Mitigation of diffuse agricultural pollution is therefore essential to ensure that farm produce is of sufficient quantity and quality (whether for subsistence purposes or large-scale commercial enterprises), to protect the environment (whether on a voluntary basis or to reach legal requirements) and to avoid negative impacts on peoples' livelihoods. Such measures may tackle the contaminant at

source, mobilisation, transport or delivery from land to water, but they must always be sustainable. Reducing and preventing diffuse agricultural pollution is always challenging and is compounded in parts of the world where climatic conditions are unfavourable, resources are scarce and infrastructure is under-developed. Understandably in such circumstances, environmental matters are often perceived as being of little importance.

In many countries legislation and regulation have become effective at tackling point sources of pollution, which are relatively easy to identify and monitor. Compared to point source pollution, there have been relatively few studies into the extent and impacts of diffuse agricultural pollution in developing countries. However, DEFRA (2002) concluded that diffuse pollution and its impacts are increasing throughout the UK (total nitrogen loads up to 9,700% higher in UK lakes in 1988 compared to 1931) and that such sources now need to be identified, quantified and controlled, in order to protect water quality. Such conclusions are likely to be valid across the world (Pearce 1998).

2.2 Water as a livelihood asset: multiple uses of irrigation and drainage systems

Whilst irrigation systems are often designed for a single purpose, there is a wide recognition that they do have many other uses (see, for example, Bakker, et al 1999) and that these secondary purposes are of critical local importance (Hussein, et al, 2005) – particularly for ensuring a positive impact on poverty reduction as it is often the poorest people who are most dependant on these sources. The situation in the Kirindi Oya system[12] in southern Sri Lanka, described by Bakker is typical of many irrigated areas. Water from the irrigation system is used for

- irrigated field crops
- irrigation of kitchen gardens (from canals or groundwater)
- domestic uses (washing and bathing)
- livestock
- fisheries
- maintaining the downstream environment in a wetland ecosystem

In this case, canal water is not used directly for drinking[13], but leakage from the canal system does recharge the shallow aquifer from which some drinking water is taken. Canal and drainage water is also used as a raw water source for treated drinking water supplies.

The water quality requirements for irrigation of field crops are generally not very stringent[14], and it is salinity which most commonly limits the re-use of drainage water for irrigation[15]. However, other uses

[12] This is the adjacent catchment to one of our case study sites in the Walawe catchment, but is further into the dry zone and has a slightly more extreme and dry climate

[13] Such surface waters are invariably highly polluted in bacteriological terms and are unfit for human consumption - few people would willingly drink it, except casually when working in the field; we did not find anyone dependent on untreated canal water as their drinking water source, we believe that this is extremely rare in the study countries and indeed worldwide although we have observed this is in some places such as Kyrgyzstan (Mott MacDonald, 2005). This is rare and provision of safe drinking water should be a priority in such places.

[14] although the limits for nitrate in Egyptian irrigation water are more stringent than those of the WHO for drinking water

[15] Use of municipal pollution from sewage does have an impact on human health and may affect soils or crops adversely (Cornish et al, 2001, regarding peri-urban irrigation), and industrial pollution can have a serious impact depending on the nature of the pollutant. However, these are outside the scope of this study, and study areas were selected which are not affected by these factors

(particularly drinking water) may have more stringent requirements for water quality: these standards may not be met if the same water is used for purposes which are not formally recognised in either the design or management of the scheme.

(i) Reuse for agriculture

In Sri Lanka water is diverted from drains either informally by individual farmers, via anicuts (generally built by the irrigation department), or via tanks (for which the Agrarian Services Department provides assistance). Water quality is not regarded as an issue by any of these individuals or agencies, and no formal guidelines either exist or are considered necessary in Sri Lanka. In Egypt, water salinity is more of a concern, so drainage water is less used and is managed either as a last resort at times of extreme shortage by individual farmers, or by pumping drainage water into canals. Formal reuse pump stations are managed by the irrigation department so as to limit salinity of the mixed water. Other water quality parameters are generally not considered significant, but more comprehensive guidelines have recently been prepared (NAWQAM, 2004) covering a range of parameters - including pesticides and nitrate.

(ii) Drinking water and domestic uses

Water is not used in Kirindi Oya directly for drinking (Bakker et al 1999), but leakage from the canal system does recharge the shallow aquifer from which some drinking water is taken. The tanks and canals are also used as a bulk supply for piped water supplies, which is then treated by filtration and/or chlorination. These observations are equally true of many irrigated areas, including the study sites in Egypt and Sri Lanka.

Some of these uses are formally recognised: there are quantitative rights to abstraction for drinking water schemes, and these are given priority over irrigation at times of shortage. Informal drinking water supplies (ie shallow wells), however, do not have such protected rights: well water levels rise because of seepage, but may be adversely affected either permanently by canal lining (Meijer, 2000) or seasonally by canal closures.

Bacteriological quality is usually the most important factor for drinking water (and is the reason untreated canal or drain water is so rarely used for drinking), but chemical quality of shallow groundwater is often more of a concern. Geochemical factors are important in Sri Lanka, where high fluoride concentrations are of particular concern although many people continue to drink the water. Salinity limits the use of groundwater for drinking in Egypt. Agrochemical pollution is less serious than these issues, but high nitrates are associated with some health problems and many diseases have been attributed to chronic exposure to low levels of pesticides. Those who rely on agro-wells within cultivated areas are particularly vulnerable to such exposure.

Domestic and recreational uses of canals are very common, even in areas with a piped supply as the large volume of water in canals makes them attractive sources. Water quality is less significant for such uses, with appearance and turbidity being dominant factors – particularly in drains. Disease transmission by bathing in canals is possible: schistosomiasis is the most important risk, but this is essentially unrelated to water quality[16]. This is common in Egypt[17], and restricts the amount people

[16] transmission depends on contamination of surface waters (in which people bathe) by human faeces or urine from infected people and which are inhabited by certain species of snail

bathe in canals. All water-borne diseases can be transmitted through bathing water, although domestic hygiene is a much more important transmission mechanism (Feachem, 1978). Various zoonoses, such as leptospirosis, cryptosporidiosis and giardiasis, could be theoretically be transmitted via bathing in rivers in which buffalo have wallowed further upstream. However, the infective dose is such that the risk through this route must be extremely low[18].

(iii) Fisheries

Fisheries are important in Kirindi Oya both in tanks and coastal lagoons (Bakker et al, 1999). There are fisheries cooperative societies for managing fisheries in irrigation tanks (reservoirs). However, these organisations are not involved in management of the irrigation system – and this can lead to conflict (for example over water levels in tanks, or access of cattle to canals). Lack of integrated management of fisheries and irrigation is a common problem (Nguyen-Khoa et al 2005). In this case, fisheries developed around small seasonal flows in the streams, and brackish coastal lagoons but now have to cope with larger, perennial low-salinity drainage water.

There are several categories of fisheries in irrigated areas in Egypt and Sri Lanka

- Formally licensed fisheries in tanks and lakes, which are systematically managed and may be restocked. Only those who are registered members of the fisheries societies are eligible to take part in these;
- Informal fishing on a casual basis in canals, drains and tanks (sometimes leading to conflict with the fisheries societies). This is usually a supplementary source of income or nutrition. Some people may collect molluscs, which are most vulnerable to poor water quality
- Fish farming may also be practised in irrigated areas.

Water quality is also significant for fisheries, as quality can affect fish numbers, quality and species distribution either through several mechanisms

- direct contact with pesticides in water or macrophytes
- through a change in salinity
- indirectly, as a consequence of eutrophication, which will affect fish habitats.

(iv) Livestock

Livestock are traditionally very important in the dry zone of Sri Lanka, and they graze on the relatively large areas of land for which there is too little water to grow crops. Increasing development of irrigation has enabled greater cultivation and reduced the grazing areas – which has led to potential conflict between livestock and agriculture. In this area, agriculture is largely mechanised so that cattle are not needed for ploughing. In Egypt, however, people are more dependent on cattle for both draught

[17] it occurs in many parts of Africa and Latin America. One form is found in parts of south-east and est asia, but not in Sri Lanka (Oomen et al 1994)

[18] Norman Begg, Iain Blair, Ralf Reintjes, Julius Weinberg, Jeremy Hawker (2005) Communicable Disease Control Handbook , Blackwell, Oxford

power and as a source of manure. This is a common situation in farming systems in many parts of the world and there is usually more complementarity than conflict.

Canals and drains are the main sources of water for cattle, and are particularly important for buffaloes which need to wallow, although the amount of water they consume is not significant. However, they do have an impact on water quality, can contribute towards eutrophication, and can damage infrastructure.

In many places, such as Egypt where there is no natural grazing and all fodder is grown on irrigated land, assessment of the environmental impact should take account of the differences in cropping needed: fodder crops are likely to have a lower requirement for agro-chemicals.

As is so often the case, cattle owners' societies have been established for livestock farmers in Sri Lanka. However, like fisheries societies, these organisations are not involved in management of the irrigation system, and do not have any formal contact with irrigation system managers – and this can lead to conflict (for example, over access of cattle to canals).

(v) Summary

There are three distinct economic activities dependent on water in and downstream of the irrigated area: agriculture, livestock and fisheries. Domestic and recreational uses of water are important for a wide range of people, but generally the poorest people who are less likely to have reliable access to tap water are must dependent on surface water, and are thus most affected by water quality.

As will be discussed below, these livelihoods are particularly vulnerable to changes in water quality and quantity.

2.3 Impact of land and water management on water quality

2.3.1 Introduction

As agriculture is the major user of water in rural areas, it can be expected to have the main impact on downstream uses. The main impact is on the quantity of water in the various watercourses. Irrigated agriculture consumes large quantities of water, and a substantial quantity is 'lost' to groundwater or drains. Some of this lost water can be reused but only in other times or places – downstream irrigation users often complain that they only receive water when late in the season when it is of no use and just causes flooding (see eg Mott MacDonald, 2005). This is true at the tail of the study area in Sri Lanka (Seneratne and Clemett, 2003).

Although the flows in natural or artificial drainage channels may increase causing problems of flooding or reductions in salinity, there is usually a large reduction in downstream flows in the rivers from which water is diverted, with numerous impacts on both quantity and quality (Adams, 1992). The difficulty in managing the quantity of water means that quality issues are largely ignored. If quality is an issue it is usually only salinity that is considered (El-Sayed, 2005): agrochemical pollution is almost always ignored. The reduced volume of water in these channels means that there is little water to dilute such pollutants which may thus be recorded in relatively high concentrations (de

Silva et al 2001, who deducted organochlorine pesticides in the Walawe river downstream of the main irrigation offtake)

Water uses can be divided into categories: consumptive and non-consumptive. Irrigation is the main consumptive use, with water being diverted from the river channel for use by the crop or evaporation: only a small proportion of water is returned to the river or other watercourses. Most other uses are non-consumptive, but may pollute the water. Some involve diversion from the main channel and then returning it further downstream – hydropower is a common example, although not one found in the study areas. This can cause local problems of water quality or quantity – as is found further upstream in the Walawe river (Molle et al, 2005)

2.3.2 Changes in water quality - nutrients

(i) Introduction

Fertilisers are applied to land by most farmers, in some cases in excessive quantities. Nitrogen is an essential nutrient which is found naturally in soils and may be supplemented by atmospheric deposition of nitrogen. Some crops can also fix atmospheric nitrogen – which is an important feature of many crop rotations. These sources usually, however, need to be augmented artificially by fertiliser to increase crop yields. Amounts and forms of nitrogen this vary in time and space, but there is an overall balance of nitrogen – this is achieved through removal of nitrogen by crops, changes in organic and mineral nitrogen in the soil, volatilisation, leaching and runoff.

A proportion of the total nitrates are dissolved and lost to surface or groundwater. The quantity and timing of applications relative to crop requirements and rainfall or irrigation, and the characteristics of the soil have a profound influence on losses and hence on water quality (Hatch et al, 2002). To some extent this inevitable – particularly in arid regions where additional water needs to be applied to leach salts into the drains - but it can be minimised by careful timing and appropriate agricultural practices.

Most discussion of nutrients relates to nitrates since although phosphate fertilisers may be used excessively, phosphates are generally well-retained in soils, and are less of a pollution threat. Only soluble reactive ortho-phosphate (SRP) is generally associated with the soluble phase, but concentrations in drainage water are not generally high enough to contribute significantly to eutrophication.

The intensity of fertiliser use has implications for agricultural production and the potential environmental impacts of nutrient run-off from farmland. Agricultural research in the UK, summarised by Defra (2004), shows that nutrient requirements (and hence consumption) vary for different crop types and are influenced by previous land management, soil type and climatic factors. Fertiliser applications should not exceed the crop requirement and should account for soil organic matter, crop residues and organic manures. Furthermore, timing of the fertiliser application should coincide when it is needed for crop growth. Where these principles are ignored there is an increased risk that nutrient run-off may occur. In Europe the EC Drinking Water Directive, enacted in 1980 and effective in 1985, established a maximum admissible nitrate (NO_3) concentration of fifty mg/l. Previously, however, a higher limit of 100 mg/l had applied in England; even that level was advisory, and water with more nitrates was not considered polluted. In Europe the Nitrates Directive seeks to control nitrates from agriculture requiring measures to be implemented restricting the use of inorganic

and organic fertilisers in designated areas where surface or ground waters exceed or are at risk of exceeding nitrate concentrations of 50 mg/l.

Fertilisers are subsidised in many countries (including Sri Lanka, where increased fertiliser subsidies were promised in the recent presidential elections) – particularly by of fertiliser applications and irrigation to ensure that most is taken up by crops. Fertiliser applications are much higher in Egypt, but these are no longer subsidised – partly to reduce the environmental impact (see Chapter 4)

(ii) Egypt

Some studies in Egypt have shown high nitrates in drainage water (Abdel Dayem, 1992), and this is considered to be of concern because of the problems of increased weed growth that it causes. Nitrates are naturally most concentrated in field drains (where up to 150 ppm was detected) but are diluted in surface drains by irrigation losses and direct runoff. Nevertheless, the concentrations remained high enough to cause problems. They also detected nitrates in groundwater, but at lower concentrations (35 ppm) – this was in shallow wells which are not safe for drinking (for other reasons).

Although salinity is traditionally regarded as the most serious water quality problem in Egypt, Van Achthoven et al (2004) now regard organic and inorganic pollution of drains as more serious that rising salinity in Egypt – they highlight bacteriological pollution, ammonia and cadmium but remain uncertain about accumulation of pesticides due to lack of data. The also noted very high levels of BOD (reporting 98ppm as compared to a standard on 10 ppm). This is a logical conclusion from the studies of coastal lakes in Egypt, where van Achthoven considers that eutrophication from agricultural pollution has had a greater impact than the reduction of salinity in damaging aquatic ecology. It has reduced fish quality and created anoxic conditions.

However, they still consider industrial pollution (heavy metals and BOD) to be of the greatest immediate concern. Lake Qarun is slightly eutrophic (Harza 2000), but phosphates are the limiting nutrient and these are supplied more from municipal sources. Effluent from Batts drain, which originates close to Fayoum city and is highly polluted with urban waste, is the main source of pollutants in Lake Qarun. The western part of the watershed, including that draining into Wadi Rayan lakes has less municipal waste and thus eutrophication is less of a problem. Gupta et al (2003) also review water quality in the lake and reported a significant decline in many chemical parameters although not in nitrates, and they did not monitor pesticides.

Lake Maryut (a small and highly polluted lake on the outskirts of Alexandria) has been the focus of several studies. (Saad, 2003) reporting on studies in the 1980s concluded that the problem was largely of agricultural origin. Boltz & Hinckley, however, reviewed the status a decade later in the context of designing waste water disposal facilities and concluded that agricultural pollution was relatively less important than municipal waste. In other studies in Egypt, El-Fayoumy measured nitrogen losses after irrigation of field plots, and detected elevated nitrate levels in drainage and groundwater. They concluded that frequent small applications of fertiliser would reduce losses and increase efficiency of use. Abdel Gawad (2002) reviewed the drainage reuse policy in Egypt and largely focused on salinity. This he stated to be the immediate problem, although he ranked it less serious than bacteriological, pesticide, metal and nutrient pollution. He does not examine these in detail but considers the main health risks to be through consumption of crops irrigated with polluted water. Pollution from agrochemical sources thus still appears to be more of a potential problem in Egypt than the main determinant of surface water quality, although the number of rigorous studies appears to be very small.

(iii) Sri Lanka

The situation in Sri Lanka is slightly different from Egypt Fertiliser application rates are generally lower, rainfall is higher and there is little recharge of groundwater in much of the country. Thus excess nutrients tend to get washed off and diluted, leading in most places to wastage but not excess concentrations. There are, however, important exceptions – particularly in areas where vegetables are the dominant crops: the Sri Lanka State of the Environment Report (SoER 2001) identifies nutrient pollution of water from agriculture as being an important aspect of pollution, along with urbanisation and industrialisation.

Most research on the impact of fertilizer application appears to have been concentrated in the highlands where intensive vegetable cultivation takes place and much less has been done in the intermediate zone of Sri Lanka where paddy production is highest - although the application of chemical fertilisers, particularly N and manure, to rice paddy is also important (Sirisena *et al.*, 2004),

Gunatilleke (2004) for example underlines the influence of the use of nitrogenous fertilisers on groundwater. A study carried out by Gunawardena *et al*. (1998) concluded that stream water quality of the major watershed areas in the upcountry had already deteriorated to alarming proportions, due to intensive agriculture and unsound practices including high levels of fertiliser and pesticide use for vegetable production. The comparative study took place at Horton Plains, an area of natural montane forest and grassland located in the eastern edge of the wet zone, and Black Pool village 10km north, an area of intensive irrigated agriculture. During the rainy season, excess water drains out of the fields, back to the stream, thus helping to transport pollutants downstream. The study found nitrate levels in stream water in excess of WHO recommendations (10mg/l for potable use) at Black Pool for most of the Yala season. Nitrogen concentrations detected in in stream water quality in Black Pool ranged from 0.163 to 63.8 mg/l NO_3-N and 0.0 to 1.68 mg/l NH_4-N. For comparison, the figures in the undisturbed catchment in Horton Plains ranging from 0.0 to 1.37 mg/l NO_3-N and 0.0 to 0.32 mg/l NH_4-N. They observed application rates of organic fertilizer to be 10-13 tons/ha/yr on a dry weight basis, equivalent to around 500 kg/ha/yr. The application of both organic and inorganic fertilizer was found to be double that recommended by the Department of Agriculture.

In the North Western Province 79% of the 12,000 large diameter shallow wells in the region had nitrate concentrations above levels advocated by WHO (as high as 200 mg/l) according to SoER (2001) and this was attributed to fertiliser and agro-chemicals. UNEP (2003) cite work published by Nagarajah et al (1988) who reports of high groundwater nitrate concentrations in the shallow limestone aquifer beneath the Jaffna peninsula with concentrations in excess of 50 mg/l and rising to more than 175 mg/l. In general the highest concentrations were associated with intensively cultivated areas where 2 to 3 crops of vegetables and tobacco were raised each year, requiring large quantities of fertiliser and manure. A similar pattern was observed in Kalpitiya Peninsula where double or triple cropping of onions and chillies were undertaken, with heavy use of nitrogen fertiliser on permeable sandy soils overlying a sand aquifer. Jayakody (2002) investigated soil fertility and nutrient contamination in another area of intensive vegetable production in the central highlands and found low phosphorus levels but nitrate levels in drinking water wells in excess of WHO recommendations. In some cases they observed algal growth in wells with high nitrate levels.

However, this is not a universal pattern – even in areas of intensive input use: de Silva (2004) noted very low N in agro wells in vegetable-growing areas of Kurunegala district, which he attributed to the soil type, groundwater depth and rate of abstraction. Wijewardena *et al.* (2001) came to a similar conclusion in another area of intensive vegetable cultivation in the upcountry region and found nitrate

levels in groundwater below 2.5mg/l, well within WHO recommendations for drinking water, despite excessive fertiliser use (particularly potassium fertilisers and organic manure). He also attributed this to the local soil type, although he gave no details of the nitrogen balance calculation. Phosphorus concentrations were also measured and found to be very low (below 1mg/l). However, potassium was present in appreciable amounts (1.3 – 22.7 mg/l) and may be attributed to the apparently high level of potassium fertilizer application.

Work in this field is largely limited to analysis of groundwater, although a study compiled by Matsuno (1998) on multiple uses of water in Kirindi Oya system, Hambantota district, included analysis of the quality of surface water, groundwater and the Embilikala Lagoon – including nitrate, nitrite and other chemical parameters. These were all found to be within the standards for drinking water. Considering the stringency of this standard and the fact that surface water in the drains is never or rarely used (except after treatment), this suggests that agro-chemicals are not posing a major threat to health, the environment or downstream users.

There are several eutrophic lakes in Sri Lanka, but all those mentioned by Dias (2004) are in municipal areas. There is one example of eutrophication which has been attributed to agricultural pollution through fertiliser runoff. This is the Kotmale reservoir (Piyasiri 1995, 2000) which is surrounded by a large number of adjacent tea estates. The low importance given to agricultural pollution in Sri Lanka is evident from the fact that it is not mentioned in national policy.

(iv) Other countries and regions

Elsewhere in Asia, similar low levels of problems due to fertilisers are reported. Li Zhang (1999) notes that there is slight and increasing nitrate contamination from fertilisers in Huanghe (China) where input use is very high. In India, Agrawal (1999) reports that nutrient levels are still extremely low (although slightly elevated levels are detected in some groundwater) as chemical applications are still low. He is more concerned by the large number of buffalo (as well as humans) bathing in the water courses, and believes that soil erosion is a more significant form of agricultural pollution. Similarly Tonmanee (1999) reports that there is no problem of fertiliser pollution yet in Thailand.

Livestock are an important source of nutrient supply to watercourses in some places Organic wastes from agriculture include cattle, pig and poultry manure and are valuable sources of most plant nutrients as well as acting as soil conditioners and structural improvers. In Egypt, manure is commonly used in place of commercial fertilisers (FAO, 2003). Livestock manure contains environmentally significant quantities of nitrogen (ammonium being the principal inorganic form), and phosphorous, and thus has a potential impact on eutrophication and nitrate pollution of water. Livestock manure if misapplied to land can pollute water courses primarily through the capacity to utilise oxygen during the breakdown and oxidation of carbon, nitrogen and sulphur compounds present in the waste[19].

In the UK manure and silage effluents together make up over 70% of farm pollution incidents and these are mostly point source impacts arising from farm yards and buildings that house livestock, and the incidence of land runoff are small averaging 12% of all agricultural incidents between 1996 and 1998 (Foy et al.). The predominance of point source farm pollution makes it difficult to assess the

[19] Other water quality hazards from livestock wastes include animal pathogens, some of which can cause human diseases. Diseases of animals which can be transmitted to humans are referred to as zoonoses – leptospirosis being one example relevant to this study

impact of land spreading of manures on water quality, although Foy and Kirk (1995) found that BOD and ammonium concentrations in 42 small rivers in two Northern Ireland river catchments were positively correlated to animal numbers and hence manure and silage production.

2.3.3 Changes in water quality – pesticides

(i) Introduction

Pesticides can play an important role in agricultural production, but their use can have negative environmental impacts on water quality and aquatic biodiversity, while pesticide residues in food can have implications for human health. The term pesticide used here includes herbicides, insecticides and fungicides and other biocides (such as nematicides).. In an agricultural system, pesticides may be applied directly to the plants, to the soil's surface, or to the soil below the surface. Pesticides can be lost by degradation, evaporation and other dissipation processes from each location.

Pesticides may reach both surface and ground waters by several pathways including surface runoff, erosion, leaching, spray drift (when crops are sprayed near canals or drains), improper disposal of containers and accidental spills (O'Neill, 1990) as well as deliberately (in order to control water weeds, snails or mosquito breeding grounds).Jongbloed (1999) reports that spray drift is the main route for pollution of water bodies. Irrigation technology can govern the fate and transport of a pesticide in soil through control of the soil moisture regime. Pesticide fate (and hence environmental risk) is primarily governed by vapour pressure, sorption characteristics, solubility in water, and environmental persistence (Binks et al., 2002). The persistence of pesticides in the environment is dependent on factors such as their susceptibility to attack by micro-organisms and enzymes, and soil and water temperature - pesticides tend to break down better in warm, moist soil than in cool, dry soil.

Pesticides reach water as a result of point source or diffuse pollution. Point source pollution can be from spills that occur when pesticides are mixed or loaded, and are small areas of high concentrations of pesticides that can contaminate large areas of water over time and are most likely to cause acute incidents. Pesticides also make their way into water from fields where they are applied and these inputs are termed diffuse sources. Most of the pollution of aquatic systems by pesticides comes about primarily through their legitimate use, although spills and illegal use and disposal are also implicated.

Leaching of pesticides occurs when the substance is moved through the soil in solution, for example with drainage water or run-off. Normally soil will act as a filter in this process leaving the water relatively free of pesticides, but differences in soil and pesticide properties influence this movement.

Vapour pressure governs the tendency for pesticides to volatilise and be lost to the atmosphere in gaseous form, while sorption properties govern bonding to organic and inorganic soil surfaces. Sorption properties limit the mobility of pesticides in the environment, and are influenced by factors including soil organic matter and clay content and soil pH. Pesticides with greater water solubility often have lower sorption behaviour which makes them more mobile in the environment and hence more prone to leaching to water bodies. Environmental contamination from pesticides also occurs from spills from the sprayer tank (Williams and Croxford citing Harris *et al*., 1991) and the washings from the cleaning of the sprayer equipment (Williams and Croxford citing Higginbotham *et al*. 1999).

The persistence of pesticides in the environment differs greatly and is dependent on factors such as their susceptibility to attack by micro-organisms and enzymes, and soil temperature and water content.

Several of these processes are influenced by irrigation and different irrigation practices affect the way water enters, and moves through, the soil and have profound effects on whether there is runoff and whether agrochemicals will be leached remove or left in place (Pearce, 1998).

The residues of pesticides in food and water are a concern since pesticide products are deliberately introduced into the environment and are designed to kill target pests. In England the Water Supply (Water Quality) Act set maximum acceptable levels for pesticides in water intended for human consumption of 0.1 ug/l for a single pesticide and 0.5 ug/l for all pesticides. Improvements in drinking water with respect to the 0.1 ug/l limit are largely attributed to improved water treatment, but may also be because of the introduction of more environmentally benign active ingredients (Williams and Croxford) or the adoption of improved methods of application and administration of pesticides.

Pesticides are used in much smaller quantities than fertilisers, and they are more difficult and more expensive to detect. Considerable effort has gone into modelling the environmental fate of pesticides, but this is too is complex as there are so many different factors (Silsoe, 1998). The MAMAS project is attempting to set and calibrate a model in Sri Lanka: the initial results (MAMAS, 2005) are promising but more work needs to be done. Factors that influence the fate of pesticides in water include:

- Application method
- Timing relative to irrigation / rainfall
- Pesticide characteristics (decay rate, solubility, sorptivity)

Few systematic studies have been done anywhere in the world, and none in Egypt, Sri Lanka or other comparable countries, where only a few spot measurements have been made. A detailed study of the impact on water quality in Sweden by Kreuger showed a very variable response to pesticide application in Sweden (varying by orders of magnitude). The response would be different in Egypt where, for example, application methods are less carefully controlled, temperature is much higher, there is no rainfall, and field drains are piped, but large variations would still be expected.

(ii) Egypt

There are some studies of pesticides in Egypt but most of these dates back to the 1980s when there was concern over high concentrations of persistent organochlorine (OC) pesticides such as DDT, and crude methods of application such as aerial spraying. Studies in 1980s found OCs in Lake Maryut (Saad, 2003) and demonstrated that this was mainly of agricultural origin. Shereif found that most people preferred to eat fish from areas affected by agricultural drainage where OCs were detected to parts of the lake fed by treated sewage where water is of better quality.

The environmental fate and behaviour of pesticides in Egypt has been a concern since the 1970s. Much of this research is related to the persistent organochlorines such as DDT, and little specific recent information is available. Pesticides have been detected in the Nile, its canals and drainage systems (Saad) as well as the coastal lagoons. Saad reviewed studies undertaken during the 1970s and 1980s, which found lakes in the Nile Delta to be polluted with agricultural pesticides and fertilisers as well as sewage and industrial wastes. DDT and its metabolites were detected in water, sediments and fish in Lake Maryut, even though it had been banned several years earlier. Bioaccumulation effects were observed, with fish containing higher levels of pesticides than water, and sediment containing higher levels still. Seasonal variations in pesticide concentrations at the coast were attributed to climatic conditions and discharge rates (Saad).

El-Sebae (1989) also provides an overview of the fate and undesirable effects of pesticides in Egypt. He reports that the relatively high levels of chlorinated insecticides in soil years after cessation of application reflect the high persistence and long half-life of such compounds in the soil. El-Sebae also discusses some of the negative impacts of pesticides, notably the chlorinated hydrocarbons and their persistence in soil, lake sediments and the food chain commenting on the "relatively high levels of chlorinated insecticides in soils years after cessation of application reflect the high persistence and the long half-life of such compounds in the soil". The adverse affects identified by El-Sabae of chlorinated insecticides include the negative effects on soil organisms, including earthworms, collembolans and insect larvae, phytotoxicity in corn affecting plant height. Adverse impacts of organophosphorus insecticides such as trichlrofun and DDVP, were reported to be delayed neuropathy in man.

Organochlorine pesticides were considered to be of a threat to the aquatic environment in the Fayoum (Van Zon & Kevin, 1992), with DDT believed to be in use for many years after it was banned. Fish species from Fayoum were found to be near to the safe limits prescribed under Egyptian Law in certain cases. They also considered that use of pesticides was increasing even on low return crops, such as rice, wheat, beans and maize because of growing resistance

These studies are of some relevance to the present situation, and because of their persistence these pesticides continue to impact on livelihoods (eg through fish). Such pesticides are, however, now banned and new pesticides have different characteristics and curiously there are few recent studies of pesticides in water. Tchounwou (2001) in one of the few recent studies in Egypt found pesticides in soil and water in Sharkia governorate. He also found contamination of milk, fish and fruit, and reported that aldicarb (0.12 ppb in water) and carbosulphan (0.15 ppb) were of particular concern for health after taking account of actual exposure. Tchounwou also detected methomyl (0.1 ppb), larvan (0.01 ppb), pirimicarb (0.28 ppb), DDT (0.03 ppb), chlorpyrifos (0.02 ppb) and anilofos (0.06 ppb) in water. These concentrations were not considered to be of concern to health because of the low exposure. Unfortunately the paper does not fully describe the rationale of the sample selection but they included canals, fields and field drains.

In parts of Egypt, intensive pesticide use has resulted in disease resistance, and has led to a gradual change in recommendations. For example, Toxaphene was phased out of use in the early 1960's because of its failure to control cotton leafworm (El-Sabae, 1989) and replaced by Carbaryl and trichlorfos which also failed after 4-5 years due to resistance. The need for food security in arid and semi-arid climates means that pesticides will continue to be used for the foreseeable future, however integrated management systems will increasingly need to be used to minimise the effects on the environment (El-Sheikh, 2003).

(iii) Sri Lanka

Sri Lanka has given high priority to investigating issues relating to indiscriminate use of pesticides, and their impact on human health and the environment (Nugaliyadde *et al*., 2003), but research has focused on the direct health impacts of occupational and deliberate pesticide poisoning. Hospital data in Sri Lanka shows that the majority of the 11000 pesticide poisoning cases admitted each year (Senanayake, 2002) are self-inflicted, mainly by young adults living in rural agricultural areas where agrochemicals are easily available. In several agricultural districts it precedes all other causes of death in government hospitals (van der Hoek and Konradsen; in Smit, 2002). Whilst this obviously does not relate to diffuse agricultural pollution, it raises issues around storage, use and availability of dangerous

chemicals for agricultural purposes. In Mahaweli H system for example, where a very high incidence of serious pesticide poisoning was observed, 68 % was due to intentional ingestion of liquid pesticides. In Embilipitya and Chandrikawewa hospitals 242 cases of pesticide poisoning were admitted in one year, of which 83 % were intentional poisonings and in the 149 cases where the container was available for inspection almost all involved organophosphate insecticides (van der Hoek and Konradsen; in Smit, 2002). Similarly 75 % of the cases presented nationally involved organophosphorus insecticides (Senanayake, 2002).

Occupational poisoning by exposure to pesticides is less well documented in Sri Lanka (van der Hoek *et al*., 1998; cited by Smit, 2002) but 24 % of farmers surveyed (n=122) had suffered at least once from acute occupational pesticide poisoning, reporting symptoms of fainting or unconsciousness, vomiting, nausea, blurred vision, headache and dizziness (Smit, 2002).

Pesticide laws have been evolving in Sri Lanka since 1962 and many substances such as DDT and endrin have now been banned, resulting in a decline of 60% in pesticide imports between the mid 1980s to the mid 1990s,. However, organochlorine compounds, including DDT, are highly persistent in the environment and can still be detected years after their usage has stopped. This time coincided with an increase in the herbicides which are now very widely used for rice (which is broadcast rather than transplanted, making weed control critical). In the 1980's, pesticides and fertilizers were subsidised and used together as packaged technologies for blanket application, in many cases without consideration for the nature of the rice crop or efficient use of the chemicals (van der Berg, 2002). With the growing concern over the impact of use (and abuse) of pesticides this policy was changed. In recent years, Integrated Pest Management (IPM) has been promoted by the Department of Agriculture to reduce the use of chemicals.

It is estimated that an average of 0.7 kg/ha of active pesticide ingredients is used in Sri Lanka, compared to 0.6 kg/ha in Thailand and 0.15 kg/ha in India. According to Nugaliyadde *et al.* (2003), efforts made by regulatory authorities, extension services and pesticide industries to educate farmers on correct pesticide usage have been unsuccessful in reducing environmental contamination. Van den Brink *et al.* (2003) similarly found that the majority of farmers that they interviewed in the North Central Province of Sri Lanka were aware of the hazards of pesticides and the safety measures for their application, but largely ignored them.

The application method and timing of agrochemical is also important in understanding their fate and likely impacts. Spray drift, drainage, runoff, atmospheric deposition and accidental spills can all contribute to the contamination of watercourses. Van den Brink *et al.* (2003) undertook a preliminary risk assessment as part of the Managing Agrochemicals in Multi-use Aquatic Systems (MAMAS) project in Sri Lanka and Thailand, focusing on spray drift which they consider to be the main route for contamination of watercourses. As would be expected in a risk assessment they made worst case assumptions at each step. For example, it was assumed that there would be 100 % drift across the irrigation canal surface as applications are close to the field canals which are very small, and that all drinking water was taken from these canals, but a second scenario was also run in which decay and other factors were included. The report concluded that there was a high risk to aquatic ecosystems and human health through contaminated drinking water and fish consumption. In the subsequent fieldwork they found elevated levels of pesticides in watercourses close to the points of application and are using this data to calibrate a model of pesticide fate (van den Brink et al, 2005): this work is still in progress.

Aponso *et al*. (2003) analysed water for pesticide residues in tanks and drinking water supplies in two major agricultural areas of the dry zone of Sri Lanka. They also surveyed the local population and found that pesticides were being used incorrectly and excessively, thus posing a risk to their own health and the environment. Despite this, pesticide residues were not detected in most samples. This perhaps surprising result, given the known agrochemical use, was attributed to enhanced dissipation caused by hot weather conditions, higher radiation, basic pH and organic carbon in the water, and unavailability of long persistent pesticides. Aravinna *et al.* (2004) did detect pesticide residues in irrigation wells, but only from high yielding wells located in the middle of a cultivated field. Shallow wells located outside the field showed no traces of pesticide residues, suggesting that this is not likely to be a major health concern.

Ravasinghe (2004) attempted to quantify through a single field trial of propanil (a common post-emergent selective herbicide for ric) loss from a paddy field. However the loss of propanil with runoff in a wet zone paddy field in this study was negligible.Ravasinghe detected concentrations in the outflow after 2, 7 and 11 days of 6.135 µg/l, 1.293 µg/l and 0.116 µg/l respectively. There is no guideline set for propanil and it would be inappropriate to develop one as it is readily transformed into metabolites. These metabolites are more toxic but there are inadequate data to enable the derivation of guideline values for them (WHO, 2004).

Pesticide concentrations tend to quickly drop below detectable levels in rice field water, by means of adsorption, degradation and volatilization (de Silva, 2003). This may explain why, in spite of their wide usage, detections in water are rare. Water quality of Kala Oya Basin, measured for MASL by the Centre for Analytical Research and Development (CARD), (2003), involved surface water and groundwater quality studies, and found pesticides to be below detection limits[20]. Crop products (chillies) grown in the Kala Oya catchment have been rejected from international trade in the past, because they contained traces of pesticides (Perera, Pers Comm.), but this relates to application practices rather than water quality.

The cost and difficulty of monitoring pesticide in water has led many people to model the fate of pesticides rather then measure it directly. Watawala *et al*. (2004) have ranked the four most commonly used pesticides according to their leaching potential. Carbofuran was found to pose the greatest risk to the environment, followed by Propanil, MCPA and penthoate Trials using LEACHM (Leaching Estimation and Chemistry Model, which predicts leaching on the basis of solubility and decay rate) found that the fate of pesticides varied widely between different types of pesticides and among different soil series under different agro-climatic zones. Several particular soil series were identified as being at high risk of groundwater contamination by 2,4,D (Adikaram, 2002).

Kumari (2004) also found that predicted leaching losses were negligible for diuron, chlorpyifos and 2,4-D in all but one soil type, through there were substantial variations depending on the soil type. Based on the model the potential for groundwater contamination from carbofuran is high in the intermediate zone of Sri Lanka. It was surmised that this was a function of the soil type in the area which is coarse-textured soil with low organic matter and relatively high saturated hydraulic conductivity. Wilasini (2004) also found that coarse textured soil in the intermediate zone had a higher potential for contamination, in this instance by propanil. Using lysimeters, Wilasini found that

[20] So far, most pesticides studies in Sri Lanka have only looked at the measured parameters with respect to recommended standards and have therefore not reported any actual measured values.

contamination occurred initially through surface runoff, and after a few days through leaching. Assessment of the fate of soil applied pesticide is necessary to minimise the adverse off-site effects (Kumari, 2004).

(iv) Other countries and regions

Globally studies focus on persistent pesticides, as these are the only ones that can easily be detected in water. Li and Zhang (1999) in Huanghe (China) found organochlorines in ground water even though they were banned long before the study (DDT and HCT were detected in paddy areas and aldicarb in cotton cropped areas). A review of studies in Turkey (Harmancioglu et al 2001) found organochlorines in surface waters (aldrin 0.9 ppb) in 1976, and reported that found predatory (beneficial) insect populations were reduced by pesticides in the 1980s. Honey bees were found to be affected by pesticides (including the herbicides atrazine and 2-4D). Aerial spraying (for malaria control as well as agriculture) was considered particularly bad. They also reported a risk to wetlands from pesticides and sediments, but whether the impacts were beneficial or harmful depended on location. Some wetlands were also affected by a reduction in salinity, with an increased risk of eutrophication due to nutrients and sediment.

Pingali reported on the impact of pesticide use in paddy field and noted that surface runoff and leaching to groundwater meant that there was a small yield benefit from pesticide use which was offset by negative effects on soil micro flora/fauna – and recommended that it would be better to reduce 80% of pesticides used on rice in Philippines.

The NAWQA study (Domagalski, 2000) in the Sacramento basin (California) detected a wide range of pesticides in surface waters. Those detected included modern pesticides with short half-lives – such as carbosulphan, propanil and chlorpyrifos, which are used in our case study areas. Water was sampled at the outfalls to two sub-basins on a monthly or bi-monthly basis for 18 months – these were a 4,274 km2 agricultural (rice-growing) area, a smaller (88 km2) urban catchment as well as the main river (60,000 km2). Pesticides were detected in the agricultural basin, but at much lower concentrations than in the urban basin. Concentrations in agricultural run-off did not exceed allowable concentrations nor did they affect aquatic life. Urban runoff was however a concern, mainly due to insecticide applications to lawns and gardens (diazinon was found at unacceptably high concentrations in all samples). Water quality in the Sacramento river itself remained of adequate quality because of dilution

In Denmark, Kronvang found subsurface drain concentrations of pesticides high, but noted that they decay very rapidly (within hours after application). Highly soluble pesticides (eg dimethoate) had a loss factor of 0.057-.088%, as compared to 0.00042-.0031% for hydrophobic pesticides.

2.3.4 Bacteriological Water quality

Bacteriological water quality is normally the most critical water quality parameter for sources used for drinking although geochemical factors may also be important (most famously arsenic in Bangladesh, but high fluoride levels are a well-recognised concern in Sri Lanka). Poor bacteriological water quality is usually due to human activity, directly by bathing and washing in canals, or indirectly through disposal of untreated or partly treated sewage in canals. Promiscuous defaecation in empty canals ensures that pathogens are ubiquitously dispersed in countries where sanitation facilities are inadequate. Very high levels of faecal coliforms are therefore to be found in canals in hot climates. This is not strictly a form of agricultural pollution, although agricultural workers do contribute to the problem.

Farm animals such as cattle are also a source of pathogens within the environment, and this will presumably have an impact on livestock health further downstream, as well as on water for recreational purposes.

Bacteriological contamination of canals and other watercourses is often an issue of high local interest, and in this study attracted much more interest than our specific concerns with agro-chemicals.

2.3.5 Eutrophication

The main impact of excess nutrients in surface waters is eutrophication - enrichment of waters with plant nutrients. Although there are many sources of nutrients in surface waters, agrochemicals are a major contributing factor. A particular characteristic of eutrophication is the production of “algal blooms”. In reality, this often leads to the complete dominance of the ecosystem by a small number of organisms, often algae. By blanketing the area, the chemistry of the ecosystem will be disrupted. Due to the increased biomass, anoxia (or partial anoxia) will often ensue, thus resulting in further loss of biodiversity, both in the water body and to the surrounding ecosystem. Algal blooms can also be potentially toxic. Eutrophication of the sea can cause “red tides”, where whorl flagellum algae eat the excess nutrients and multiply rapidly. Fish and shellfish the die as their gills are filled with the red tide plankton, robbing them of oxygen. Some of these algae secrete toxins, and people have been poisoned after eating shellfish which have fed on this particular type of plankton.

Depending on the usage, eutrophication can thus have a profound effect upon human activity. Ongley (1996) summarises the main symptoms and impacts of eutrophication, which are valid for both inland and coastal waters, as:

- Increase in production and biomass of phytoplankton, attached algae and macrophytes
- Shift in habitat characteristics due to change of aquatic plants
- Replacement of desirable fish by less desirable fish
- Production of toxins by certain algae
- Deoxygenation of water which often results in fish kills, especially after collapse of algal blooms
- Infilling and clogging of irrigation canals with aquatic weeds leading to greater maintenance costs for infrastructure or difficulties for navigation
- Loss of recreational use of water due to slime, weed infestation and noxious odour from decaying algae
- Impediments to navigation
- Adverse impacts on fishing industry, with reduced fish yields.

Nutrient enrichment of waters due to man’s activities is associated with runoff, erosion and leaching of inorganic and organic fertilizers and sewage from urban and rural populations (EC, 2002). Besides these two sources a third source, atmospheric deposition, can be significant. In Europe the European

Environment Agency (EEA) have identified agriculture as being the principal source of nitrogen pollution and industry and household waste-water as being the principal source of phosphorous pollution (EEA, 1998). The UK shows a similar trend with the largest source of nitrate in surface waters coming from nitrogen derived from agriculture (D'Arcy *et al.*). In Asia the FAO (2000) identify agricultural activities as having a negative impact on water quality that can give rise to eutrophication of water bodies. In rapidly industrializing nations or regions of Asia un-controlled discharge of human and industrial waste-waters is also contributing to a decline in the quality of water. 'Agriculture, as the single largest user of freshwater on a global basis and as a major cause of degradation of surface and groundwater runoff, has cause to be concerned about the global implications of water quality' (FAO, 2000).

The limiting nutrient for eutrophication of freshwater is usually phosphate – which is mainly from household and municipal waste, but in salt or brackish waters (such as coastal lagoons), nitrates are the limiting nutrient. These are predominantly of agricultural origin.

2.4 Diffuse agricultural pollution in wider context of water quality

Diffuse agricultural pollution is not a widely recognised problem, and locally most people are more concerned about access to water *per se.* Where people are worried about water quality they are almost invariably concerned about other parameters – usually bacteriological quality for drinking water sources, and salinity for agricultural uses. Where chemical pollution is perceived to cause problems it is usually because of obvious point sources (industrial or municipal waste outfalls) which are very poorly controlled in many countries (see IEDS 2003 for example regarding Bangladesh, and Birdlife International regarding Lake Maryut in Egypt). The most obvious impact on rivers downstream of irrigation offtakes is the reduction of water quantity (Adams, 1992). This has a secondary impact on water quality by reducing the volume in which pollutants can be dissolved

There is a growing perception that agro-chemicals may be causing problems, and sometimes various diseases are attributed to pesticides. This is reflected by general statements in literature (eg by IDRC), the popular press and public opinion, but as will be apparent from the literature review above it is hard to substantiate with hard evidence. There are undoubted problems with aspects of pesticide use – application techniques, deliberate self-poisoning, and so on – but the impact of agro-chemical pollution of water is hard to isolate. It is both more difficult to study because of its intrinsically diffuse nature, and it is masked by a number of more immediate and more obvious problems.

This lack of evidence, of course, does not mean that there is no problem, and one objective of this study is to start to fill this gap in.

Programmes are being started in many countries to elucidate the problems of water quality (particularly in Europe, in response to the requirements of the water framework directive). A national groundwater monitoring network is being established in Egypt (Dawoud, 2004) and a surface water monitoring programme (NAWQAM) has been set up – but pesticides are not included in these programmes.

2.5 Impact of deteriorating water quality

Agrochemical pollution has a relatively subtle impact on water quality, and it does not directly affect livelihood strategies until it reaches extreme levels – for example destroying fisheries (either by killing

the fish or making them unmarketable). However, it may have a number of effects which will affect peoples livelihoods and possibly cause them to modify their strategies. A recent book on the impact of pesticides on livelihoods does not even mention water quality as a problem – the influence of issues related to the direct use of pesticides are overwhelming (PAN)

There are a large number of downstream uses which are affected by irrigation development. Adams (2000) provided a review of the impacts as part of the World Commission of Dams report – although this was specifically related to the impact of large dams, the review is essentially true of irrigation development as a whole. In the context of Egypt[21] and Sri Lanka, the main impacts are due to the large increases in flows in some natural channels which are used to remove agricultural drainage flows. These discharge into brackish coastal lagoons. The large flows of freshwater change the salinity of the lagoons, and bring in sediments and nutrients. By changing the salinity of these shallow water bodies, weed growth – particularly water hyacinth – is rapid, and the lagoons soon become eutrophic. Sediment and nutrients brought in with the drainage water compound the problem. Since much of the water is diverted away from the source river, there is little water left in the river channel to dilute polluted return flows - resulting for example in high pesticide concentrations, (de Silva 2001).

(i) Egypt

Nutrient enrichment of drains and lakes is affecting the potential of water bodies such as Lake Maryut to be used for recreation and the fishing industry and increasing the cost of keeping them clean and open. Saad (2003) concludes that a substantial reduction in both fertilisers and pesticides will be required to restore water quality. In some places the Egyptian limit of 30 ppm of nitrate in drainage water to be reused for irrigation (based on the FAO (1985) classification of irrigation water) is at risk of being exceeded. Whilst lower concentrations can be beneficial to a crop, excess nitrogen can result in yield loss. For example, Pescod (1992) cites Morishita (1985) who reported that nitrogen enriched water can supply excessive nutrients to rice plants resulting in lodging, failure to ripen and increased risk from pest and disease attack due to excessive vegetative growth.

Fish sampled at Wadi Rayan were found to contain high levels of heavy metals, particularly cadmium and lead (Ministry of Water Resources and Irrigation, 2000). Indeed, heavy metals from Fayoum fish farms are reported to be among the highest in Egypt. Although no data is available on the source of these metals, cadmium is known to be present in phosphatic fertilisers. Pesticides were also noted to be an extensive contaminant of fish. Residues found were lindane, chlordane, aldrin and DDT-isomers, with the latter two reported as being 10 and 300 times the maximum allowable concentrations respectively (Ministry of Water Resources and Irrigation, 2000).

Wadi Rayan (together with Lake Qarun) has a number of ecological and socio-economic functions being a unique resource of surface water located in a desert landscape with negligent rainfall. Although the area of study is centred around Wadi Rayan, Lake Qarun may serve as a useful comparison, in that Qarun has been subjected to incoming water from drainage for a far longer term than Wadi Rayan. Therefore, the state of the waters of Lake Qarun may serve as an indicator of the possible future of Wadi Rayan. Also, successful mitigation measures for Lake Qarun may also point to a course of action to reduce pollution (or potential pollution) problems in Wadi Rayan.

The principal functions of Wadi Rayan are (Arcadis, 1994b): -

[21] there are four lagoons on the Mediterranean coast which take much of the drainage water from the Nile delta, although the study area drains into an inland lake and is totally separate from these lagoons

- Environmental and natural resources – including being an important route for bird migration as well as housing a range of indigenous fauna and flora. Rare species include the Egyptian Nightjar and the Slender-horned Gazelle

- Fishing and fisheries

- Tourism and recreation

- Receptacle for wastewater – mainly agricultural drainage

- Water supply for local irrigation

In 2000, 20% of irrigation water was deposited in Lake Qarun. Increasing irrigation and drainage volumes in Fayoum to aid mitigation of saline soils will impact upon water levels in Wadi Rayan and Lake Qarun. Should drainage volumes increase, lake levels will only be maintained either by limiting agricultural activity or by actively pumping water from these lakes. In as study of Lake Qarun by Van Zon & Kevin (1992), neither of these options was determined to be feasible so, the conclusion was, Lake Qarun water levels would have to rise in order for agricultural land to be supplied. The projected surface area was predicted to increase by another 11, 000 hectares by 2040. Sediment is also a problem, resulting in the basin having a lower storage capacity (United States Environmental Protection Agency, 2000). Higher water levels in the lake will lead to inundation of surrounding agricultural land and may have an impact upon infrastructure of hotels, houses and other buildings (Arcadis *et al.*, 2001). However, reducing the volume of water could also have an impact upon tourism as that may result in the exposure of polluted beaches. Similar impacts would occur in Wadi Rayan due to changes in the amount of incoming drainage water, although there is currently a much smaller vulnerable area of agriculture and tourism facilities.

In Wadi Rayan, water levels appear to have decreased in recent years, although there does not appear to be any literature confirming this point and it is not known whether this is part of a significant trend. Should the levels decrease substantially, tourism could be affected, both by the eco-village and other facilities being too far from the water's edge and through the possibility of waterfalls discontinuing (Arcadis *et al.*, 2001). Falling levels could also reduce the territory of water birds.

The quality of water from fisheries is partially governed by Egyptian Law 48 – microbiological standards for fisheries. The fishing in Lake Qarun, once a thriving industry has declined to a huge extent. Salinity is a major problem with now even seawater fish unable to breed (Arcadis *et al.*, 2001). Fish must be restocked annually to maintain an ever decreasing fisheries industry. Eutrophication was also considered a problem in 2000 (United States Environmental Protection Agency, 2000) and both salinity and nutrient status were expected to increase further due to the water demands of agricultural expansion causing additional reuse of drainage water. These trends will have a further impact upon fisheries, the lake ecosystem and tourism. Heavy metals were of a very high load in fish from Lake Qarun, in particular, fish with a higher percentage of body fat (Kadder, 2000). Heavy metals were found to be accumulated by fish and waters of Wadi Rayan (Van Zon & Kevin, 1992). Although not specifically from Wadi Rayan, fish in Egypt have been found to contain heavy metals well above FAO's Maximum Allowable Concentration (MAC). Organochlorine pesticides in 100% of Egyptian fish were found to be above the prescribed MAC (NWRP, 2000). In broad terms, a lower quality of water results in a lower quality of fish. Naturally, there is also an impact upon the community ecology of the lake as a whole. Indeed, continuing increases in salinity could result in the formation of a dead lake, unable to support life (United States Environmental Protection Agency, 2000).

Salinity in the mid-1990s in Wadi Rayan was judged to be higher in the first lake when approaching the exit to the subsequent lakes, in comparison with the entrance of the water to the lake at the outlet of the Wadi Drain (Arcadis *et al.*, 1994). The salinity was considerably higher in the lower lake where there is no outflow, only loss through evaporation. The hydrology of the lower lake means that salinity and concentration of other contaminants is likely to continue to rise, ultimately with a similar impact upon fish stocks and the ecosystem in general as in Lake Qarun if all other conditions remain as present. As Wadi Rayan is used to irrigate farmland created around 2000, increasing salinity and pollutant concentrations in the lake implies a lower quality of irrigation water and therefore, a lower yield of crop (Arcadis *et al.*, 2001).

Metals, in general, in the water of Wadi Rayan were found to have decreased from 1988 to 2000 (Saleh *et al.*, 2000). Cadmium, however, was found to have increased significantly, with the suggestion that this may be an indicator of human waste.

Tourism will be influenced by pollution. Increased pollution will result in less recreational use of the waters, not to mention the possibility of foul smells. Drainage water is not the only source of pollution within Wadi Rayan. The existence of a fishery in the second lake can contribute to a negative effect (particularly increased ammoniacal nitrogen) in the third lake (Arcadis *et al..*, 2001).

Some suggestions have been made regarding sacrificing the lower lake (where there is no outflow for contaminants) to save the upper (Arcadis *et al.*, 2001). However, the water demand for agriculture from the upper lake is already oversubscribed consequently negating this proposal. Most of the tourist facilities are also in the lower lake, thus, a significant reduction in its water quality will have an economic effect.

In Fayoum today, the marshes, tamarix scrub and dry forest present as late as the 19th Century has all disappeared (Van Zon & Kevin, 1992), primarily due to natural processes, although aided by abandonment of the land after the Roman Occupation and through the Middle Ages. The vegetation of Fayoum is now largely the sparse desert flora. Some of these plants are, however, still of high conservation value, due to their rarity.

Like the vegetation, the fauna of the area has changed from the species rich environment of the Neolithic period, where crocodile, elephant and leopard could all be found, to the animals able to survive in the harsh desert landscape. Even so, this area is still home to a number of rare fauna, in particular, the near-extinct slender-horned gazelle. Almost half of the bird-life in Egypt has been recorded in the Fayoum area (Van Zon & Kevin, 1992), with wetlands being important for passing and overwintering migrating water birds. Bird life has also benefited from the Wadi Rayan lakes. These lakes provide a winter home to tufted duck, coot and pochard, as well as to the resident reed bed dwellers.

(ii) Sri Lanka

The Kachchigal *Ara* system is not only used for irrigation water distribution and drainage collection, but serves many other functions of great socioeconomic and ecological importance. The widely spread rural communities of the Kachchigal *Ara* catchment area do not receive pipe-borne domestic supplies of water and therefore rely heavily on the irrigation canals, tanks, *ara* and coastal lagoon for all their domestic uses, with the exception of direct consumption (which is from groundwater or delivered by “water bowsers”). Livestock needs, home garden cultivation, fishing and wastewater

disposal are included in the list of multiple uses. The tanks and Kalametiya lagoon are also important natural resources, supporting fishery activity, ecosystems and the bird sanctuary at Kalametiya.

Downstream livelihoods developed around small seasonal freshwater flows and brackish water fisheries. There was sufficient water for a limited area of paddy cultivation, which could co-exist with fisheries in the adjacent lagoons. The changes in flow regime affect both livelihood patterns adversely (Senaratne et al. 2003). These changes in flow volumes and consequent changes in salinity (either reduced because of diversions, or increased because of drainage) have had a profound impact. They have also caused considerable sedimentation and a reduction in the area of the lagoon. There has clearly been a change in the eutrophication status, although data is lacking, and the short term impact of the tsunami has included scouring out the Kalametiya lagoon. This has made it impossible to observe eutrophication in the short term, but it would be interesting to observe the changes in water quality and biomass over the next few years

There is growing interest in the downstream environmental impacts of the quality of irrigation drainage water. The Bundala National Park wetland system, located in the dry zone of the southeast coast of Sri Lanka is one of the three RAMSAR sites in Sri Lanka. Agricultural drainage from a section of the Kirindi Oya catchment, upstream of the Bundala wetlands, was diverted into two interconnected lagoons, as a management practice introduced in 1986. The impacts of this drainage water have been studied in terms of its quantity and quality. It has not only changed the water environment from being brackish to fresh (Matsuno & van der Hoek, 2000), but also causes seasonal loading of nutrients to enter the system (Piyankarage, 2002). Although drainage water is considered to be one of the major causes of the decline in shrimp and fish populations (Kaluratne, 1999), there is still a lack of knowledge about the actual impacts of drainage water on the overall ecosystem of the park (Matsuno et al. 1998). This is probably, in part, due to lagoonal water quality also being affected by other factors, such as livestock additions and breaching of the sandbar between Malala Lagoon and the sea (Piyankarage, 2002). Another problem is that quantification of such impacts is only possible if the conditions of the ecosystem before the initiation of the impacts are known. Smakhtin & Piyankarage (2003) use a third lagoon in the Bundala system, which does not receive irrigation drainage flows and which has been shown to be unaffected by agriculture (Piyankarage *et al.* In Press) as a reference wetland. This provides a means of modelling the probable water quality and quantity changes caused by irrigation drainage flows into the two impacted lagoons. It thus enables a better understanding of linkages between water quality characteristics of the lagoons and their aquatic life.

The health risks of polluted water need to put into context of health risks of using agrochemicals: direct contact is a much greater risk, although one that can be mitigated by appropriate application techniques. Deliberate self-harm is a distressingly common problem in Sri Lanka, and has been the focus of much research (eg IWMI, 2002). Whilst better techniques can greatly reduce the risks to those who apply the pesticides, water pollution, however, affects not them but those further downstream who use the polluted water – there is growing concern over the long-term impacts of very low-level environmental exposure. This is believed to cause neurological and mental health problems (Konradsen, pers comm.).

2.6 Mitigation measures

There are few studies of mitigation measures in developing countries – as the problem itself is hardly recognised. Control of diffuse pollution has become a major concern in Europe. Frost el al (1999) for example recommend a package of measures in Scotland. These include leaving water margins

unsprayed, reduce use of inputs, better management of slurry, and control of soil erosion by providing a permanently grassed buffer between field and water. Both the technical requirements and the socio-economic and political contexts are so different in other parts of the world that it is not possible simply to apply the same methods.

Mtetwa and Schutte (2003) who have developed a community based management protocol for diffuse pollution control in agro-rural watersheds and tested it in Southern Africa. They recognise the fact that in developing and semi-developed countries, water shortages and food security take precedence over water quality issues, hence their approach focuses on stakeholder participation and empowerment.

The first stage of the protocol is the establishment of structures i.e. formal or in-formal groupings of stakeholders who will develop and implement measures that address the identified problems. This is followed by recording of baseline conditions, awareness creation, empowerment, implementation of the agreed mitigation programme, and finally monitoring progress and reviewing the strategy (Mtetwa & Schutte, 2003). The initial stage of the four-year project was the establishment of baseline data covering fertiliser, manure and pesticide consumption along with monitoring water quality data. Reported results indicated that nutrients were flushed into the study catchment, which coincided with dates of fertiliser application and rainfall events, although the levels of nitrates were mostly below the recommended limits of discharge. Following the community involvement in monitoring and data collection, and raising awareness of risks associated with poor land management practices a protocol was developed to reduce the risk of diffuse pollution – these processes included erecting contour ridges; establishment of grass strips; more efficient use of fertilisers; alternatives to biocides; conservation of natural resources. Testing of the protocol in the Muda river catchment of Zimbabwe has so far proved positive though longer time scales will be needed to fully monitor environmental improvements.

Mtetwa and Schutte point out that dealing with the "problem (*pollution*) at the headwaters of such a catchment goes a long way in reducing the nutrient and sediment loads and protecting the quality of water for downstream users". Achthoven *et al*. (2004) also make such an observation, referring especially to the use of drains, and stating that efforts should be made to reduce pollution (agricultural and non-agricultural) at source.

2.7 Gaps in knowledge: the research question

This overview of the background to the problem highlights a number of gaps in knowledge of the problems caused by diffuse agricultural, which enabled us to refine our research objectives and methods:

- The extent to which agrochemicals are reaching water bodies in developing countries is very little studied. Most studies are one-off measurements in a few locations and do not analyse pollution systematically. A lot of them were done some time ago and relate to products which are now banned. A water quality monitoring programme has been set up in Egypt but not yet in Sri Lanka, which includes salinity and nutrients but not pesticides;
- The impact of pollution on livelihoods is commonly stated to be severe but little or no evidence is available to substantiate this. Livelihood strategies are changing but for other reasons;

- There is little knowledge of the impact of agrochemical parameters of water quality on environment. Changes in quality are almost invariably accompanied by much larger changes in water quality which mask (or swamp) the impact of water quality changes;
- There are methodological problems, particularly for monitoring pesticides, as concentrations are low and vary in both time and space. This creates difficulties for selection of methods, study scale and sampling locations, and testing frequency. There is very little data even to understand the present situation – it is extremely hard to predict trends;
- Understanding the causes and impacts of pollution requires a multidisciplinary approach, whereas most previous studies have had a narrow technical focus. It is evident that there is a poor understanding between disciplines, and that the wider context of agricultural pollution is either not understood or ignored;
- Appropriate measures to mitigate pollution and pesticide risks need to be put in context: there are other problems which are more serious in the short term, but is there scope to reduce pollution at the same time as improving productivity (thereby reducing vulnerability to future changes).

These factors led to our focus our study in the field study on:

- establishing a regular monitoring programme at a small catchment scale, but with intensive sub-areas for detailed investigation.
- Assessment of agricultural policies and practices at national and regional scale, as well as detailed observations at local level
- A comprehensive study of the role of water in livelihoods, to enable us to appreciate implications of pollution in the wider context.

The field study was then followed by analysis of the field data in order to interpret the inter-relations between the various components, and a comparision of the findings between the two case studies in order to draw more general conclusions

3 Methods

3.1 Case Study Selection

The purpose of the study was to draw wider conclusions on the impact of and potential mitigation measures for diffuse agricultural pollution in large-scale irrigation schemes on the basis of two case studies in different countries. These case studies thus needed to be carefully selected to ensure that they were as representative as possible of irrigated agriculture.

The two case study countries were selected to have:

- Contrasting agro-ecological environments
- Locally recognised problem of agro-chemical pollution
- large-scale irrigation and drainage systems with many characteristics common to the region
- Established links with local partners willing to collaborate on the study.

On this basis Egypt and Sri Lanka were selected. Within these countries we used the following criteria were used for the selection of the case study sites:

- Existing surface water quality problem which can be (almost) completely attributed to agricultural pollution (as opposed to municipal or industrial)[22].
- Likely existence of socio-economic and ecological impacts.
- Ease of accessibility with no significant security or logistics issues.
- Scale of study manageable within project budget and timeframe (realistic catchment size).
- Availability of existing information.

These were to ensure that the study could be implemented with the limited time and resources available and would be have as widespread a relevance as possible.

In each country a long list of potential sites was drawn up on the basis of local knowledge and secondary data. Selected sites were then visited (Lake Burullus and Wadi Rayan in Egypt, and Kirindi Oya, Kirama Oya and Kachchigal *ara* in Sri Lanka), to enable a final selection. It should be noted that there are other sites, such as Lake Maryut in Egypt and the central highlands of Sri Lanka, which are likely to suffer more from pollution. However, agriculture in these sites is a relatively small source of pollution as compared to municipal and industrial sources.

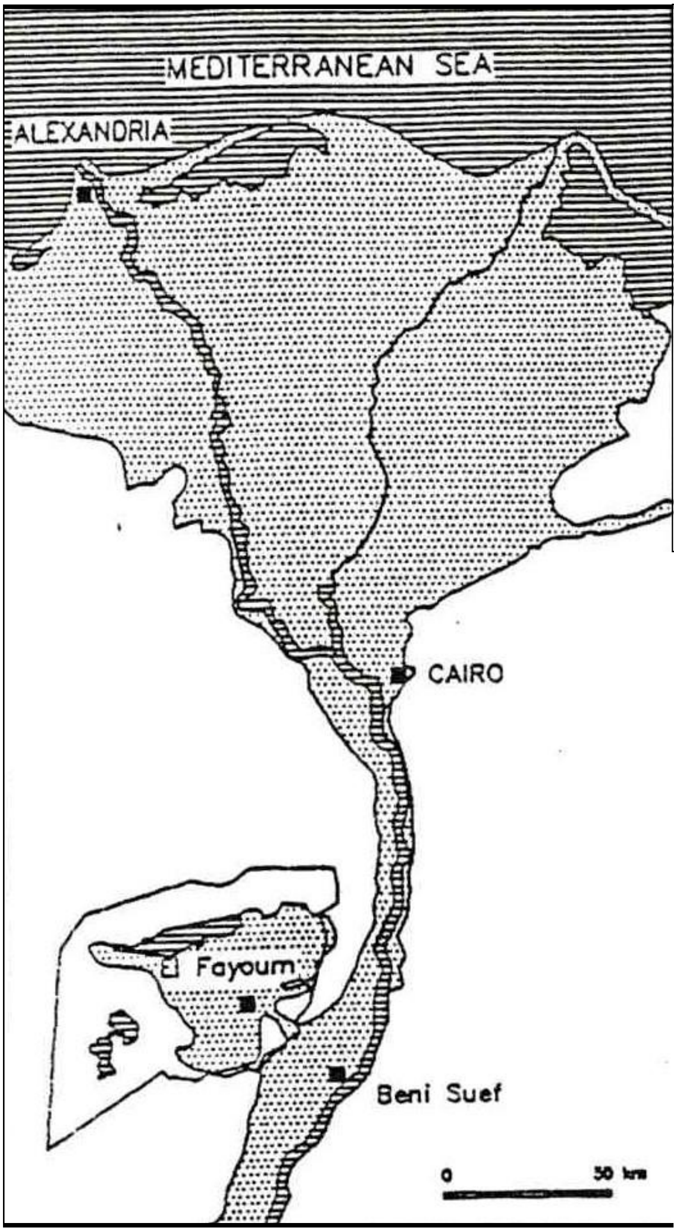
Wadi Rayan, in the Fayoum, was selected in Egypt in preference to Lake Burullus because of its size, making more practical to undertake a monitoring programme with the resources available. Kachchigal *ara* (in the dry zone in the south of the country) was selected in Sri Lanka, as it incorporates a tank cascade system typical of Sri Lanka (and parts of South India), and has an assured irrigation supply – unlike Kirindi Oya where there was no assurance that irrigation would be possible during the study period. Access was found to be a potential problem during the wet season at Kirama Oya.

[22] this in practice meant that peri-urban irrigation schemes (which are often where a high proportion of input-intensive crops, such as vegetables, are grown) were excluded. Whilst this might be regarded as a weakness of the study, the more rural schemes selected are more representative of irrigated agriculture as a whole.

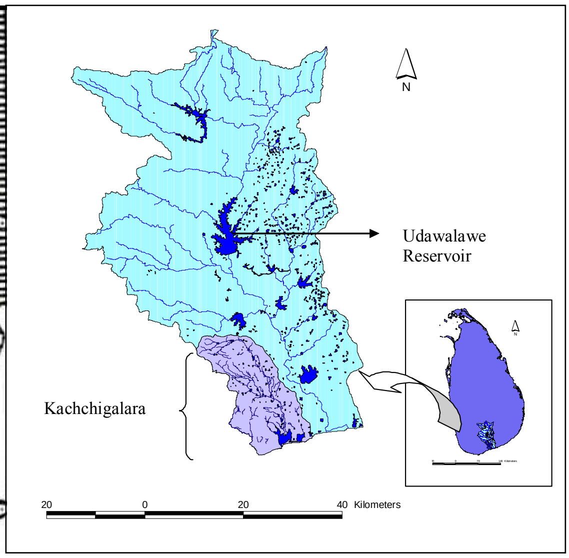
It is clear that there is a wide range in agro-ecological and social factors which influence the nature and impact of water pollution, and it is not possible to represent all irrigated areas by a small number of sites. However, the two sites selected offer two very contrasting environments and comparison of these two sites, supplemented by a review of the literature, should enable wider conclusions to be drawn on the likely impact of agrochemical pollution, measures that should be taken to minimise the risks, and the need for further or more detailed studies.

Figure 3.1: Location of case study sites

Location of Fayoum in Egypt



Location of Kachchigal*ara* in Sri Lanka



3.2 Water quality monitoring

The objective of the water quality sampling programme is to obtain a broad understanding of the main agrochemical-derived pollutants at key locations in downstream surface waters within the study catchment, and to provide some information on typical concentrations, as well as spatial and temporal variations. It was not intended to provide comprehensive, regular, monitoring of every drain. Sampling of other materials, such as sediment, fish, and milk was also undertaken as found necessary to complement the agricultural, socio-economic and ecological assessments.

(i) Sampling locations

The study areas are quite large, and thus it was necessary to design a monitoring programme which gave an overview of problems throughout the catchment and a detailed understanding within a smaller area. The general study focused on the main canals and drains, whereas the detailed studies looked at conditions within small drains. Sampling was not done within fields.

The general study at Fayoum included the main supply to the entire system, and the wadi drain at various points, and the lakes into which it discharges. In Kachchigala ara, we monitored the canal inflow and several points along the *ara* as far as the coastal lagoon. We also monitored nine additional points in the first month (which was in a period with no agriculture) to ensure that we understood the relative impact of non-agricultural sources.

The detailed study areas were selected so that the impact of observed agricultural practices could be related to monitored water quality. This meant that there needed to be a small well-defined drainage catchment. In Wadi Rayan, we selected the Sha'lan secondary drainage catchment in Ibshway district and monitored canal flows serving this area as well as two collector drains and the secondary drain as it flowed out of this area. In Kachchigal ara, we identified two small drains one draining into the Kachchigala *ara* at Metigatwalawewa in the upper part of the catchment, and the other at Ethbatuwa at the tail of the system. These are small tributary drains of the Kachchigala *ara* which did not have any tanks on them, which could be expected to affect concentrations of pollutants, and which had few houses within the catchment.

Wadi Rayan

The general study covered seven locations from the main supply from the Nile to the last lake.

- **Site 10**: Located on Bahr Yussef, which transports water from the Nile and is the only source of water for the Wadi El-Rayan catchment.
- **Site 9:** The start of Wadi El-Rayan Drain downstream of Al-Mukhtalatah village just after branching off from Wadi Qarun Drain. This is the main drain of the study area
- **Site 8**: Sampling location selected on Bahr El-Nazla, a main canal before any drainage water from the Wadi El-Rayan Drain is added.
- **Site 6**: At the end of the Wadi El-Rayan drain, before discharging into the first lake in Wadi El-Rayan. This location is also included in the NAWQAM Project.
- **Site 7**: Just before the waterfall between the first and the second Wadi El-Rayan Lake, where water levels are also automatically recorded. This location is also included in the NAWQAM Project.

- **Site 12:** The centre of the second Wadi El-Rayan Lake drains into a second lake, where a sampling location has been selected.
- **Site 11:** Drinking water sampled in Wadi El-Rayan village..

The Detailed Study area focused on five locations around Sha'lan village

- **Site 1:** Bahr El-Banat canal, immediately upstream of the detailed study area.
- **Site 2:** At Hanna Habib on the secondary canal flowing from Bahr El-Banat.
- **Site 3:** A collector drain taking water from a maize-beans area.
- **Site 5: A** collector draining a cotton-berseem area..
- **Site 4:** The secondary drain taking all drainage waters from the detailed study area.

Table 3.1: Sampling Sites List

Site	Name	Coordinates	Location	Type	Study Site	Remarks
1	Bahr El-Banat	29 17 52 N 30 34 88 E	Iz. Wadi El-Rayan	Main Canal	Detailed study	Before mixing with drain water
2	Hanna Habib	29 19 22 N 30 34 22 E	Downstream of village	Main Canal	Detailed study	Canal water used for irrigation
3	Collector 1	29 19 17 N 30 3512 E	Detailed study area	Tertiary Drain	Detailed study	Maize field.
4	Secondary drain	29 18 30 N 30 35 20 E	Detailed study area	Secondary Drain	Detailed study	Combined drainage
5	Collector 2	29 18 44 N 30 35 18 E	Detailed study area	Tertiary Drain	Detailed study	Cotton field.
6	End of tunnel	29 17 38 N 30 35 10 E	End of Wadi tunnel	Primary Drain	General study	Entrance Wadi El-Rayan 1st lake
7	Upstream Waterfall	29 17 50 N 30 25 22 E	Waterfall	Lake	General study	Outlet Wadi El-Rayan 1st lake
8	Bahr el-Nazla	29 17 77 N 30 35 79 E	Iz. El-Sadawi	Main canal	General study	before mixing with drain water
9	Wadi El-Rayan	29 17 42N 30 36 16.4E	Downstream of Al-Mukhtalatah	Primary Drain	General study	Mixed urban-rural drainage
10	Bahr Yussef	29 14 59.4 N 30 54 38.7E	Upstream of Al-Fayyum	Primary Canal (Nile)	General study	Sole inflow to study site
11	Drinking Water		Iz. Wadi El-Rayan	Drinking water	General study	Treatment station
12	Second Lake		Wadi El-Rayan 2nd lake	Lake	General study	-

For the water quality study, 12 sampling points were selected to cover the drainage system of Kachchigala catchment, with an additional 7 sampling sites were also included for the first round of sampling to ensure that we were able to distinguish the impact of urban pollution from agricultural.

The sites are shown schematically in Figure 3.3

Figure 3.2: Location of sample sites: Egypt

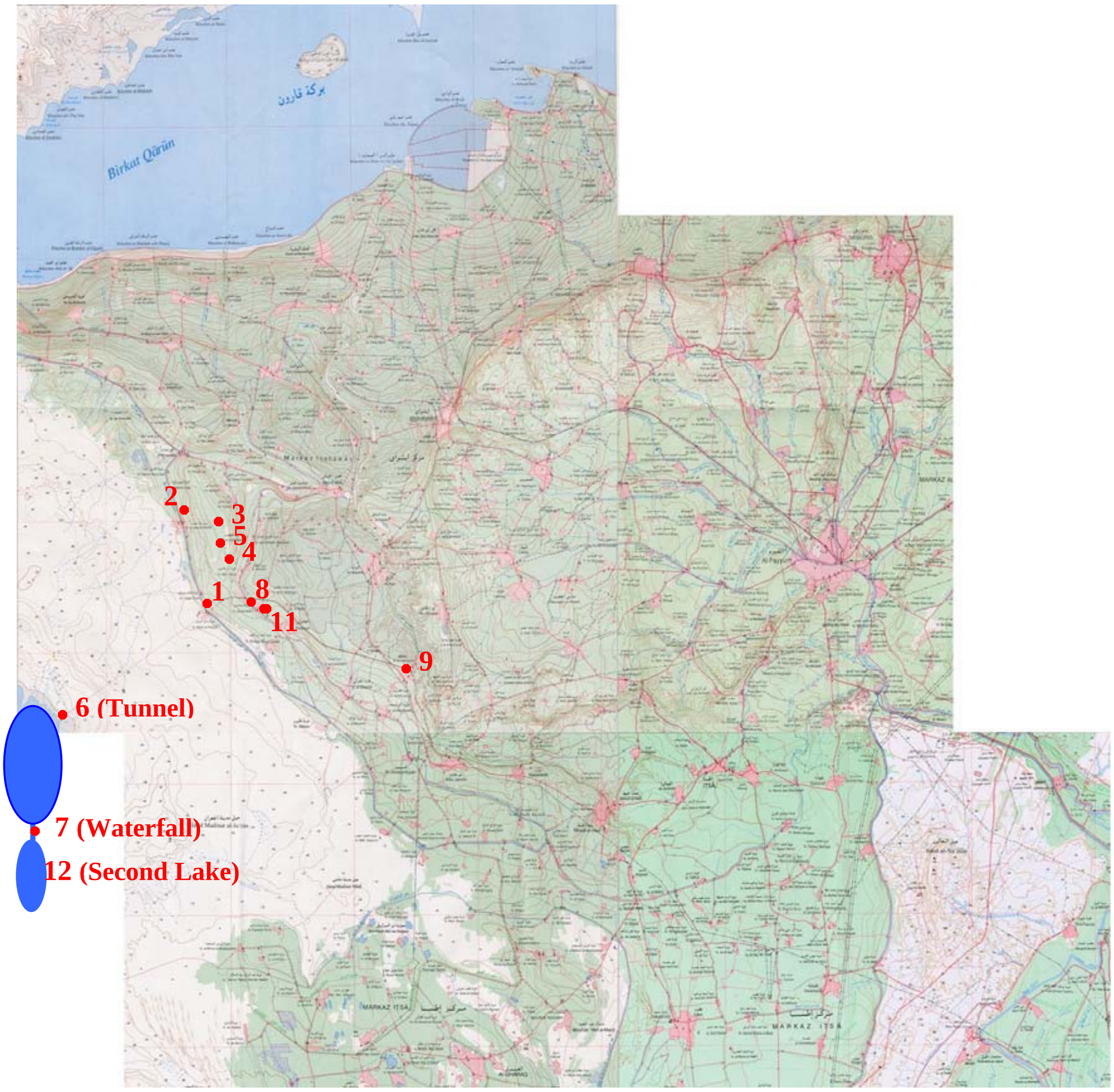


Table 3.2: Description of the water quality sampling sites

No	Site name	Type	Coordinates	Nearest village	Surrounding crops
1	Mamadala BC	Irrigation canal	N 06^0 16.326' E 080^0 52.042'	Kachchigala	paddy, coconut
2	Kachchigala *ara*	*ara*(main)	N 06^0 15.448' E 080^0 52.544'	Uswewa	paddy
3	Metigathwala	Drainage channel from paddy fields	N 06^0 14.894' E 080^0 52.759'	Metigathwala	paddy
4	Metigathwala *wewa*	wewa	N 06^0 14.083' E 080^0 53.068'	Metigathwala	paddy, banana
5	Kalawelwala	*Ara*(main)	N 06^0 12.923' E 080^0 54.581'	Samagipura	paddy
6	Maha Jandura *wewa*	canal across abandoned tank	N 06^0 11.666' E 080^0 54.993'	Maha Jandura	paddy, vegetable
7	Molanagoda	*Ara* (major tributary)	N 06^0 10.195' E 080^0 54.603'	Angunakolapelassa	paddy
8	Handunkatuwa	*Ara* (main)	N 06^0 09.836' E 080^0 55.544'	Handunkatuwa	paddy
9	Ethbatuwa	Drainage channel from paddy fields	N 06^0 09.489' E 080^0 56.066'	Ethbatuwa	paddy
10	Hungama bridge	*Ara* (main)	N 06^0 06.616' E 080^0 56.213'	Hungama	Wetland, paddy
11	Kalamatiya lagoon	lagoon	N 06^0 05.198' E 080^0 56.109'	Hungama	Wetland, paddy
12	Siyambalakatu *ara*	*ara* (minor tributary)	N 06^0 12.107' E 080^0 54.863'	Kachchigala	paddy, banana

The rationale for selecting each site is summarised in Table 3.3

Table 3.3: Rationale for site selection

No	Reason for selection
1	To understand the quality of the water as it enters the irrigation/drainage network at the upper end of the catchment (reference data).
2	Ara towards upstream end of catchment
3	A field drainage channel, into which only water from the surrounding rice fields drains – area for which agricultural practices were monitored.
4	A tank lying across the *ara*; water draining into the tank from the Kachchigala Ara and from irrigated fields will be stored for some time, with opportunity for settlement and accumulation of sediments and concentration of pollutants; fishing by the local community for food occurs in the tank.
5	The local community rely heavily on this part of *ara* for activites such as bathing and clothes washing.
12	Siyabalakatuwa Ara drains into Kachchigala Ara, carrying water from three upstream tanks and an irrigated area on the left bank.
6	Water from the *ara* is diverted to Jandura Tank just above an anicut; the tank is now abandoned with only a channel through it, from which people obtain water.
7	Water from several tanks above the site and from Angunakolapelassa town flows into the *ara* at the site; any pollution due to waste water from the town should be present at the site.
8	Jandura Ara collects drainage water from the surrounding area, and joins with Kachchigala

No	Reason for selection
	A*ra* just downstream.
9	A major channel which carries only drainage water from the surrounding paddy lands; any pollution due to agrochemicals would be present at the site; the second area selected for detailed agricultural studies.
10	Entry point of the Kachchigala Ara into Kalametiya Lagoon, representing the last point in the stream where the cumulative effects of upstream irrigation return flows could be apparent in the water and in the sediments and aquatic biota; fishing by the local community for fish and crustaceans for food.
11	Inflows from the ara pass into Kalametiya Lagoon and through the lagoon mouth into the sea; any agrochemical pollutants could be expected to end up in the lagoon; as the water is resident in the lagoon for a considerable period, any pollutants might be expected to affect local communities, who use the lagoon water and harvest fish and other aquatic resources from it, as well as the natural ecosystem.

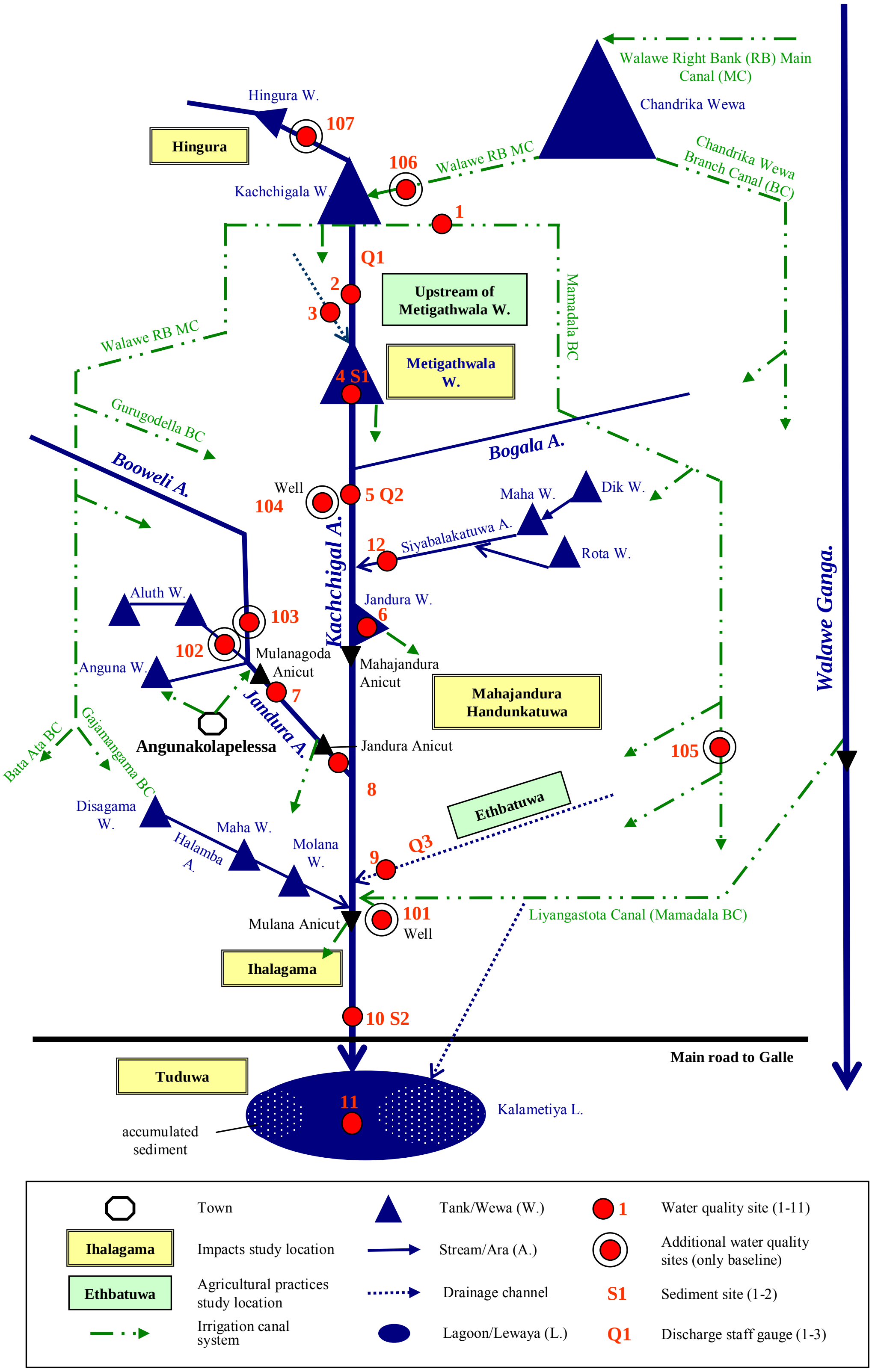
Table 3.4: Additional sites including in first round of sampling (April 2005)

No	Site name	Type	GPS	Nearest village	Surrounding crop(s)
101	Mulana	well 2 m from the Kachchigala Ara and near a small irrigation canal,	N 06^0 08.896' E 080^0 56.025'	Mulana	paddy, semi-natural vegetation
102	Aluth Wewa	Jandura Ara just downstream of the wewa	N 06^0 10.262' E 080^0 53.839'	Angunakolapelassa	paddy
103	Booweli Ara	ara	N 06^0 10.292' E 080^0 53.855'	Angunakolapelassa	paddy
104	Kalawelwala	well near Kachchigala Ara,	N 06^0 12.266' E 080^0 54.531'	Kalawelwala	paddy
105	Mamadala	Irrigation branch canal – at tail	N 06^0 11.085' E 080^0 56.635'	Sirimapura	paddy, banana
106	Chandrika Wewa	RBMC from the wewa	N 06^0 16.428' E 080^0 51.866'	Kachchigala	semi-natural vegetation
107	Hingura	Kachchigala Ara just downstream of Hingura Wewa	N 06^0 16.307' E 080^0 51.436'	Hingura	paddy

These additional sites were intended to clarify:

- the relationship between ara water and adjacent groundwater (by comparison of sites 101 and 104, with sites 5 and 10 respectively);
- the impact of Angunukolapellassa (by comparison of site 7 with sites 102 and 103);
- the changes along a major irrigation canal (by comparison of sites 1 and 105)
- water quality in natural and interbasin transfer channels (including impact of tanks on the latter) (by comparison of sites 107, 106 and 1)

Figure 3.3: Schematic layout of sampling points and detailed study areas



(ii) Water Quality Parameters and Monitoring Procedures

The parameters examined in this project were:

- Pesticides
- Nutrients (Nitrogen, Phosphorus)
- Major ions (Calcium, sodium, potassium, manganese, sulphates, chloride, bicarbonate)
- Suspended solids, dissolved oxygen, biological oxygen demand (BOD)
- Heavy metals
- Microbiological indicators (Faecal Coliforms, total Coliforms).

The timing of sampling was linked to the crop calendar, and was intended to be approximately monthly during the crop seasons, although this was adjusted slightly to correspond to planned applications of agrochemicals. However, as we monitored drainage collected from a group of fields which would all have chemicals applied on slightly different times (rather than to conditions in individual fields), we did not match the sampling precisely to the dates of individual farmers activities

Details on the sampling, preservation, storage transportation and analysis procedures are described in detail in the appendices, together with details of in-situ analyses (temperature, pH, TDS, EC and DO). Samples were collected by the grab sample method, and analysed in central laboratories in Colombo and Cairo in accordance with standard procedures (generally APHA). A systematic Quality Assurance system was set up, including testing of blanks and duplicates.

As a measure of general ecosystem condition and to ascertain whether or not there was any contamination with agrochemicals of the natural resources used as food by local people, both sediment samples and samples of aquatic fauna were collected for analysis of agrochemical (pesticide) residues. Wadi Rayan drain and lakes in Egypt, and Metigathwala *Wewa* (site 4) and the Kachchigala Ara at Hungama (site 10) were selected as suitable sites in Sri Lanka. Although an attempt was made to sample the Kachchigala Wewa left bank canal, as it is also a fishing site for local villagers, no fish were caught on the sampling occasion. Sediment samples were collected from an undisturbed area of the bed with a benthic grab sampler, bagged and stored on ice for return to the laboratory. Both indigenous and exotic (tilapia) fish species were collected from the cast and gill net catches of local fishermen at the two sites. At site 4, in addition, bivalve molluscs were hand collected from sandy areas in shallow areas close to the tank waters' edge. Although not a diet item for humans, they are a component of the tank food web. Moreover, they were expected to be a useful indicator, as they may bioaccumulate pesticides while filter feeding. At site 10, crustaceans (a range of prawn species, including *Macrobrachium* sp.) were collected by local fishers using a dip net. The prawns are used for human consumption as well as being a suitable indicator group for pollutants. All aquatic fauna were placed in separate plastic bags and transferred to ice, for transportation to the laboratory.

3.2.2 Limitations of methods

Pesticide monitoring is particularly difficult, as the products are applied in very small quantities and decay quite rapidly. The various different pesticides may have very different characteristics (solubility, adsorption to sediments etc).

The timing of water sampling is particularly important: Ongley (1996) states that for pesticides that are highly soluble in water monitoring must be closely linked to periods of pesticide use and may only be detectable shortly after application and that "monitoring programmes that are operated on a monthly or quarterly basis are unlikely to be able to quantify the presence or determine the significance of pesticides in surface waters".

Our approach was to sample at a small catchment level, containing land operated by a large number of farmers. Not all will apply chemicals simultaneously, but pesticides are applied at different times to different fields in the catchment. With regular monthly sampling it is likely that one or more farmers within the catchment will have applied chemicals immediately before the samples were taken, but these will be diluted by runoff from other parts - on which chemicals were applied at different times. As surface runoff is rapid, decay rates are probably less significant than dilution effects in small catchments – pesticides are simply washed out of the area before they decay – but decay becomes more important the large the catchment.

The sampling methodology was designed to identify whether there were background levels of agro-chemicals in the water and, because of logistical constraints did not consider transient levels which would be difficult to evaluate in terms of their significance for environmental impact and would have required a more targeted approach, sampling water to coincide with irrigation events and applications.

As will be seen later, our results indicate that during one year of sampling at these selected sites no pesticides were detected or, where detects did occur, they were not above Egyptian or International standards. The rational for the sampling methods used are comparable to other national schemes. For example, in the UK the EA have historically operated a monthly (or less frequent) surveillance scheme for pesticides to establish trends in environmental concentrations. Although more recently sampling schemes are being implemented which target periods of high pesticide application and rainfall events in order to quantify the effects of application practice and mitigation measures.

In places where pesticides applications are high and ubiquitous (such as the Sacramento valley in California – Domagalski, 2000) this approach is highly likely to detect pesticides, but the dilution effects in areas (such as our study sites) where a smaller proportion of farmers apply pesticides or they use them less frequently may be too great – pesticides may be diluted below the limits of detection.

Pesticides are adsorbed onto sediments, and thus water with a high suspended sediment load may have a low content of dissolved pesticides. Ongley (1996) points out that older pesticides and hydrophobic carcinogens such as PAH's and PCB's are poorly monitored by water samples because these compounds are transported in association with suspended matter, for example approximately 67% of DDT is transported at sediment concentrations as low as 100 mg/l and increases to 93% at 1000 mg/l of suspended sediment. He adds that sediment associated pesticide levels are often much higher than recorded and that a multi-media approach (water + sediment + biota) sampling may more accurately characterise pesticides in the aquatic environment. This is more likely to be a problem in Sri Lanka than Egypt as suspended sediment loads are rather higher

Even if contaminated samples are correctly collected, it is very difficult to analyse for pesticides in water (Pesticide Action Network, 2000):

- there are many compounds of different chemical types in use, which means that scanning samples is expensive;
- it is difficult to isolate specific pesticides from the multitude of other chemicals in water;

- some pesticides are highly toxic at low concentrations close to detection limits, and large volumes of water are needed for sample analysis;
- further work is needed to establish characteristics of pesticide degradation for many soils;
- soil and hydrogeological mapping is needed in order to predict vulnerable catchment areas;
- pesticides can be adsorbed to soil or other particulate matter or suspended solids found in sediments;
- seasonal variation in sampling and changes in weather conditions such as rain can affect levels of pesticides in water;
- high levels of organic matter in water can mask low concentrations of pesticides making them difficult to detect.

A review across the EU of the impact of pesticides in water found that 'acceptable analytical methods are only available for approximately a quarter of all active substances' and also noted that techniques for insecticides and fungicides especially were required – most analysis tends to focus on herbicides (Pesticides Action Network, 2000).

3.3 Stakeholder, policy and institutional review

We undertook an *a priori* stakeholder analysis to identify primary and secondary stakeholders within each case study site, distinguishing primary stakeholders (who were provisionally differentiated as those parties likely to be directly affected by the project) and secondary stakeholders or their representatives (those not directly involved in the project, but ultimately affected by one or other of its outputs). We made a preliminary assessment of the likely impact (positive and/or negative) that the implementation of the project might have on individual stakeholder interests, as well as a relative prioritisation of their interests in the catchment. In this we ranked the extent to which stakeholders might be affected, on a scale from 1 (most significantly affected), through 3 (moderately) to 5 (least significantly affected). We also reviewed the policies, legislation and institutional arrangements pertinent to the main stakeholders identified. We updated both of these analyses at the end of the study.

3.4 Agricultural studies: causes of pollution

These studies aimed to provide an overview of the policy and economic context of agricultural practices, detailed observations of farming practices, and compilation of data on trends in input use (fertilisers, pesticides and manure) at both local and national levels to indicate the pressures on environment. We achieved this by a combination of field observations and farmer surveys, compilation of agricultural statistics, and interviews with government officers and local specialists. As noted in section 3.2, we selected sub-areas for detailed agricultural observations in each case study, one in the upstream part of the catchment and one in the downstream,

We used the DPSIR framework (Table 3.5) as a way of summarising the findings of the study, relating pressures on and the state of environment to driving forces (government policy, markets).

Table 3.5: DPSIR Framework

Component of the framework	Relevant information presented in the report
Drivers (D)	Government policies on improving agriculture productivity. Institutional and other management arrangements to improve agriculture production and provide other support to economy (employment etc.)
Pressures (P)	The agencies and other individuals involved in agriculture are compelled to respond to the government driving forces and implement various intensive agriculture development programs to improve production (application of increased quantity of fertilizer and other inputs and improved agriculture technologies and so on)
State of environment (S)	Changes in the existing environment due to intensive agriculture: soil fertility, water quality, forest , land use pattern and cropping systems etc.
Impact (I)	Impact on social environment (diseases), deterioration of natural resources, water, forest and other properties such as bio-diversity.
Responses (R)	Changes in government driving forces, the intervention of water saving techniques, options for addressing water quality deterioration, reduction of synthetic fertilizer and agro-chemicals and implementation of eco-agricultural practices etc

In Egypt, we selected a single area, but covered two villages within this area: Hanna Habib in the upper part of the Sha'lan drainage catchment, and Sha'lan in the lower part of the catchment. In Sri Lanka, we selected two separate distinct areas: one in the upstream part of the catchment and one in the downstream, each draining to a single point for detailed observations of agricultural practices.

The two Sri Lankan sites were chosen to be predominantly paddy-growing areas without tanks, and with as few settlements as possible, so that applications of agro-chemicals could be related to water quality at the outfall.

- Metigathwala – catchment of one drain discharging upstream of MGWW, and the catchment of Kachchigala *ara* between Kachchigala wewa and Methigatwala wewa. This includes 4 Farmer Organisations (FOs) - covering both Mahaweli and non-Mahaweli areas
- Ethbatuwa – catchment of one drain discharging into Kachchigala *ara* at the tail This includes 3 Farmer Organisations (each responsible for one distributary canal – MM10D3, MM10D4, and MM11D1)

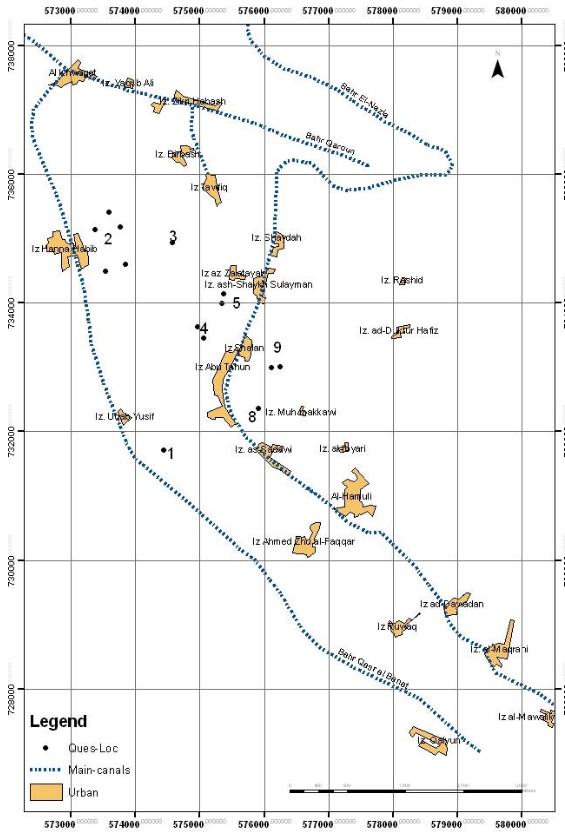
A sample of 10 farmers was randomly selected in each FO to monitor their agricultural practices. In this case all farmers were allocated the same area by MASL and thus there was no need to stratify the sample. The 70 farmers kept a daily diary to document their agricultural practices and the field assistant visited the field every day and ensured that all information was documented systematically.

In Egypt, we monitored practices by means of a spreadsheet questionnaire administered monthly to 15 farmers, chosen to be representative of the area as a whole. We ensured that the distribution of farm sizes in the sample were the same as in the entire district.

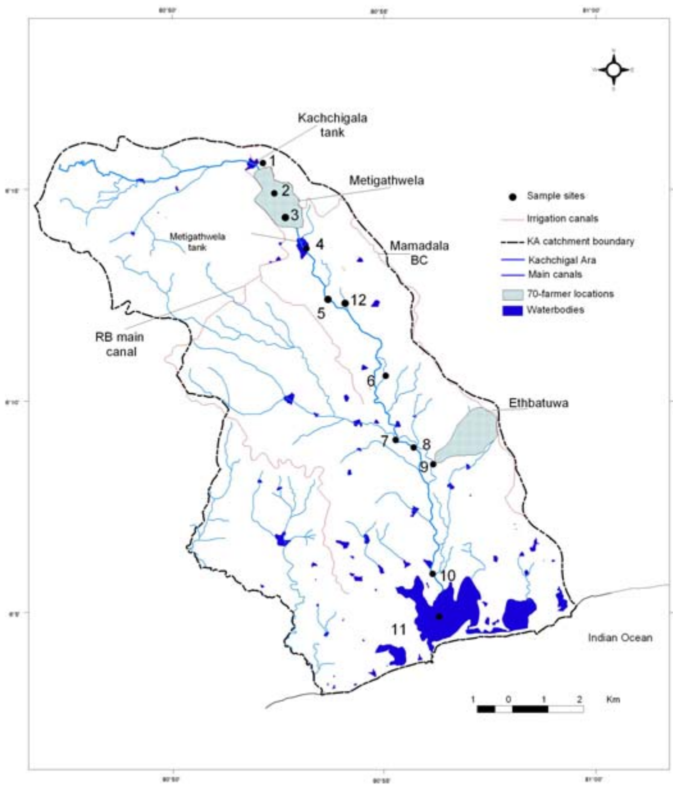
Detailed farm-level observations were placed in a local and national context through collection of statistics and other secondary information and data from line agencies, universities and fertilizer and agro-chemical retailers.

Figure 3.4: Sites for agricultural observations

Wadi Rayan



Kachigala ara



3.5 Livelihoods studies: impacts of pollution

3.5.1 Background

To determine the impact of any diffuse agricultural pollution on communities living in the area it was decided that a livelihoods approach would be adopted. The methodology followed the format of the sustainable livelihoods approach developed by Chambers and Conway (1992), Scoones (1998), Carney (1998) and Carney and Ashley (1999) and was based on the DFID model which is generally regarded as a useful framework for rural research (Jones and Carswell, 2004). This model was adopted to ensure that the research covered both productive activities and reproductive activities through regarding the five livelihoods capital assets.

Specifically the work considered:

- The physical assets that the household had access to, specifically in relation to water resources, such as irrigation structures, drinking wells and piped water supplies;

- The natural capital that people could depend on including land and water availability, and fishing and grazing grounds;
- Financial capital as this may affect ability to buy pesticides and ability to access better quality water.
- Human capital, predominantly in relation to understanding about water quality and its impacts on health, and pest management.
- Social capital is of relevance in terms of farmers' cooperatives and other networks through which knowledge about agricultural practices, irrigation and pest management is shared. Sharing water resources if some become unavailable or too polluted may also be of importance.
- Finally many or all of these relate to the income generating activities of the household which may either pollute water bodies, be affected by water pollution, or both.

Due to the timescale and the nature of the project it was proposed that the methods employed would draw on participatory approaches, described by Chambers (1994) as a "family of approaches and methods that enable local people to share, enhance and analyze their knowledge". This was very important as it would allow community members to elaborate their feelings regarding pollution and quality of water, as well as allowing the researchers to provide information to the community on water quality indicators collected during the project.

3.5.2 Objectives and approach

The livelihood studies had the following objectives:

- to understand the role of water in livelihoods, and the sources used for these purposes; and
- to assess the impact of changes in water quality and how the use of polluted drainage water impacts on livelihood options, strategies and outcomes for low-income men and women downstream
- Predict and compare how different proposed pollution mitigating options would impact on the livelihoods of both downstream water users and upstream farmers who use irrigation water

This was done in three stages:

- Literature review, key informant interviews, and basic data collection
- Initial livelihoods analysis including water use and impact of water pollution on livelihoods based on elements of "Sustainable Livelihoods" model[23], and working with focus groups using participatory techniques (including but not limited to social and resource mapping, and water use matrices)
- Follow-up studies using similar techniques once one season of water quality data had been collected so that livelihoods could be discussed in the context of actual water quality conditions. Options for mitigation measures were also discussed in these groups.

[23] IDS(2003): Livelihoods Connect – Sustainable Livelihoods Distance Learning Guide

3.5.3 Locations for detailed study

Following a rapid reconnaissance and discussions with village leaders in various villages, we selected areas and villages for more detailed investigation through focus group discussions:

(i) Egypt

We worked initially in three villages to represent the upper and lower parts of the detailed study area, but expanded this after the first round of interviews to include two other villages which were more dependent on reuse of drainage water in some seasons. The villages chosen were

- Yakub Yousef, taking water from a direct offtake from the Banat main canal – and thus with a good supply of relatively clean water
- Hana Habib, taking water from a secondary canal and with a less satisfactory supply
- Sha'lan, adjacent to the Nazla main canal but with some farmers dependent on the tail ends of canals offtaking from the Banat canal
- Zalatiya, at the tail of the Faragala canal – a poorly supplied subsidiary of the Banat canal, where farmers make use of drainage water
- Koliya at the tail of a secondary canal (from further upstream on Nazla) but adjacent to the Sha'lan drain from which farmers can take water in extremis (but try to avoid doing so, because it is so saline)

(ii) Sri Lanka

Following a rapid reconnaissance and discussions with village leaders in various villages, we selected five areas for more detailed investigation through focus group discussions:

- Hingura: upstream of the irrigated area, dependent on *chena,* dryland agriculture and occasional irrigation from small tanks on the seasonal *ara*
- Metigathwalawewa/ Amaratungagama : a fishing community at the head of the system, also with large numbers of livestock. This community had access to the largest tank on the main stream of the ara
- Mahajandura/Handunkatuwa/ Wadumesthrigama: an agricultural community in the middle of the system
- Mulana and Ihalagama, an agricultural community reliant on the downstream section of the *ara* for most purposes
- Thuduwa; a fishing community dependent on the coastal lagoons

3.5.4 Field methods

Groups were selected in Sri Lanka on the basis of a household census provided by local authorities and a wealth ranking undertaken at the start of the study. Groups were selected more informally in Egypt due to lack of reliable census data, but in each case took account of

- Location and type of community (farming, formal or informal fishing, livestock, ecotourism, drainage water users, etc)

- Wealth and land tenure status, access to water
- Use of drainage water (or drainage mixed with water from other sources) in livelihood activities, as opposed to water from other, unpolluted, sources
- Gender

In these studies we aimed to elucidate

- the main livelihood options, strategies and outcomes, and local variations thereof among low-income rural men and women in the study area, disaggregating according to gender.
- any significant trends in both livelihoods and the use and quality of drainage water
- any differences in use of drainage water based on other factors such as access, land tenure status, etc.
- perceptions of changes over time concerning the quality of drainage water and the impact of this on livelihood options, strategies and outcomes
- differences concerning the quality of drainage water and its use between communities located at different points in relation to the agricultural pollution, and the related impact on livelihoods

3.6 Identification and analysis of mitigation measures

Identification of potential measures for mitigation of pollution was undertaken in several stages:

- Compilation of impacts and potential impacts (making allowance for both future trends in impacts and uncertainties in the magnitude of impacts)
- Identification of related measures needed for other reasons (such as to optimise agricultural production, to reduce direct exposure to pesticides, etc)
- Identification of drivers for change, given that legislation related to agricultural pollution is relatively weak and difficult to enforce
- Compilation of experiences from literature, covering both the measures needed and practical methods for implementing them in developing countries;
- Specific recommendations for case study sites; and
- Generalised recommendations for irrigated areas with comparable conditions

4 Egypt Case Study

4.1 Description of Case Study Site

We selected the Wadi El-Rayan catchment in the Fayoum region, 90 km south-west of Cairo (Figure 3.1) as the study area. This occupies a large and exceptionally fertile depression in the Western Desert. It is an area of intensive agriculture, reliant solely on irrigation from the Nile, as this area has negligible rainfall. The catchment has a large rural population, who depend predominantly on agriculture (with some fishing and aquaculture) for their livelihoods. Due to the limitations on water quantity, there is a large amount of re-use of drainage water for irrigation by farmers downstream and hence the quality of the water available decreases significantly towards the downstream end of the system. Field observations also indicated that in many parts of the catchment, rural communities also rely on the agricultural drainage water for washing and livestock watering. There is, therefore, considerable vulnerability of poor rural communities to surface water pollution from agriculture in this area. This reliance on the re-utilisation of agricultural drainage water by poor rural communities for a wide range of uses is typical of many of the agricultural areas of Egypt, such as the Nile Delta.

Water is taken from the Nile at Assiut barrage via the Ibrahimiya canal and travels first through the agricultural district of Beni Suef before entering Fayoum (about 250 km from Assiut). All of the water entering Fayoum is carried by the Bahr Yussef canal, and is then delivered to agricultural areas through a vast network of canals. This is an ancient irrigation system, but one which has been systematically updated and improved. After irrigation, drainage water from the land is then collected through a network of drains that ultimately flow into either Lake Qarun or Wadi El-Rayan, both of which are landlocked lakes, with no outlets. Originally all water flowed to Lake Qarun, but because of increasing problems with the quality and level of water in this lake, a new drain was dug to divert part of the drainage water to a depression in the desert. This depression then became flooded to form the Wadi el-Rayan lakes

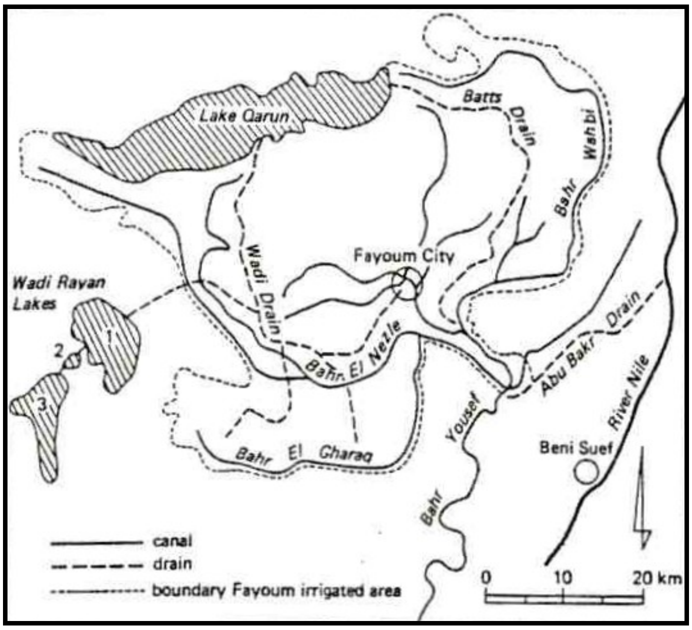
During prehistoric times the water level was higher than today and the Nile regularly flooded through the low mountains separating it from the Fayoum depression. However, today, the Fayoum depression is no more affected by the Nile natural flooding and is characterized by an entirely closed drainage system with very distinct hydrological boundaries, there being only one inlet and no outlet to the sea.

The amount of water supplied to the Fayoum varies seasonally. The highest supply occurs during the rice growing season (summer) and the lowest during winter (Hewison, 2002). During January, the supply is halted completely, allowing the canals to dry and make it possible to maintain the canal system.

Until the 19th Century, farmers relied on a basin irrigation system: land was flooded to a depth of around 1 m, which was allowed to percolate into the soil rather than be allowed to run off. Crops were planted and received no further water through to harvesting. Although this system was easy and cheap to implement, it did mean that only one crop could be planted. This system was replaced in the 19th century by a system of perennial irrigation, relying on a complex arrangement of canals and drains. Although complicated and expensive, this system does allow water to be regulated to each field, making it possible to cultivate two or three crops per year (Hewison, 2002).

After irrigation, drainage water from the land is collected through a network of secondary and tertiary drains that flow into larger main drains. Figure 4.1 shows the location of the Main Canal and Drains in the Fayoum Depression.

Figure 4.1: Location of Main Drains in the Fayoum Depression



The two main drains of interest in this study are the Wadi El-Rayan drain and the Wadi Qarun drain discharge in Lakes Rayan and Qarum respectively. Wadi Qarun drain contains a mixture of agricultural and industrial/ domestic sewage. Part of this is diverted into the Wadi El-Rayan drain (which thuss contains some industrial and municipal waste) but thereafter it is fed almost exclusively by agricultural run-off. We sampled the diverted water at the head of the drain, as well as the drain at various locations further downstream (see chapter 3). Lake Qarun collected all excess agricultural drainage water, until the construction of the Wadi El-Rayan lakes, which are man-made wetlands formed in the 1970s (EEAA, 2002) when a watercourse comprising a 9 km open channel and an 8 km tunnel was cut through the desert from the western side of the Fayoum Depression to the large, dry sub-depression of Wadi El-Rayan. This diversion allowed the rise in the water-table in the Fayoum main depression and the water level in Lake Qarun to be controlled. Therefore, the amount of water that could be used in the Fayoum depression was no longer limited by drainage capacity, and in consequence more land in the Fayoum depression could be reclaimed and production could increase.

The lakes were also developed for fishing and tourism. Today, the upper lake is mainly used for fish farming, while additional gravity fed fish farms are located immediately adjacent to the lake. The upper lake then feeds the lower lake by means of a waterfall, which is the only one existing in Egypt.

Both the Qarun Lake and the Wadi Rayan Lakes are landlocked lakes, with no outlets. Some water is pumped from the Rayan lakes to irrigate new agricultural areas along the southern shore and there are suggestions to expand these areas in the future. A lack of drainage in these new agricultural areas has resulted in the soil becoming increasingly saline.

The whole Fayoum depression is under the jurisdiction of one central governing body: the Fayoum Governorate, which is broken down into six administrative districts (*markaz)*, with the detailed study area being located in Ibshaway district. At the next administrative level come the villages, called

qarya, each of which has an appointed *umda*, responsible for representing the government in his community, settling disputes and keeping a general peace. The authority of an *umda* covers not only the main village, but also the hamlets, called *izba*, that lie within the village boundaries. An *izba* is any nuclear settlement too small to have its own *umda*. The total population of the governorate is reported to be 1,724,547 (about 3% of the total population of Egypt) while Ibshaway markaz, has 318,169 inhabitants.

Around 60% of the population of Fayoum work in agriculture in the 430,000 feddans[24] of cultivated ground. According to Euroconsult (1994), around 10% of agriculture is undertaken by the Egyptian Government, whilst 90% is by individual farmers. Around half of the field crops are fodder (Arcadis et al., 2000).

The Fayoum farming system is based around three cropping seasons:

- Winter (Oct-Apr) – wheat, berseem beans and vegetables
- Summer (Mar-Oct) – sorghum, cotton, maize and rice
- Nili (July – Dec) maize and vegetable

In addition there are some perennial crops – citrus, dates, and other fruits

4.2 Institutional Context and Stakeholder Analysis

4.2.1 Institutional Context and Legislation

(i) Background

The Ministry of Water Resources and Irrigation (MWRI) is the main institution for determining national water policy and for managing water quality. The major water related issues facing the MWRI are those of scarcity and water quality deterioration. As a consequence, the Ministry recently prepared a long term National Water Policy and Strategy covering the period to 2017, with three major themes: optimal use of existing water resources, water quality protection and pollution abatement, and development of new water resources in cooperation with the Nile Basin riparian countries.

A new "water reuse policy" encourages the optimal reuse of agricultural drainage water, which remains widespread particularly for irrigation and for aquaculture. This requires greater consideration of the quality of water available for reuse and means that the government now gives a higher priority to pollution control and abatement. However, there is still no integrated, coordinated and policy-driven approach taking account of agreed priorities, and Government efforts are hampered by an acute shortage of appropriately-skilled professionals and the strict technical focus of line ministries. However, there have been some recent capacity building projects within the planning sector of the MWRI and the Egyptian Environmental Affair Authority to help alleviate this problem.

Some water quality monitoring is now done by various Government research institutes, although it is mainly targeted at point source pollution. However, data dissemination remains difficult and as a result of the high cost of collecting data it is often seen as a commodity, even within one ministry.

[24] 1 feddan ≈ 0.4 hectare ≈ 1.038 acres

The Fayoum Irrigation Department, within MWRI is specifically responsible for the management of the main drains and irrigation canals in the Wadi El-Rayan catchment area. Several other ministries are directly and indirectly involved in water quality issues in terms of planning, operations, research, monitoring and regulations as follow:

- Ministry of Water Resources and Irrigation (MWRI)
- Egyptian Environmental Affairs Agency (EEAA)
- Ministry of Health and Population (MoHP)
- Ministry of Agriculture and Land Reclamation (MALR)
- Ministry of Industry, General Organization for Industry (GOFI)
- Ministry of Scientific Research
- Ministry of Housing, Utilities and New Communities (MoHUNC)
- Ministry of Local Development, Organisation for the Restructure and Development of Egyptian Villages (ORDEV).

(ii) Key Legislation

The key laws related to water quality management are listed in Table 4.1

Table 4.1: Overview of surface water quality-related laws and decrees in Egypt

Level of legislation	Number / Year	Topic
Law	93 1962	Drainage to sewer systems
Presidential Decree	421 1962	Ratification of Marpol Convention
Ministerial Decree MHUNC	649 1962	Implementation of law 93/1962
Presidential Decree MPWWR[25]	2703 1966	High committee for water (Ministry of Health)
Law	38 1967	Bathing and washing in Streams
Ministerial Decree MPWWR	331 1970	Executive committee of water
Law	74 1971	Clearance of weeds/ dead animal disposal in streams
Law	27 1978	Control of potable water sources
Law	57 1978	Treatment of ponds, marshes and swamps
Ministerial Decree MoHP	7/1 1979	Specifications for potable water
Law	27 1982	Water resources for drinking water / domestic use
Law	48 1982	Protection of Nile River from pollution
Ministerial Decree MPWWR	170 1982	Establishing High Committee of the Nile
Ministerial Decree MOI	380 1982	Technology and pollution
Presidential Decree	631 1982	Establishing Environmental Affairs Authority
Ministerial Decree MPWWR	8 1983	Implementation of Law 48/1982
Law	12 1984	Irrigation & drainage and license of groundwater wells
Ministerial Decree MPWWR	43 1985	Regulation of drains and waterways
Prime Minister Decree	1476 1985	Executive committee for industrial drainage to Nile
Ministerial Decree MPWWR	9 1988	Amendment of provisions of decree 8/1983

[25] In 1999 the MPWWR changed its name to MWRI

Level of legislation	Number / Year	Topic
Ministerial Decree MHUNC	9 1989	Drainage of wastewater (related to 93/1962)
Law	4 1994	Environmental Protection including tasks EEAA
Law	213 1994	Follow up to law 12/1984 on water user organizations
Law	256 1994	Wastewater quality guidelines for irrigation.

(iii) Institutional Responsibilities

An overview of surface water quality-related laws and decrees in Egypt is presented in Table 4.1. These official texts bring the regulator and all environmental organisations to share the responsibilities of water quality, discharge licensing, and environmental protection and even non compliance to the standards. Water quality management is mainly controlled by law No. 48, under which the MWRI is responsible for providing suitable water to all users but with an emphasis on irrigation.

Under Law No. 12 of 1984, MWRI retained the overall responsibility for the management of all water resources, including available surface water resources of the Nile system, irrigation water, drainage water and groundwater. Surface water quality standards are set by a decree of the Minister of MWRI after agreement is reached in a high committee chaired by the MoHP and including other ministries. Standards currently exist for point sources of effluent in surface water and ambient concentrations in surface water, as well as for drainage water reuse stations (mixing with canal water). These standards have not been changed since the law was established in 1982. Drinking water standards are set by the MoHP and were adjusted in 1998.

Law 48/1982 prohibits discharge to the Nile River, irrigation canals, drains, lakes and groundwater without a license issued by the MWRI. Licenses can only be issued for the discharge of effluents that meet government standards and each license specifies the quantity and quality of effluent permitted to be discharged. Fines are levied for unlicensed discharges. Licenses can be revoked under certain conditions. If, for example, the pollution level of a licensed discharge increases and a facility fails to install appropriate treatment within three months, the license can be revoked. Recently the minister of MWRI initiated an inter-ministerial committee to discuss water quality standards under Decree 8/1983 and Law 48/1982.

The responsibility to monitor to these licenses through the analysis of discharges has been delegated to the Ministry of Health and Population (MoHP). This is the main organization responsible for safeguarding drinking water quality and is responsible for public health in general. Within the framework of Law No. 48 / 1982, which deals with effluent discharges to water bodies, MoHP is involved in standard setting and compliance monitoring of wastewater discharges. MoHP samples and analyses drain waters to be mixed with irrigation waters, industrial and domestic wastewater treatment plant effluents and wastes discharged from river vessels. In case of non-compliance of discharges, the MWRI generally takes action upon messages from the MoHP.

Within the National Water Research Centre (NWRC), (which is part of MWRI), the Nile Research Institute, the Drainage Research Institute (DRI) and the Research Institute for Ground Water focus on monitoring ambient water quality in the Nile, irrigation and drainage canals, and groundwater, respectively. Within the Wadi Rayan catchment, it is the DRI who have the responsibility for routine monitoring of ambient water quality in the surface water drains.

In practice only licensed discharges are monitored regularly, although the majority of facilities are unlicensed. Due to the lack of funds and economic employment considerations, actual enforcement for cases involving public facilities, comprising the majority of all pollution sources, is almost nonexistent. At present EEAA staff is being trained to improve the enforcement of environmental impact assessment (EIA) laws whereas Compliance Action Plans (CAPS) are being agreed to obtain

grace period for compliance. These actions are being undertaken while the EEAA is establishing an Egyptian environmental information system (EEIS) to give shape to its role as the coordinator of environmental monitoring. But as in many countries, due to the difficulties of monitoring sources of diffuse agricultural pollution, legislation and standards for pollution control are predominantly targeted at point source pollution. The MoHP further samples and analyzes all intakes treated outflows from drinking water treatment plants and production wells. The latter is also responsible of taking action whenever the drinking water is noncompliant with government regulations (especially with respect to the bacterial contamination).

The Environmental Health Department (EHD) is responsible for monitoring with respect to potable water sources (Nile River and canals). The quality of the Nile is monitored regularly each month in order to check the water quality as a source of drinking water: a sample is taken upstream and downstream of each discharge point (103 locations).

The Egyptian Environmental Affairs Agency (EEAA) is responsible for preparing legislation and decrees to protect the environment in Egypt and is responsible for setting standards and monitoring compliance, although, the MWRI retains overall responsibility for the management of surface water quality. The EEAA also participates in the preparation and implementation of the national program for environmental monitoring and data utilization. The lakes and area surrounding Wadi El-Rayan represent a special situation, as this area was designated a Protected Area in 1989, which places overall responsibility for the management of the area and lakes within the jurisdiction of EEAA.

The Ministry of Higher Education and Scientific Research (MHESR) has wide-ranging duties ranging from water and environment to energy and health, with two research institutes (the National Research Centre - NRC - and the National Institute for Oceanography and Fisheries -NIOF) which collect samples for specific research projects.. The Ministry also supports sustainable socio-economic development, the promotion of information technology, managing the regional aspects of the Mediterranean Sea, and preservation of the cultural heritage.

4.2.2 Interests of key stakeholders

Table 4.2: Major Stakeholders for the Wadi El-Rayan

Stakeholder Group	Interests	Likely impact	Relative Priorities
Primary Stakeholders			
Individual farmers	• Improved quality of irrigation water. • Pressure to modify agricultural practices	+/-	1
Fish farmers	• Improved quality of water to fish farms	+	2
Lake fishermen	• Improved quantity and quality of fish from Wadi El-Rayan	+	2
Livestock farmers	• Improved quality of water for livestock watering and bathing	+	2
Rural communities	• Improved availability and quality of fish from Wadi El-Rayan • Improved quality of drainage water, which is used for washing etc.	+	2
Ecotourism	• Enhanced aquatic environment • Improved quality of water in lakes	+	1

Stakeholder Group	Interests	Likely impact	Relative Priorities
Secondary Stakeholders			
Ministry of Water Resources and Irrigation	• Improved management of water resources • Improved maintenance of irrigation system. • Data on surface water quality • Information on agricultural pollution	+	3
National Institute of Oceanography and Fisheries	• Improvement of inland fisheries	+	1
Ministry of Agriculture and Land Reclamation	• Project results contributing to agricultural research and extension. • Improved agricultural productivity for downstream users. • Investigation of new technologies • Pressure to modify current agricultural policies	+/-	2
Egyptian Environmental Affairs Agency	• Improved knowledge of impacts of agricultural activities	+	2
Ministry of Health and Population	• Project results contributing to knowledge of public health		2

4.3 Agricultural Policies and Practices

4.3.1 Agricultural policies

(i) Introduction to agricultural policies

The government places great importance to the agricultural sector recognizing its significant role in the national economy. It accounts for about 20% of GDP and of total exports, and about 34% of total employment (FAO, 2003). The performance of the agricultural sector in Egypt has largely been determined by policies involving government control and taxes to control both farm production and input procurement and distribution (Fawzy *et al*. 2002). In the past, both the allocation of land and crop rotations were determined by authorities to achieve mandatory delivery quotas of strategic crops such as cotton, rice and wheat. Farm inputs were distributed by the government at subsidized prices and rationed to fulfilling the plans.

This has changed since the 1980s, when the Government of Egypt (GOE) started to implement a number of reforms of the sector in an effort to improve its efficiency and reduce distortions to the agricultural market with the objective of increasing food production and thereby ensuring food security

This reform has included a wide variety of measures (FAO, 2003) starting with first Five-Year Development Plan in 1982, such as:

- gradually removing government controls on farm output prices (although this does not preclude government voluntary guarantee prices for some strategic crops), cropping areas, and procurement quotas;
- removal of farm input subsidies;

- removal of governmental constraints on private sector in importing, exporting, and distribution of farm inputs to compete with the Principal Bank for Development and Agricultural Credit (PBDAC).
- removal of governmental constraints on private sector importing and exporting agricultural crops;
- diverting gradually the role of PBDAC to financing agricultural development projects; and
- confining the role of the Ministry of Agriculture (MOA) to agricultural research, extension, policy development and implementation;

The broad objectives of the agricultural development plan are to increase the productivity of land and water through more efficient use of limited resources and reduced production costs, and thereby increase national outputs and farmers' incomes. This was expected to increase the contribution of the agricultural sector in the social and economic development of the country (FAO, 2003). More specific objectives were also defined:

- conservation of water and land resources, and expansion of land and water resource availability through sustainable measures,
- ensuring food security and poverty alleviation for the rapid growing population and generating rural job opportunities, and
- protection of the environment.

From 1992 to 2002, agricultural reform has resulted in both an increase in agricultural area of 17% (ie an increase of 225,000 ha), an increase in cropping intensity, and diversification in the crops grown.

(ii) Agricultural extension and research

The Agricultural Extension Service, through the Ministry of Agriculture and Land Reclamation (MALR), seeks to support farmers through the provision of technical advice enabling them to increase production per unit of land and water, to reduce unit cost of production and to increase farmers' incomes through gains in efficiencies and improved technologies. Advice is also provided to farmers through the Agricultural Extension and Rural Development Research Institute (AERDRT) of the national Agricultural Research Centre (ARC). ARC conducts on-farm trials on farmer fields; provides training to extension engineers and village agents and establishes national campaigns that aim to develop certain crops. Farmers also received advice via the private sector e.g. agro-chemical companies and retailers, from co-operatives and via technical assistance funded via bi-lateral and multi-lateral donors.

At the regional level agricultural extension advisors of the Department of Agriculture (MALR) co-operate with university and Research Centres. These advisors meet regularly with farmers providing training based on extension training techniques such as farmer field schools and demonstration days. Extension workers train 'guides' who in turn work with, and train, farmers who then exchange information between themselves.

The Extension service provides support to farmers and covers all crops and livestock, working especially with small farmers on soil and water management, new cropping techniques such as inter-cropping, plant protection and support to rural women. This service operates in each District with support from local Research Institutes. Discussions with the Manager of Agricultural Extension Services (El-Fayoum) would suggest that most extension support is focused on the production aspects

of agricultural with little, explicit support, to highlighting the potential environmental pressures associated with agricultural activities. The MALR and agricultural extension service actively support, through training and advice, the uptake of Integrated Pest Management (IPM) and organic farming which are both practiced in El-Fayoum. The GoE Agricultural Strategy 2017 (FAO 2003) briefly mentions the need to minimise the intensity of livestock production units to reduce the risk of animal wastes (i.e. excreta) polluting groundwaters. Notwithstanding this there does not seem to be any real appreciation of diffuse pollution from agriculture, or if there is, no clear program of measures to support farmers in minimising or controlling diffuse pollution.

The government recognises the environmental risks posed from livestock management, particularly regarding large livestock units and stresses the need for keeping clean the production process of any of the animal protein food sources; promoting livestock and poultry manure management including the recycling back to the soil to improve fertility; limiting the housing intensity of livestock to proper number to avoid contamination of ground and surface waters; recycling slaughter house by-products in the poultry livestock and fish sectors into animal protein co-castrates for feeding poultry and fish (FAO, 2003).

(iii) Fertilisers: policies and subsidies

Egypt has one of the highest rates of fertilizer application in the world. According to FAO estimates, in 1992 the rate of application amounted to 349 kilograms per hectare of agriculture land, only exceeded by South Korea with 437 kg per hectare. Between 1979 and 1991, the application rate in Egypt increased by 65 percent. There are several reasons for the increase in nutrient consumption including the increasingly intensive nature of the farming system, the gradual increase in the recommended fertilizer rate for various crops, and changes in cropping patterns to more input-intensive crops. Rate of nitrogen fertilization was more than doubled for wheat, rice and maize in 1991 as compared with 1970, because of the release of high yielding varieties and a continuous decrease in soil fertility (Hamissa and El mowelhi 1989). They also reported that the area of land cultivated also increased as land was reclaimed, thus contributing to the increase in fertilizer consumption.

Nitrogen fertilizers (urea, ammonium nitrate, ammonium sulphate, and calcium nitrate) are the most important types of fertilizers in Egypt, accounting for 86 percent of total chemical fertilizer consumption in Egypt in 1996. Phosphoric and potassic fertilizers account for 12 percent and 2 percent of total fertilizer consumption in Egypt.

Prior to 1991, PBDAC was the sole fertilizer distributor to all farmers in Egypt. Fertilisers were subsidised and distributed to growers under in-kind credit policies. Farmers repaid these in-kind loans through a crop quota delivery system. This system slowly began to change when the GOE eliminated direct production subsidies in 1989 and then removed PBDAC distribution subsidies in 1991. Private sector traders moved into fertilizer marketing in July of the same year, and by July 1992 they dominated the market.

In 1995, there was a fertilizer crisis resulting in a shortage of nitrogenous fertilizers and a dramatic rise in prices. This led to a temporary reversion back to a public sector monopoly (with PBDAC once again sole distributor of domestically-produced fertilizer), but this was a short-term measure and PBDAC was never been able to recapture the fertilizer market. Cooperatives and the private sector continued to operate parallel to the Bank, and farmers had the option of purchasing fertilizers from three primary sources: private traders, PBDAC, or their local cooperatives

(iv) Pesticides: policies, controls, subsidies and extension advice

Control of the quantity of pesticides being used in agriculture is a major policy goal of the MALR, and this is reflected in a general long-term downward trend in the intensity of pesticide use. This can be attributed to a number of policy actions:

- market reform (phasing out of subsidies);
- banning of environmentally persistent and damaging compounds such as organochlorines (such as DDT in the late 1960s);
- introduction of a more rigorous approval and registration system for pesticides;
- increasing availability of low dose compounds (requiring applications as low as 5 g/ha in contrast more than 2 kg/ha with older pesticides)
- discontinuing inefficient methods of application (aerial spraying) and phasing out of aquatic weed control by agro-chemicals the affordability of pesticides; and
- the promotion of better awareness of pesticides and environmentally benign management systems to manage pests such as integrated pest management (IPM)

These reforms are supported by the growing public concern over the environmental fate and persistence of pesticide residues both in food products and the wider environment. These changes are believed to have reduced environmental exposure to pesticides (in contrast to earlier reports, it is now believed by local veterinary officers that no pesticides are now to be found in milk[26]).

An estimated 620.000 tons of about 200 types of pesticides have been used in Egypt since 1960, but there has been a sharp decline in the annual quantities: pesticide imports from a peak of 35,000 Mt in 1984 to 10,000 Mt five years later. However, despite the reduction in pesticide consumption, they still pose both an environmental and health risk. Observations made by Tchounwou *et al*. (2002) indicate that, for example, farm workers do not follow appropriate safety precautions and that substantial amounts of pesticides are inappropriately used. It is apparent that further reductions in pesticide consumption would be feasible.

4.3.2 Agricultural practices

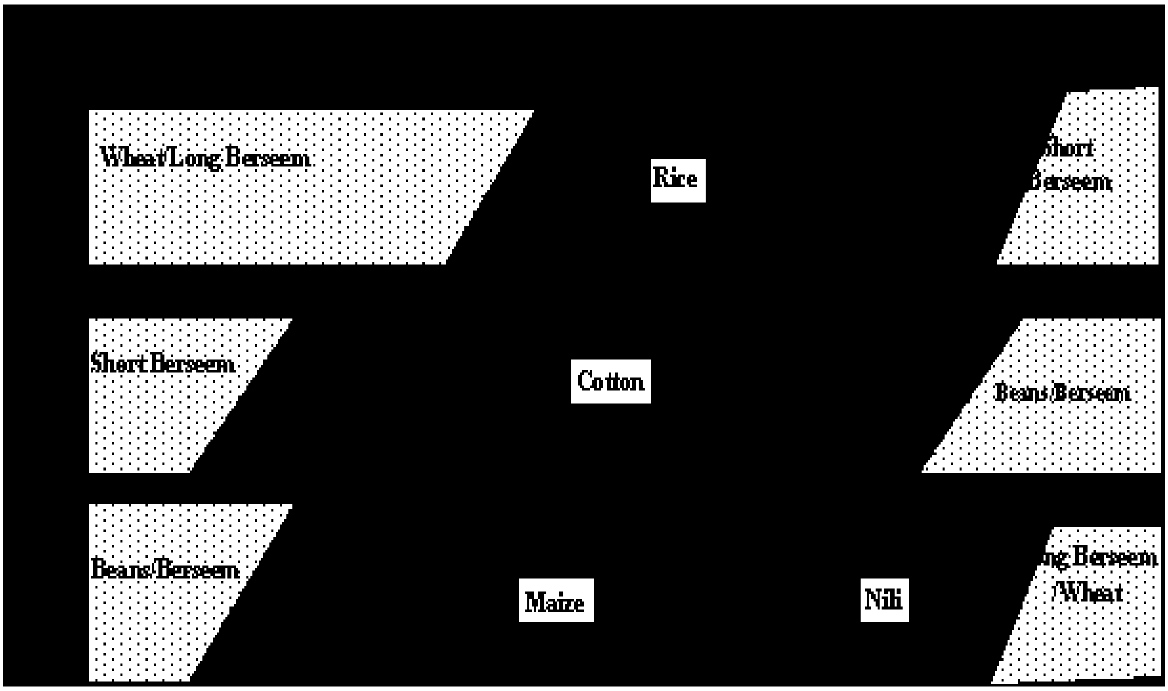
(i) Farming systems

The majority of land in Egypt is cultivated by small farmers operating as owners, tenants, and sharecroppers, or as a mixture of all three. In the Fayoum, 50% of farmers own less than 0.4ha - a rather smaller holding than the national average (FAO, 2005) of 0.6 ha. Given the small size of most holdings, most farmers are highly dependent on manual labour, although ploughing, threshing and water-pumping are mechanised. Sowing, transplanting, weeding, and harvesting are mainly performed manually. Fertilisers are broadcast by hand and pesticides are applied from knapsack sprayers. In the past, when the government had greater control over the planning and management of the agricultural sector, aerial spraying of crops to control pests was common but this was discontinued in the 1990s. Most tractors are privately owned and can be rented privately or through the local co-operative.

[26] we cannot confirm this belief from this study, as we only took a single milk sample from cattle known to occasionally consume drain water in which we did not detect any pesticides

A typical crop rotation is shown in Table 4.3 (M. Allam & R. Azim). The importance of traditional practices to maintain fertility is apparent in this rotation, which shows the inclusion of leguminous crops such as beans to fix nitrogen, and the role of fodder crops such as berseem

Table 4.3: Typical cropping calendar



(ii) Crop patterns and areas

The Egyptian agricultural sector can be grouped into four systems: field crops; horticultural crops; forest trees; and medicinal, aromatic and ornamental plant crops. There are two main cropping seasons throughout Egypt: the winter season from November to May and the summer season from May to October. There is also short season between those two main seasons locally known as the Nili season.

At a national level, the major field crops are cotton, rice and maize (summer) and wheat, berseem clover, and faba bean (winter). Cereal crops are thus dominant with 2.82 million ha grown in 1998 (FAO - 2003), followed by fodder on 1.16 million ha. Fibre crops (326,900 ha), sugar (152,934 ha), legumes (162,264 ha), and oilseeds (117,665 ha) are the other main field crops. Production of horticultural and medicinal crops is rapidly growing, both for local and outside markets.

The cropping pattern in the Fayoum is similar to that at the national level: wheat (76,000 ha) and long-berseem (56,000 ha) cover 92% of the winter crop area, with much smaller areas of barley (4800 ha), onion (3,900 ha), tomatoes (2,600 ha), and camomile (3,700 ha). Guinea corn and maize (90,000 ha) dominate the summer season (about 70% of the cropped area), with small areas of cotton (14,000 ha) and rice (13,000 ha). Nili crops are only grown a small part of the area – mostly maize (27,000 ha) and tomatoes (8000 ha).

Crop yields have changed little over the five-year period 2000 – 2004, but are generally slightly less than the national average – particularly low yields are reported for cotton in the Fayoum (Table 4.4)

Table 4.4: Crop yields of major crops (2003)

Crop	National Average kg / ha	Fayoum Average kg / ha
Cotton	3,723	2,120
Wheat	6,434	6,160
Maize	6,678	6,420
Rice	9,965	9,220

A very high proportion of land - over 90% of the land area - in the Fayoum is cultivated (Table 4.5).

Table 4.5: Cultivated and uncultivated area in Fayoum Governorate during 2003-2005

District	Cultivable area (ha)	Uncultivable area		Total area (ha)
		Housing/ha	Service/ha	
El Fayoum	32,508	1,586	768	34,862
Senoris	23,981	1,125	714	25,820
Tamia	33,111	1,246	401	34,758
Atsa	44,073	1,904	1,770	47,747
Ebshway	14,300	540	943	15,783
Yosef El Sedik	28,584	524	1,475	30,583
Total	176,557	6,925	6,071	189,553

Source: Agricultural department in Fayoum governorate, 2005

(iii) Fertiliser use

Fertilisers provide the main source of applied nutrients to the agricultural system, with other sources being applications of manures and slurries, and atmospheric deposition. According to FAO data, the total fertiliser consumption at the national level has increased by 44% in the past decade (877,442 tonnes in 1992 to 1.26 million tonnes in 2002) – an increase of 3.7% per annum. Most of this increase can be attributed to an increase in agricultural land but applications per unit area of land have increased from 318 kg/ha to 374 kg/ha (an 18% increase). Although earlier increases were largely due to introduction of new high yielding varieties which need higher rates of fertilisers, and other major changes (such as the construction of high Aswan Dam which reduced the quantity of suspended materials deposited on the soil during floods and maintained soil fertility), the recent changes are more due to changes in cropping pattern and growing awareness of the impact of fertiliser applications.

Fertiliser use recommendations are based on experiments carried out by the Ministry of Agriculture and designed to maximise crop yields. The recommended rates are averages, not tailored to specific areas and in practice, neighbouring farmers use different rates of fertilisers for the same crop. These recommendations have not been changed in the last five years.

Under Egyptian agricultural conditions, nitrogen is considered to be the most critical factor in crop production. The rate of nitrogen application in Egypt is one of the highest rates in the world and

appears to considerable loss of the easily soluble nitrogen through leaching. Such losses of nitrogen are likely to be a substantial financial waste and to pose a pollution risk in the form of nitrate contamination of surface or groundwaters (FAO, 2005).

In Egypt, there are several traditional practices (FAO, 2005) that are commonly implemented and which play a major role in restoring and maintaining soil fertility. Among these practices are:

- Planting berseem clover as a winter fodder crop before the cotton crop, providing a green manure by ploughing in after taking one or two cuts;
- Incorporating farm yard manure (FYM) into the soil during seedbed preparation. This is usually done before an important cash crop such as cotton is planted;
- Including in the crop rotation a legume crop such as: faba bean, clover and soybean, which have a positive effect on soil fertility and provide part of the nitrogen requirement.

National statistics on fertiliser use are presented in Figure 4.2 and Figure 4.3.

Figure 4.2: Total fertiliser consumption - Egypt

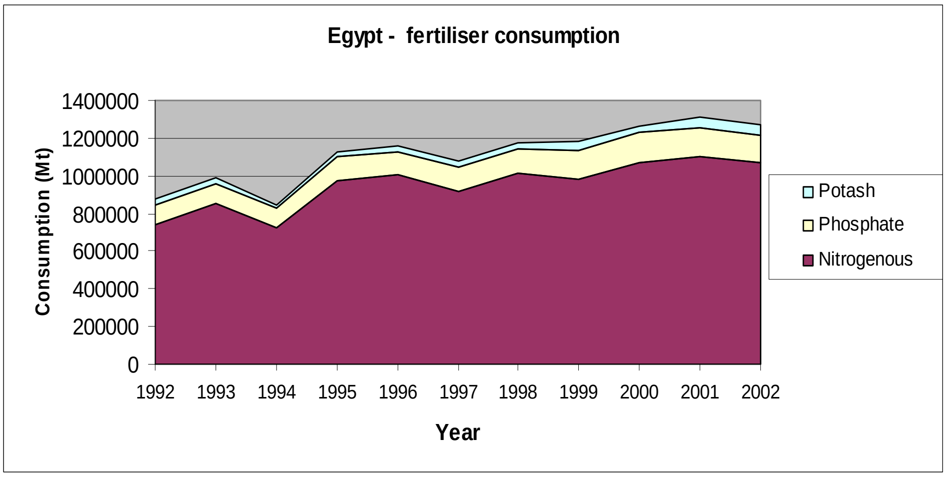
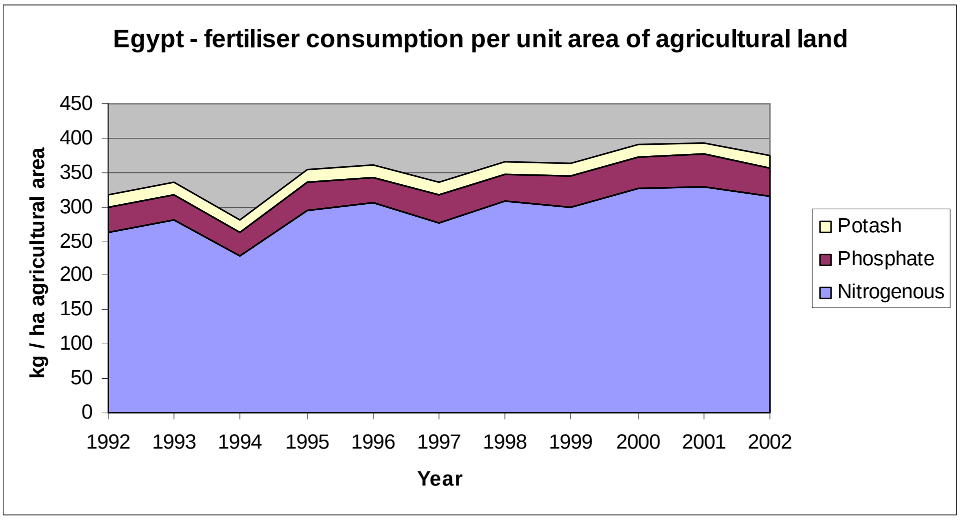


Figure 4.3: Fertiliser consumption per unit area



Statistics on actual fertiliser consumption in the Fayoum are not kept, although there are records of crop areas (and livestock numbers). The changes in fertiliser use, *assuming* all farmers comply with the recommendations, can thus be calculated for each main season as presented in Figure 4.4 and

Figure 4.5.

Figure 4.4: Estimated fertiliser applications in Fayoum (winter)

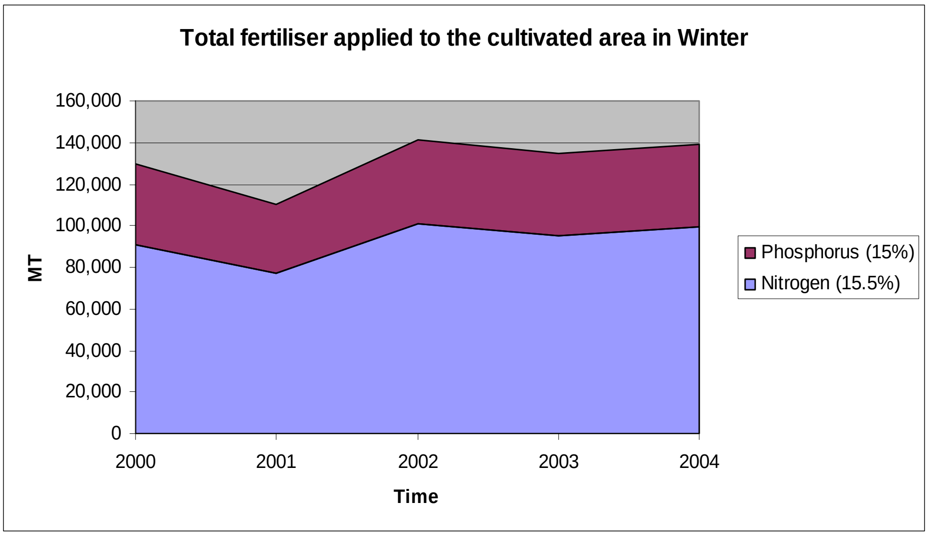
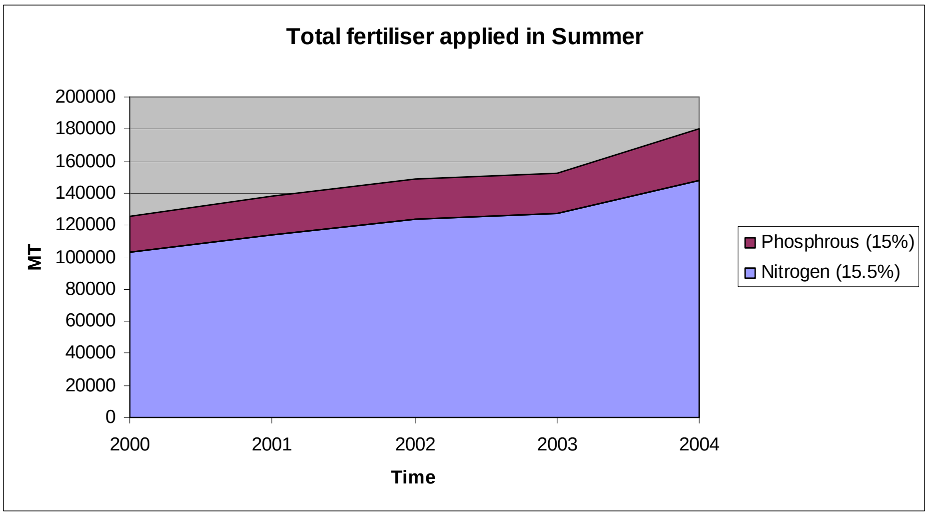


Figure 4.5: Estimated fertiliser applications in Fayoum (summer)



Although it was generally stated by agricultural authorities that farmers use excessive fertiliser, our observations were that farmers used less than the recommendations – usually because they cannot afford to comply. They appear to be well aware of the recommendations and were able to quote the recommended applications. However, the above figures are our best estimate of the overall trends in fertiliser use in the Fayoum.

While there is no simple linear relationship between amounts of fertiliser applied and subsequent nutrient loss to watercourses, this increase in fertiliser consumption can be expected to give rise to greater environmental pressure.

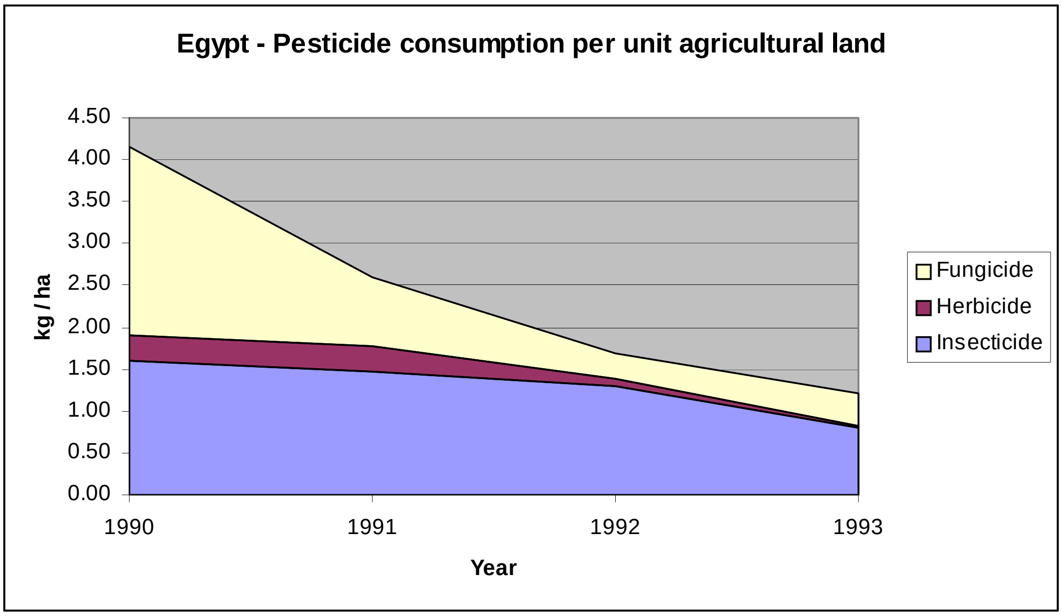
(iv) Pesticide use

Despite the strong policy to reduce pesticide use described earlier, there appears to be no system for recording actual use and we were unable to obtain reliable data on actual pesticide consumption at any level. Farmers were also reluctant to discuss the issue in detail, and possibly under-reported their use. Retailers reported a sharp decline in sales of insecticide (although not of fungicides or herbicides).

The only time series data available is total imports from 1971-1989 rising from 18,000 MT to 34,000 MT in 1984 before declining to 9.6 MT in 1989. These are however crude figures, taking no account of the type or concentration of pesticide.

There are other incomplete data sets available. For example, over the four years, from 1990 – 1993 (Figure 4.6), there was an overall decline in pesticide consumption of 71%. Pesticide News (1995) reports pesticide consumptions rose as high as 60 000 tonnes annually between the period 1952 to 1986 but had declined to 4 000 tonnes annually by 1995.

Figure 4.6: Pesticide consumption per unit area (1990-93)



FAOSTAT data, 2005

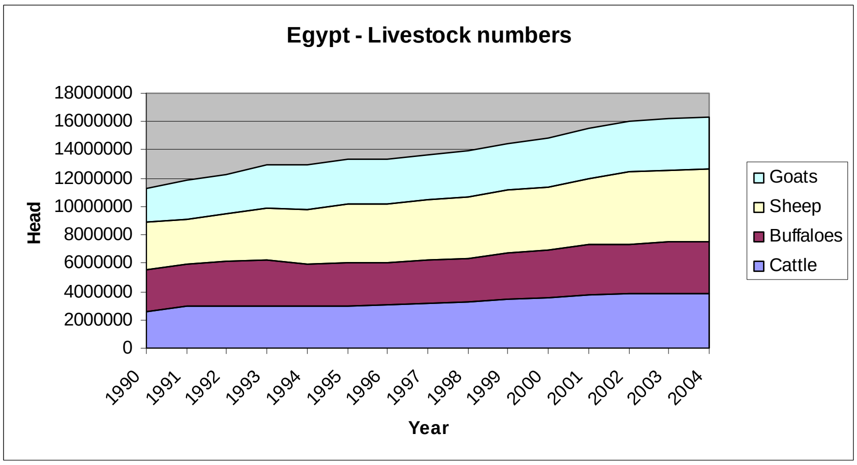
(v) Livestock

Livestock can provide a major component of nutrient loadings and balances at field and farm scale, and intensive livestock husbandry systems increase the risk of soil erosion and degradation or increase poaching risk around areas where animals have access to canals and drains. Livestock are an important part of the farming system, but numbers are limited as Egypt has virtually no permanent pastureland, and animals are fed berseem, maize, barley, and wheat (

Figure 4.7). Average livestock number per farmer are roughly one buffalo, one cow, one sheep and one goat (Abdel-Meguid and Moustafa).

There is a similar pattern in the Fayoum, where most people keep cattle for milk, meat and draught power. There are very few large livestock enterprises, with one with 500 head of cattle and perhaps 10 farms with more than 100 head, and no large stockpiles of manure. However, livestock are often allowed to bath in and drink from canals and this will pose a very small risk to water quality. There is little direct run-off of animal wastes into canals or drains since manures have a high dry matter content (due to the high temperatures and lack of rainfall) and are stored carefully for use on the land.

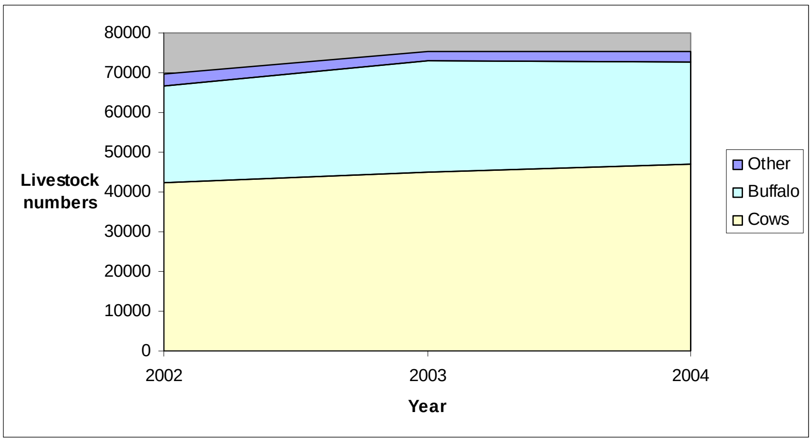
Figure 4.7: Livestock Numbers - Egypt



FAOSTAT data, 2005

There has been a similar small increase in numbers over three years within the Fayoum (about 7%)

Figure 4.8: Livestock numbers – Fayoum



4.3.3 Detailed study area

(i) Crop pattern

The most common crops grown in the summer season are maize, sorghum, cotton, sesame and sunflower whilst the most common crops grown in winter are wheat, berseem (clover) and tomatoes. Of the 15 farmers 12 grew maize (36 ha) and wheat (24.3ha) and, although only 5 grew cotton this was the second largest cultivated crop (30ha) after maize. Berseem, guinea corn, sorghum and tomatoes were widely grown and, although only 3 farmers grew sesame the total area was higher than these four other crops and this was also true for onions.

The typical agronomic practices associated with the study area are shown in Table 4.6.

Table 4.6: Agronomic practices in study area

Crop Grown	Time Of Swing	Time Of Harvesting	Chemical Fertilizer	Water Applications
maize	10-15 May	10 August-10 September	Urea	8
Sorghum	15 May-15 Jun	15 August-10 September	Urea	6
Cotton	10-15 May	20 August-15 September	Ammonium nitrate	6
Sesame	May	End of August	Urea, Super phosphate	8
Sunflower	May	End of August	Urea, Super phosphate	6
Wheat	October& November	May	Urea	4
Berseem	October	December	Super phosphate	10
Tomatoes	Winter and summer (Every 3.5 months)	Winter and summer	Urea, Super phosphate	8

(ii) Fertiliser use

There were three different fertiliser types used by the 15 farmers, urea, ammonium nitrate and triple superphosphate. In most cases inorganic fertiliser was supplemented with organic manures which were applied prior to sowing a crop. The range of fertiliser use was quite wide ranging for example from 50kg to 250 kg per feddan for wheat (mainly urea applied). This range is consistent with observations from the 1998 Egypt Wheat Producers Survey (EWPS, Croppenstedt, 2005) which was designed to be representative of farm households growing wheat in the 1997/98 season and covered 800 wheat farmers in 20 out of 26 governorates (average farm size of about 0.55 hectare). On average sample farmers use 110 kilograms of fertilizer per feddan (total of all types) but with a range of 10 to 650kg/feddan and 12 households reporting zero fertilizer use.

Drainage rates are typically of the order of 30% of irrigation supply (Ramadan et al, 1989), and combined with the residual quantities of nitrate from fertiliser that is not used by the crop during the growing season suggestes that nitrate concentrations in drainage waters should be greater than the figures observed in most of the study. This is presumably due to rapid leaching and dilution which means that there are short term peaks that are not detected in monthly samples. For example, in the case of winter wheat with typical fertiliser use efficiency, then surplus residual fertiliser N not taken up by the plant may be of the order of 60 kg N/feddan – if the recommendations are followed. Assuming an average drainage volume of 6,600 m^3 per year to Fayoum, and assuming this excess N is leached then the mean concentrations leaving the soil root zone should be around 50 mg $N0_3$/l.

This apparent discrepancy is problem due to under-use of fertiliser and to staggered timing of applications and dilution effects in the larger drains, but is worthy of further investigation. This potential loss of significant unused (i.e. residual) fertiliser N vulnerable to leaching in irrigation waters, suggests that there likely to be scope for a modest reduction (e.g. 10-20%) in *total* N applied to the agricultural system without serious yield penalties. This will be difficult to manage because of the need to irrigate frequently to maintain acceptable plant growth conditions and control the risk of

salinity and sodicity through careful management of leaching. However, more efficient irrigation techniques could be used and it is recommended that further work be undertaken in these areas to explore the practical constraints on encouraging more efficient use of irrigation waters, and of fertiliser and manure N. Greater efficiencies in utilising applied nitrogen will save farmers money as well as have environmental benefits

(iii) Pesticide use

The range of common pesticides (herbicides, insecticides, and fungicides) used in Egypt is summarised in Table 4.7. The pesticides used by farmers in the study area are summarised in Table 4.8. Herbicides are the most widely used (13 times) and were applied to wheat and berseem to control weeds. This was closely followed by insecticides which were used (9 examples of application) to control pests in cotton, moonflower, onion, maize and guinea corn. Finally, fungicides were used to control disease outbreaks in maize and guinea corn.

Table 4.7: Main pesticides used in Egypt

Crop	Pesticides	Rate of use per feddan
Cotton	Bestian	1L/ F
	Teleton	750 cm^3 / F
	Super alpha	250 cm^3 / F
	Sumi Gold	150 cm^3 / F
	Sumi alpha	600 cm^3 / F
	Skip	1.5 Kg / F
	Consult	200 cm^3 / F
Wheat	1 Fox	31.5 gm/ 100 L.Water
	Sumi 8	35 cm^3/ 100 L. Water
	Topic	140 gm/ F
	Puma Super	1.25 L./ F
	E.B.Flu 50%	500 cm^3 / F
Maize	Sia Fox 50% EC	750 cm^3 / F
	Marshal 25% WP	600 gm/F
	Hostavion 40% EC	1.25 L./ F
	Lanet 90% SP	300 gm/ F
	Neodrin	300 gm/ F
Rice	Fuoridan 10%G	6 Kg / F
	Beem 75% WP	100 gm/ F
	Sinozan	100 cm^3 / L. water
	Ronstar 25%	750 cm^3 / F
	Saturn 50% EC	2 L./ F
	Mashit 60% EC	1.5 L. / F

- Source: Directorate of Agriculture and Land Reclamation at Governorate

Table 4.8: Examples of pesticides used by farmers in the study area

Pesticide (brand name)	Used by sample farmers	Crop applied to where reported by farmer	Active ingredient	Chemical Group
Lanit	✓ (6 times)	Maize and Guinea corn	Carbamoyloxy	Carbamate
Readan	✓ (14 times)	Maize and Guinea corn		
Obek	✓ (once)	Wheat		
Pestban	✓ (once)	Cotton	Chlorpyrifos	Organophosphate
Rodmil*	✓ (once)	Tomato	mefenoxam	
Kelthane*	X		Dicofol	Organochlorine
Calical*	X		Carbaryl	Carbamate
Abamex / Romecetin*	X		Abamectin	Antibiotic
Cascade*	X		Sodium hypochlorite	Inorganic
Cypercal*	X		Cypermethrin	Pyrethroid

A short summary of the qualities (taken from Extoxnet[27]), in terms of possible environmental fate, of the listed pesticides above are given below.

- Chlorpyrifos (e.g. Pestban) has a variable persistence in water which will vary depending on the formulation and has been reported as having a half life in water of 3.5 – 20 days and that it is unstable in water. This compound has a high affinity for binding to soil particles and is unlikely to move out of the field system.
- Dicofol (e.g. Kelthane) binds very strongly to soil and is prone to breakdown in moist soils and is nearly immobile in soils and unlikely to penetrate groundwater and, even in sandy soils, was not detected below the top three inches in standard soil column tests. The high absorption coefficient means that dicofol is expected to adsorb to sediment when released in open water.
- Carbaryl (e.g. Calical) has a low persistence in soil and its degradation is mainly due to sunlight and bacteria and it has a half-life of 10 days in water.
- Abamectin (e.g. Abamex) is rapidly degraded in soil with reported half-life of 8 hours to one day and undergoes rapid photo-degradation with a half-life of 12 hours in water.
- Information held on PMEP concerning mefenoxam (e.g. Rodmil) indicates that this compound is “fairly persistent and mobile compound” with a half-life of 58.4 days.
- Other compounds such as cypermethrin (e.g. Cypercal) undergo very rapid biological degradation, and are therefore considered non-mobile.

All of the above active ingredients are considered toxic although their relatively low half-life and affinity to binding to soils means that they are unlikely to be detected at the catchment outlet and, to increase chances of detection drainage water samples would need to taken soon (a few hours) after application. Moreover, with each pesticide application representing relatively small amounts of active

[27] http://extoxnet.orst.edu

ingredient the dilution factor (in field) would result in little compound reaching the main drains, even with the more mobile compounds.

4.3.4 Summary

Egypt's agricultural strategy has focused on reducing government intervention through the gradual removal of subsidies and quotas and encouraging private sector investment to create an environment for continued agricultural development. The expansion of agricultural land (new land) through the development of new irrigation schemes coupled with the introduction of new technologies e.g. high yielding crop varieties and the provision of technical support to farmers through the agricultural extension service and research centres has also been a part of the government's strategy for the sector.

The development of the agricultural sector has seen a corresponding increase in fertiliser consumption and livestock numbers over the last decade, although there has been a continued decline in the volume of pesticides used since 1980's and now only organophosphates, carbamates and pyrethroids are used on farms rather than the more persistent organochlorines which were used previously. The increase in fertiliser use and the relatively high level of consumption may be appropriate for the new higher yielding cultivars (FAO, 2005 show increases in recommended rates for N, P and K or a range of crops between 1979/80 and 2003/04) and associated double or triple cropping widely followed in Egypt. Thus there may be a relatively small risk of loss of nutrients through leaching.

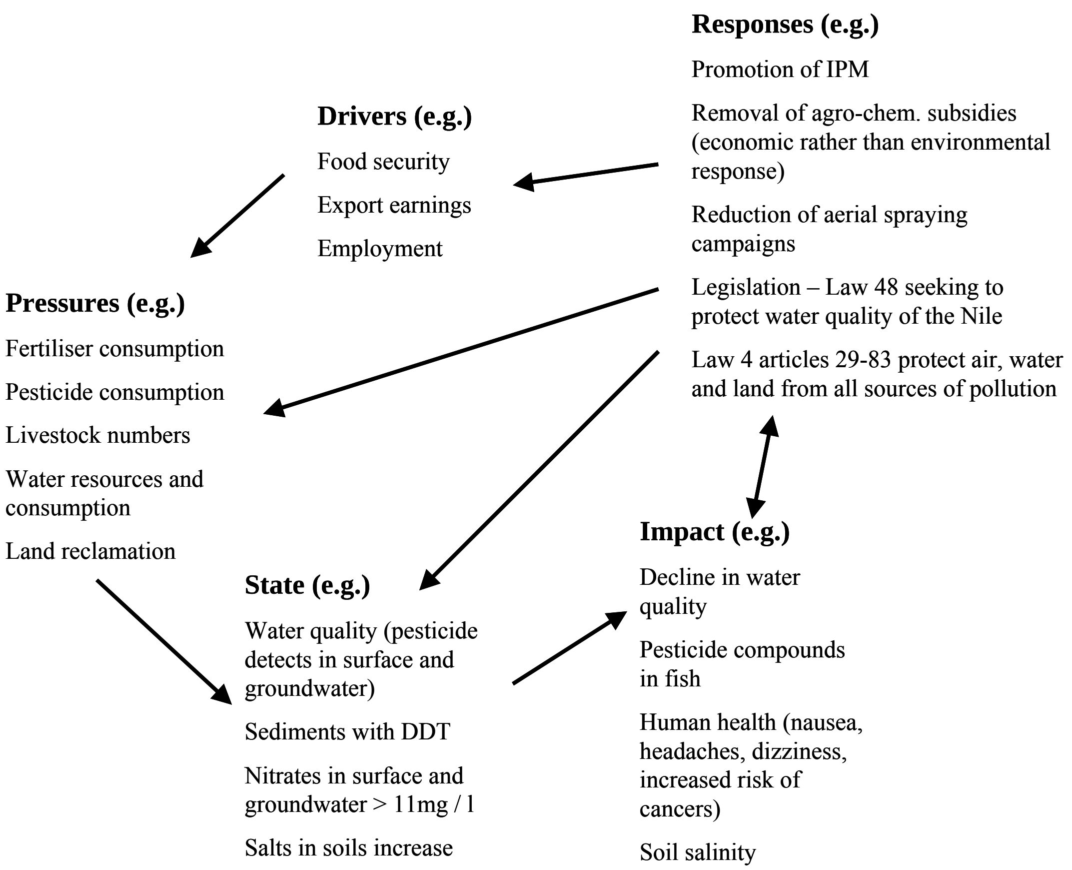
The relationship between these factors and their impact on the environment can be represented on the DPSIR[28] framework below (Figure 4.9). High temperatures will reduce the amount of liquid slurry from cattle therefore resulting in manures with high dry matter content reducing the risk of leachate reaching surface waters, although where animals are allowed to bath in canals or are tethered close to water courses there is a risk of contamination. High temperatures will also result in the rapid breakdown of pesticides and the volatilisation of inorganic fertilisers.

Policy developed in the 1970's resulted in the reuse of drainage water becoming a key component of water management practices adopted in the late 1980's. The reuse of drainage water results in increased salinity as well as an increase in organic and inorganic pollutants in the drains (Achtoven *et al*., 2004), with increasing negative consequences downstream. However, most of the rural pollution is still of human rather than agricultural origin - for example, Achtoven *et al*. (2004) cites Bazaraa (2002) who identifies contamination of drainage water as serious in the 130 stations sampled by the Drainage Research Institute (DRI) particularly coliform bacteria and heavy metals (notably cadmium associated with human waste).

Fertiliser use has increased dramatically over the last 30 years, and high levels of nutrients have been detected in some drains in the delta (although not in the Fayoum) which has caused problems of eutrophication and increased problems of maintenance. Pesticide use remains a concern despite the policy measures already introduced. Pest resistance has resulted in heavier and inappropriate use of pesticide applications and this in turn has had a negative impact on the surrounding environment (Tchounwou, 2002). Such pesticides were not detected in this study in the Fayoum, but there remains the probability that they were masked by averaging and dilution in the sampling process, and would be detected in specific locations and times.

[28] The DPSIR framework is based on the OECD DPR (Drivers, Pressures, Response) framework and modified by the European Environment Agency to incorporate environmental State and Impact.

Figure 4.9: Drivers, Pressures, State, Impact and Response Framework applied to Fayoum



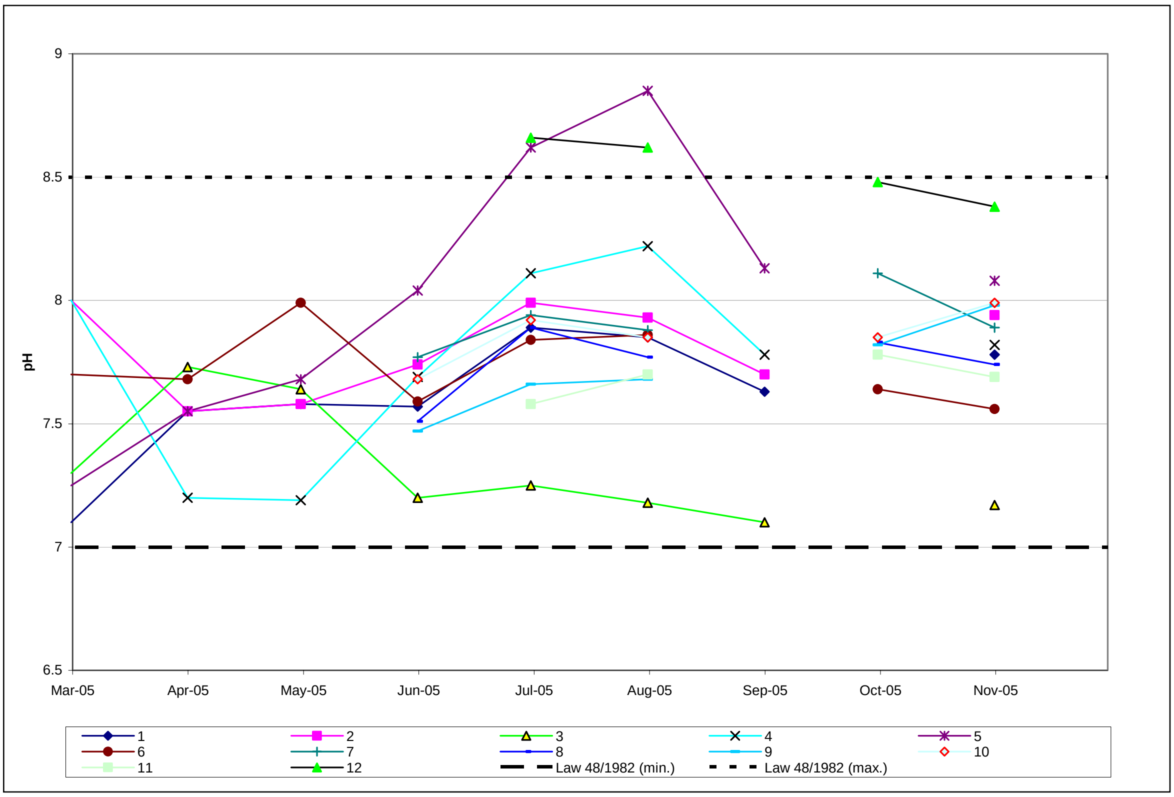
4.4 Water Quality

4.4.1 Variation in water quality through the season

(i) Physical parameters – temperature, pH

The surface water temperature follows the air temperature, reaching a peak in august and minimum in January. This has a significant impact on physico-chemical parameters of the water, as well as evaporation and the activity of aquatic fauna and flora. Conclusions related to other parameters therefore need to be related to seasonal temperature.

Figure 4.10: Seasonal Variation in pH

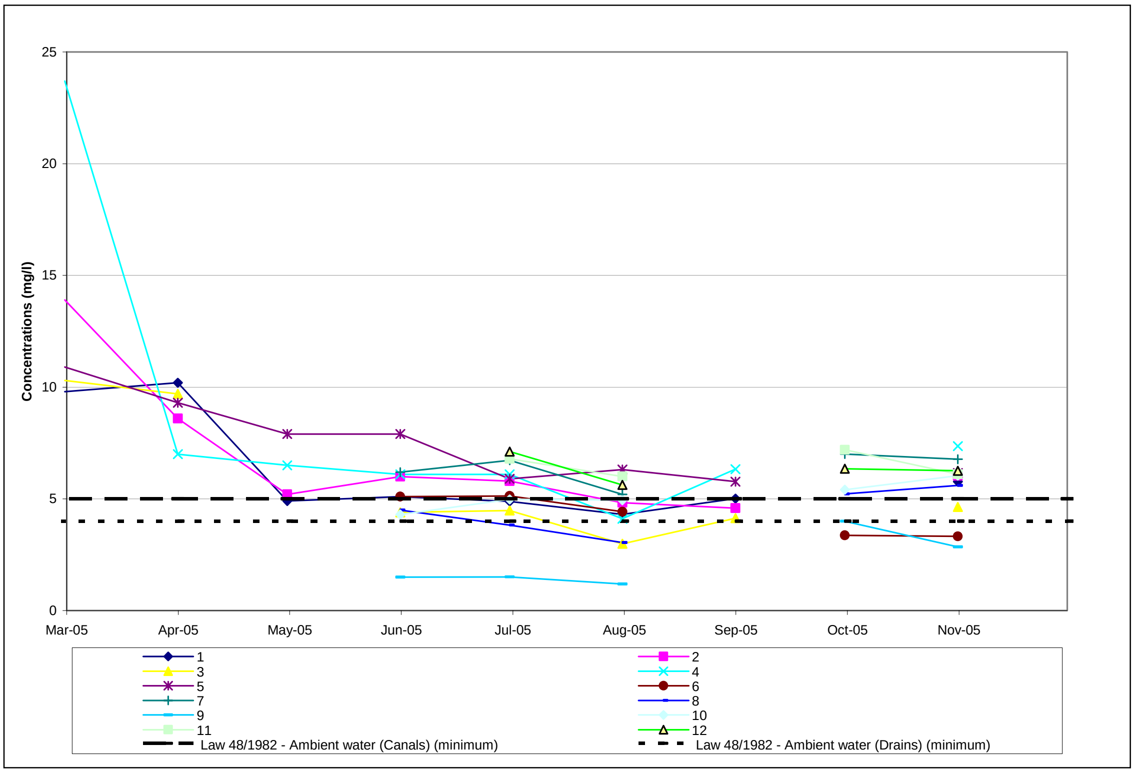


pH is an important physical parameter and has an impact on most other parameters, which respond to acidity or basicity conditions. Our study shows that the pH shows little variation throughout the monitoring program and were neutral to slightly alkaline. This is confirmed by observations from the NAWQAM (see Appendix F) study which covers several sites in the Fayoum since 2000. All year round, pH remains roughly constant and remained in compliance with Law 48/1982 range (i.e. 7 to 8.5, see Figure 4.10).

There is an increase in pH in all the sites between mid-June and mid-September, but this may be due to the temperature compensation of the apparatus used during *in situ* measurements, since the NAWQAM data which shows no obvious effect of the summer season. Higher values in winter may be explained by higher concentrations found in stagnant waters during the canal closure period. Two sites show higher values than the other during the same period, underlining spatial variations in pH measurements which will be discussed in Section 4.4.2.

(ii) Dissolved Oxygen and BOD

Figure 4.11: Seasonal variation in dissolved oxygen



Dissolved oxygen (DO) follows a reverse pattern to that of temperature (Figure 4.2) as would be expected as the amount of dissolved oxygen in surface water decreases as temperature rises. DO values drop severely between March and May, but then remain relatively stable from June to Mid-November (although they vary considerably between sampling sites). These months correspond to the time of high irrigation demand and evaporation. With values sometimes under the limit fixed by law 48, we may say that relative poor water quality is observed during summer months whereas winter months contribute to the re-oxygenation of the studied sites.

The same patterns can be observed from the NAWQAM monitoring. Dissolved oxygen concentration in surface water bodies depends on the physical, chemical and microbiological activities. A comparison with biological and chemical oxygen demand data enables us to understand the water quality in terms of organic matter and minerals present in the samples. Results show a very good correlation between COD and BOD. Both parameters show a significant decrease during the summer months whereas they remain high during the winter months. Such temporal variations may be attributed to seasonal change where atmospheric conditions clearly affect biological and chemical activities in both drains and canals thus remaining above the Standards Limits.

A slight difference is observed between drains and canals when DO, COD and BOD parameters are concerned. Such variations and their probable cause will be discussed below.

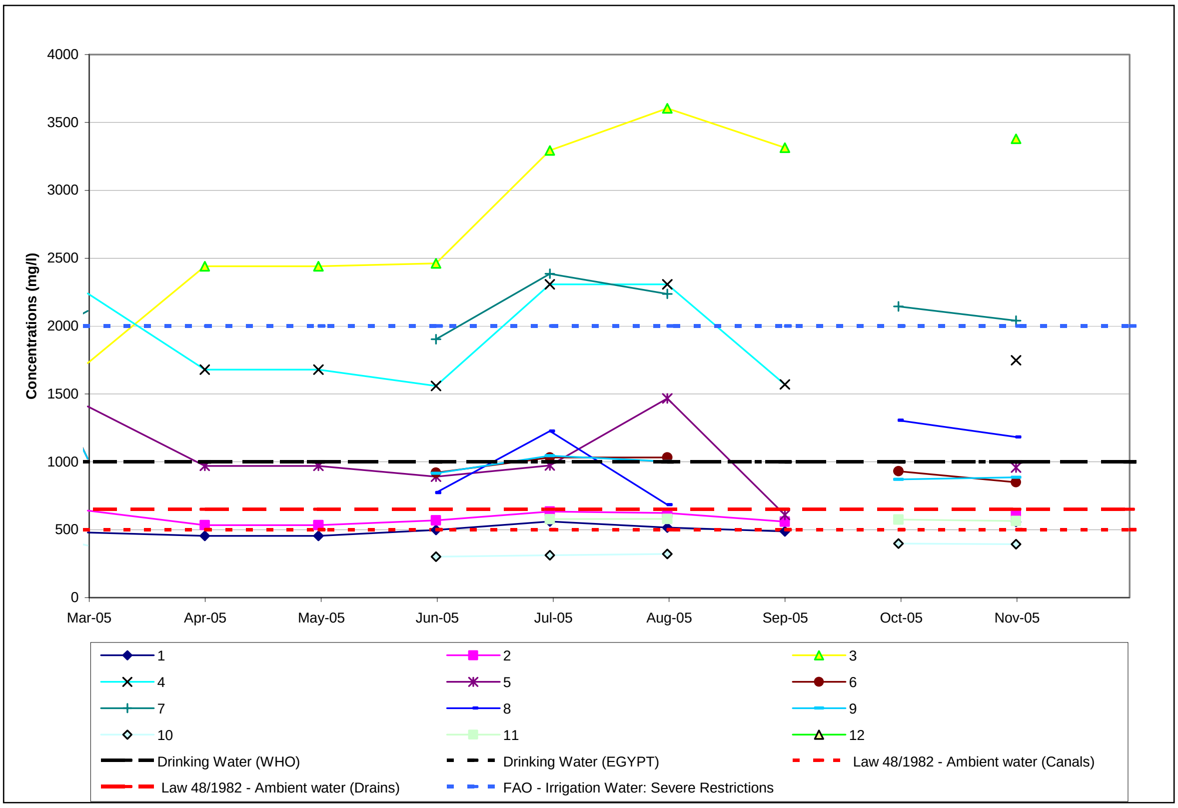
(iii) Salinity

Total Dissolved Solids (TDS) are the total concentrations of dissolved organic and inorganic solids in water. TDS values observed in surface water bodies mainly depends on evaporation whereas several factors including chemical precipitation, the nature of soils and rocks the water runs over, and human activities may as well impact on this parameter.

The observation of total dissolved solids at all sampling sites show that most values are above the limits fixed by the law 48. Most sites have similar patterns throughout the year, but with some significant increase in the summer months, particularly in July (Figure 4.12).

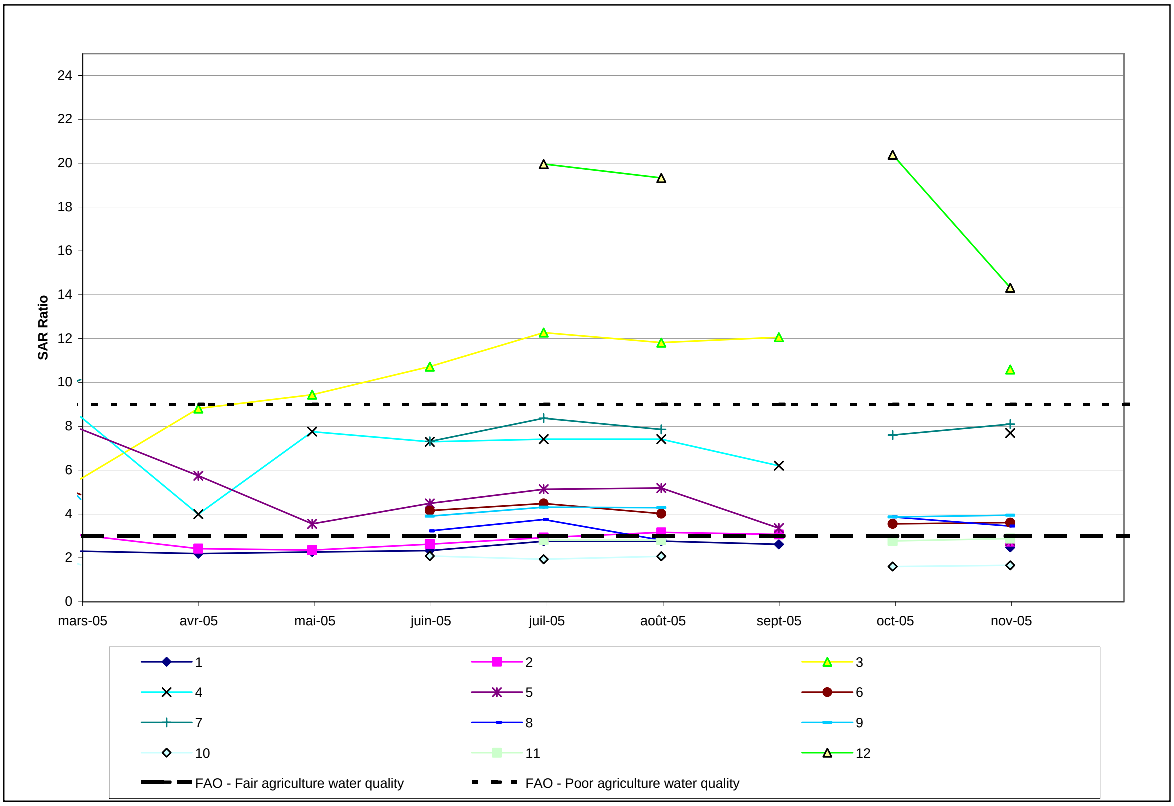
As would be expected, values obtained for the Wadi Rayan lake (the outfall of the system) are the highest observed - reaching values over 9,000 mg/l. There are of course large variations between sampling locations as will be discussed below. Electrical conductivity (EC) was also studied and the trends observed follow the ones shown by TDS as would be expected, since EC is directly dependant on TDS.

Figure 4.12: Seasonal variation in Total dissolved solids



SAR and major ions results can also be clearly linked to TDS, as they are all related to the number of ions dissolved into water. There are variations between sites, but seasonal variations are relatively small with just slight increases in the summer months. The importance of studying SAR is the toxicity of sodium in terms of modifying soil structure and causing adverse effects. Results shown by SAR measurements in all sampling sites follow the behaviour of TDS and show variations between sites.

Figure 4.13: Seasonal variation in Sodium Absorption Ratio



The TDS and SAR analyses confirm that the summer months are the most problematic period for salinity: scarcity of water at this time means that more drainage water is reused. This is confirmed by the NAWQAM data which shows approximately the same trend since 1998. The NAWQAM also shows some peaks in the period between December to March both in drains and canals which may be linked to the shut down of the system when low or no flows can cause higher concentrations.

(iv) Nutrients

The study of fertilisers focused on nitrogen and phosphorus compounds. The first includes ammonium, nitrates and nitrites, whereas phosphorus is dealt with as the phosphate form. The seasonal trends are highlighted in the following figures.

Figure 4.14: Seasonal variation in Nitrates

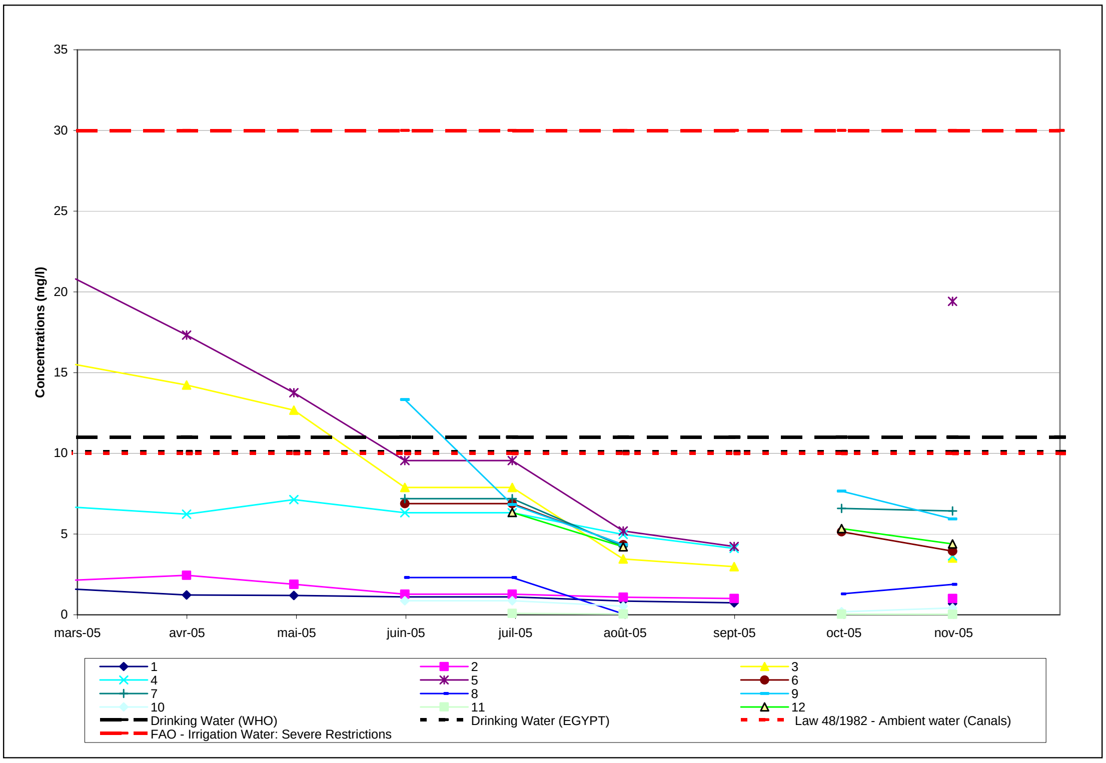
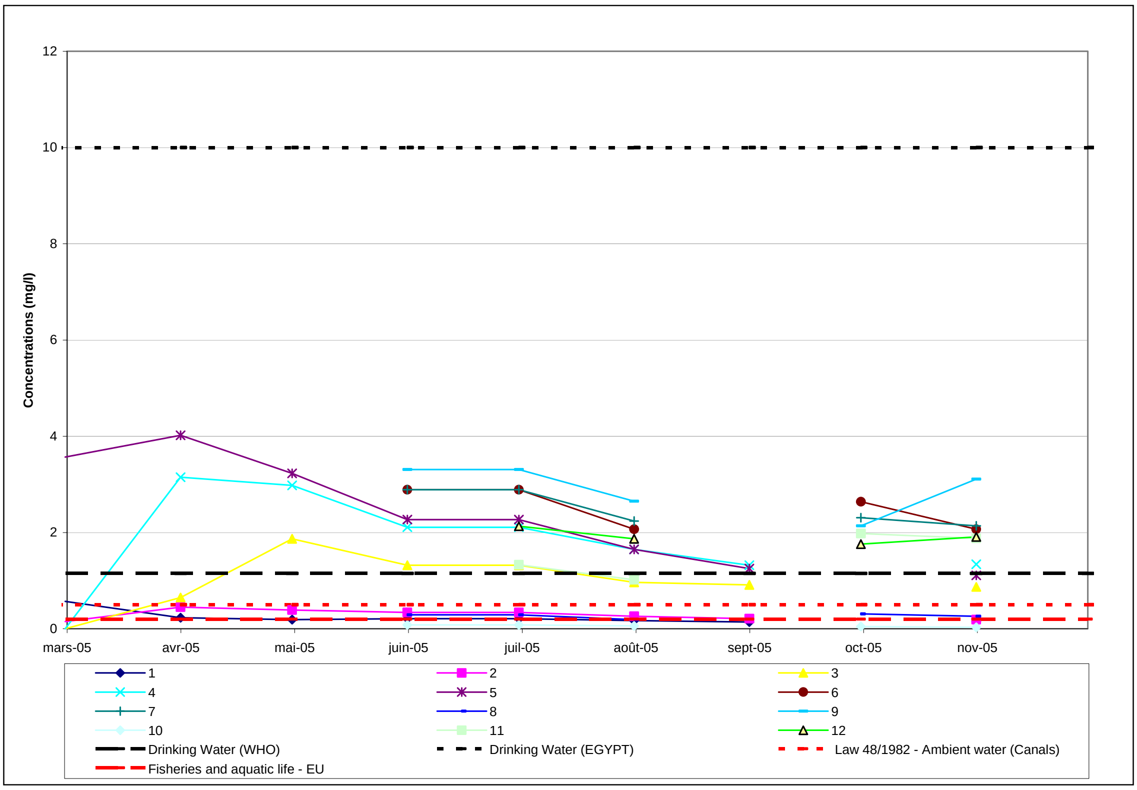


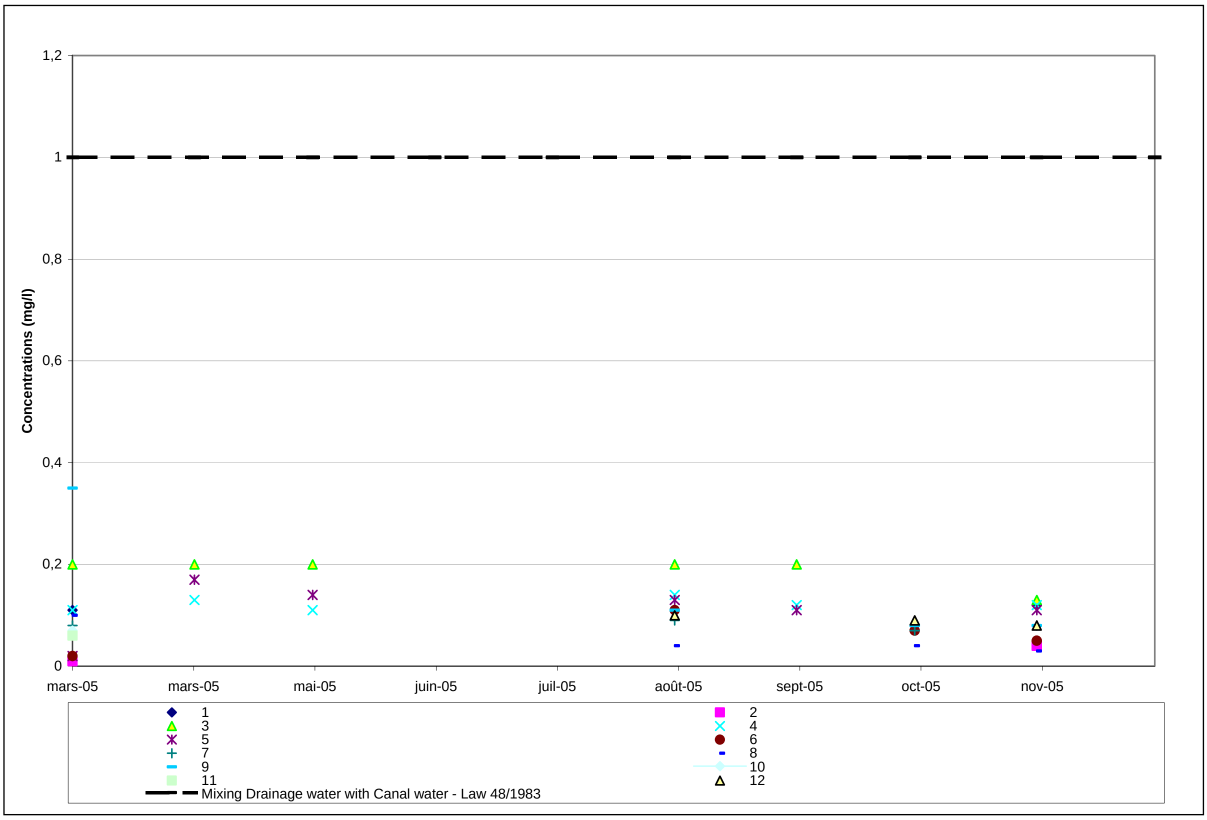
Figure 4.15: Seasonal variation in Ammonium



All the nitrogen compounds all follow similar trends (Figure 4.14 and Figure 4.15), and it is evident that site location (see section 4.4.2) is a greater influence than seasonal changes. The concentrations can however be correlated with agricultural practices – these figures indicate lower concentrations at the end of the summer when there are lower applications of urea and other fertilizers. Nitrate concentrations are above the standards early in the year, around the time that most fertilisers are applied. Ammonium is above standard for all sites during the whole monitoring period. Again this is confirmed by the NAWQAM study. The relatively high values in winter months could be attributed to the shut down of the system.

The differences in concentrations of the various forms of nitrogen can all be related to the nitrogen cycle. Nitrogen compounds brought in the soil by means of fertilizers are most of the time in the form of nitrate and ammonium. But as nitrification is a natural process in soils, the amount of nitrates becomes higher than the ammonium forms, or nitrites. As a result, water percolation and runoff may contain more nitrate than other forms before the denitrification process is started by bacteria present in the soils.

Figure 4.16: Seasonal variations in phosphates



Phosphorus compounds are present in natural water and wastewaters in the form of various type of phosphate. These are commonly classified into organophosphate, polyphosphate and organically bound phosphates. The various forms of phosphorus find their way into the water body through a variety of sources, i.e. fertilizers. In this study, the data obtained from determination of total phosphate in water in all agricultural canals and drains within Fayoum study area were below the limits of Law 48/1982 (1 mg/l). Phosphorus concentrations appear to be more uniform than nitrogen in the sense that very few variations can be seen for most sites (Figure 4.16) and it cannot easily be related to

agricultural practices. The presence of phosphorus in samples is more likely to be related to domestic uses and pollution of water. However, as in the case of nitrogen compounds, there are significant variations according to the sampling location (section 4.4.2). Nevertheless, the values remain below the limits fixed by law 48.

(v) Pesticides

The monitoring campaign did not show any significant pesticide presence, although the limitations of the methodology must be recognised – there may be short term peaks which were not detected particularly in the smaller drains, and a large proportion of the pesticide may be bound to suspended sediment and thus not detected. The majority of pesticides present in waters have been found in March which corresponds to the time when pesticides are applied early in the season. A more intensive sampling in April could have brought us to find both more compounds and higher concentrations

Table 4.9: Pesticides Detected in Fayoum

Pesticide	Site	Site Description	Date	Concentration (µg/l)	Lab. Detection Limits	WHO (µg/l) - Drinking Water	Egypt (µg/l) - Drinking Water
Abamectin	1	Banat Canal before mix	Mar-05	0.2662	0.01 - 0.05 (µg/l)	-	-
	2	Hanna Habib		0.1422			
	3	Collector 1 (maize field)		0.0674			
	3	Collector 1 (maize field)	Jul-05	0.0003			
	5	Collector 2 (cotton field)		0.0004			
	9	Wadi Rayan before mix		0.0025			
	9	Wadi Rayan before mix	Aug-05	0.0002			
	11	Drinking water		0.0004			
Aldrin	3	Collector 1 (maize field)	Mar-05	0.2040		0.03	0.03
Chlorpyriphos	1	Banat Canal before mix	Mar-05	0.1530		-	-
	2	Hanna Habib		0.2360			
Cypermethrin	4	Main drain of study area	May-05	0.0007		-	-
Dimethoate	1	Banat Canal before mix	Mar-05	0.5700		-	-
Esfenvalerate	8	Nazla before mix	Jul-05	0.0089		-	-
	1	Banat Canal before mix		0.0001			
	3	Collector 1 (maize field)		0.0013			
	11	Drinking water		0.0015			
	9	Wadi Rayan before mix	Aug-05	0.0007			
	7	Upstream of waterfall		0.0003			
Ethoprophos	2	Hanna Habib	Mar-05	0.0780			
	3	Collector 1 (maize field)		0.0660			
Gamma-BHC (Lindane)	1	Banat Canal before mix	Mar-05	0.0090		2	3
	3	Collector 1 (maize field)		0.0030			
Malathion	3	Collector 1 (maize field)	Mar-05	0.2440		-	-
Methomyl	1	Banat Canal before mix	Mar-05	0.0348		-	-

The concentrations obtained are very low, and mainly below the laboratories' detection limits, but some were found at higher concentrations which is clearly significant. Even though the concentrations are so low, these findings are potentially worrying, as the methodology we adopted mneas that we would not detect peak concentrations (the sampling locations and frequency meant that dilution and decay of pesticides would have a profound impact on the peaks). Pesticides were detected in the canals which are used as a source of drinking water, and thus a short term failure of the treatment system could result in direct human consumption of pesticides.

Pesticides in the canals are probably due to poor practices – such as washing containers, sprayers in canals, whereas those in the drains are more likely to be due to losses after application to the crop and leaching through the soil. It is revealing that the highest concentrations are to be found in the canals, and suggests that appropriate extension advice could reduce concentrations significantly. As field drains are sub-surface, spray drift into drains is unlikely to be very significant and thus percolation into the drains will be a more important route. Access to surface drains means that they are less used than canals for washing. These factors could account for the intutively surprising result that pesticide concentrations in canals are often higher than in drains.

Some of the results are slightly surprising. Abamectin, Chlorpyriphos, Dimethoate are known to be used in the area, but they do decay rapidly and thus higher concentrations probably occur at other times. The presence of Malathion is more questionable as it decays even faster (less than a week in raw river water)[29] and its use is not reported locally. Aldrin is an organochlorine pesticide which was banned from use several years before this study but it is known to be relatively persistent. Data on pesticide usage is clearly difficult to collect, and some uses may not be reliably reported.

There clearly is a seasonal variation of pesticides concentrations, as they are so closely related to agricultural practices. The mere fact that they were detected in the waters of the study area is sufficient for the purposes of this study. Their precise relationship to agricultural practices would require a more sophisticated and detailed study. A further concern is that they may break down to generate secondary products which are more dangerous than the initial ones. Heavy metals are often constituents of the pesticides, and new generations of pesticides tend to be degraded very rapidly in the natural environment leaving breakdown products which are heavy metals (and hardly degradable). In addition, such degradability of the pesticides involves breakdown products showing very low concentrations which are hardly detectable by analytic methods. These products interact with bacterial flora in soils and water which could result in bio-activation of molecules more dangerous and toxic than the parent product.

Nevertheless, values obtain during the whole campaign show pesticide detected mostly below the detection limits of the used methods. But given the crude methodology applied, their detection during the whole campaign highlights the effect of agricultural practices on water quality as well as the potential danger brought by the use of pesticides.

(vi) Metals

Heavy metals studied include Iron, Manganese, Zinc, Copper, Cadmium, Lead, Arsenic and Mercury. These showed peaks in June and July, particularly for arsenic and zinc at some sites.

[29] See http://extoxnet.orst.edu

The NAWQAM monitoring over the last few years shows that iron and manganese concentrations are roughly constant and above the limit throughout the year (except winter, when the canals are closed). These two elements are very closely linked and occur naturally in surface water bodies. The main source of iron and manganese in water is likely to be attributed to waste water (industrial and domestic) as well as natural deposits. It is likely that the constant low values observed may be attributed to non-agricultural sources and to the natural environment. In addition, these elements are of no immediate danger towards health issues but may cause a problem in irrigation water - phytotoxicity may reduce yields.

(vii) Bacteriological

Water analysis for all known pathogens would be very expensive and time consuming, and thus we just monitored total and faecal coliforms as indicators of bacteriological contamination in this project.

Figure 4.17: Seasonal variation in total coliforms

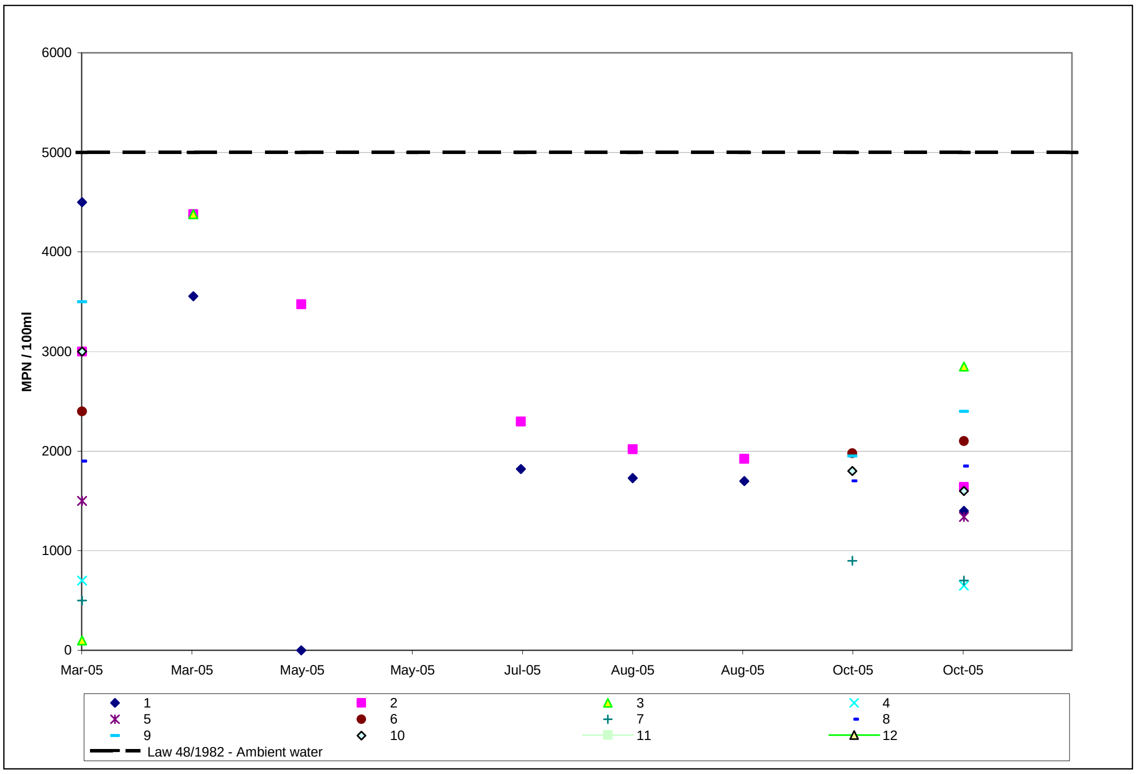


Figure 4.18: Seasonal variation in faecal coliforms

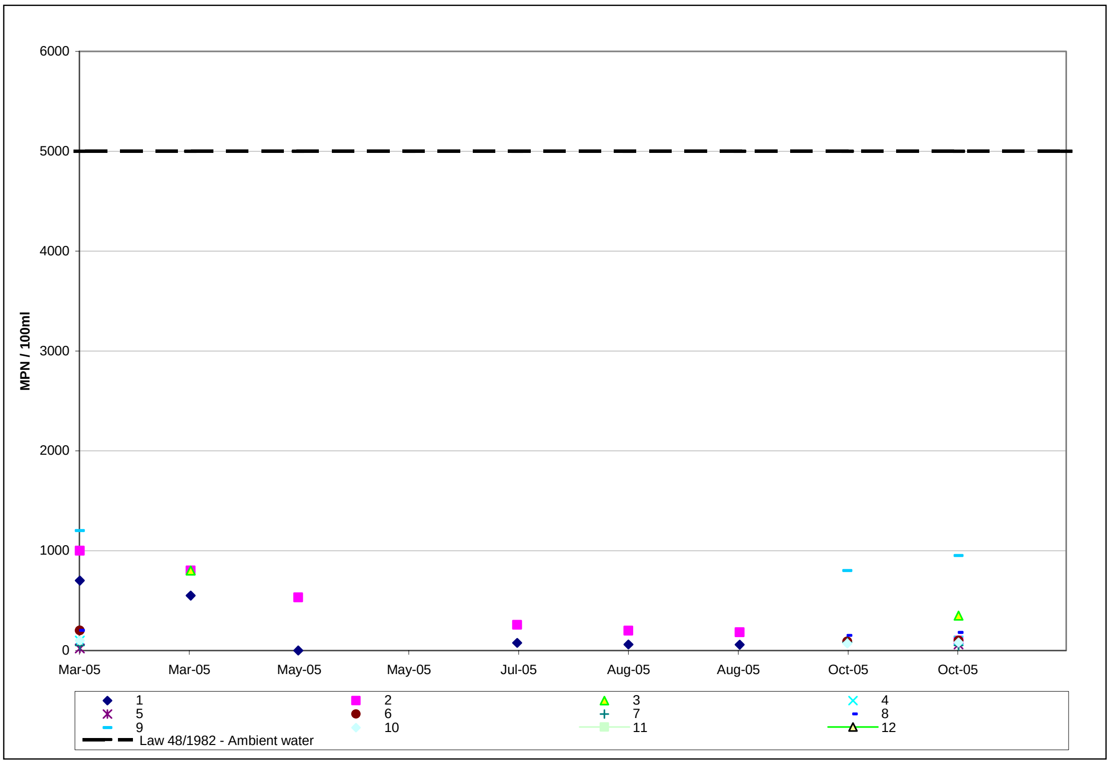
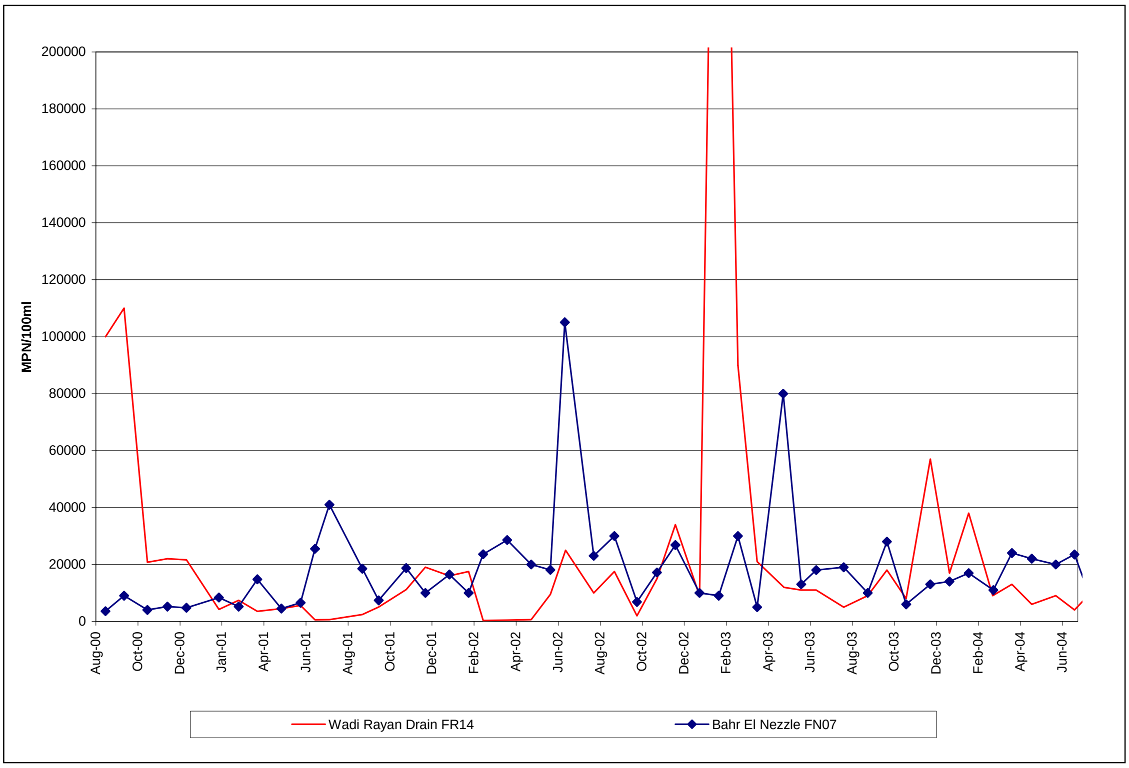


Figure 4.19: Seasonal variation in faecal coliforms (NAWQAM DATA)



This bacteriological data show poor water quality and not fit for human consumption at any sites – and indeed it is not intended for consumption. WHO recommendations are that bathing water should not exceed drinking water standards by more than a factor of ten, and these values are clearly exceeded in almost every case.

Seasonal variations are observed were winter months show the highest counts decreasing through out the year until reaching 'normal' amounts of coliforms present in surface water bodies from the study area. These trends are confirmed by the figure 4.19 which shows the NAWQAM data for Wadi Rayan Drain (in between locations 9 and 6 in the 2005 campaign) and Bahr El Nezzle (equivalent to location 8 – Nazla before Mix in the 2005 campaign. Peaks generally occur during the winter months and such values can be attributed to the shut down of the system where there is very little flow or stagnant water, with a major source of coliform bacteria from domestic waste in addition to the animal contribution (faeces and watering). Indeed, values obtained from the 2005 campaign show higher amounts of coliforms in canals rather than drains.

The very poor quality of canal water could be a health risk if there is a failure of treatment works which takes raw water from the canals. There is thus an urgent need to improve rural sanitation, although this is not related to agricultural pollution.

4.4.2 Variation in water quality down the system

In addition to seasonal variations it is apparent that there are many spatial variations down the hydrological system, which can be related to agricultural practices. These results are presented by plotting graphs of water quality against location from upstream to downstream along the x-axis. The x-axis thus represents the locations where samples have been collected down the system from the intake Bahr Yussef (location 10), through the detailed study area (locations 3 to 5) to the end at Wadi Rayan Lake (location 12). Drinking water samples are identified by location 11, and are treated water taken from site 8. It should be noted that nil values plotted on graphs correspond to 'not analysed' parameters rather than nil concentrations.

In order to avoid any duplication with the section on seasonal changes in water quality, we will only cover spatial dimension of selected parameters. This will enable us to highlight the variation of water quality down the system so that this can be related to agricultural practices in section 4.4.3.

(i) Physical parameters

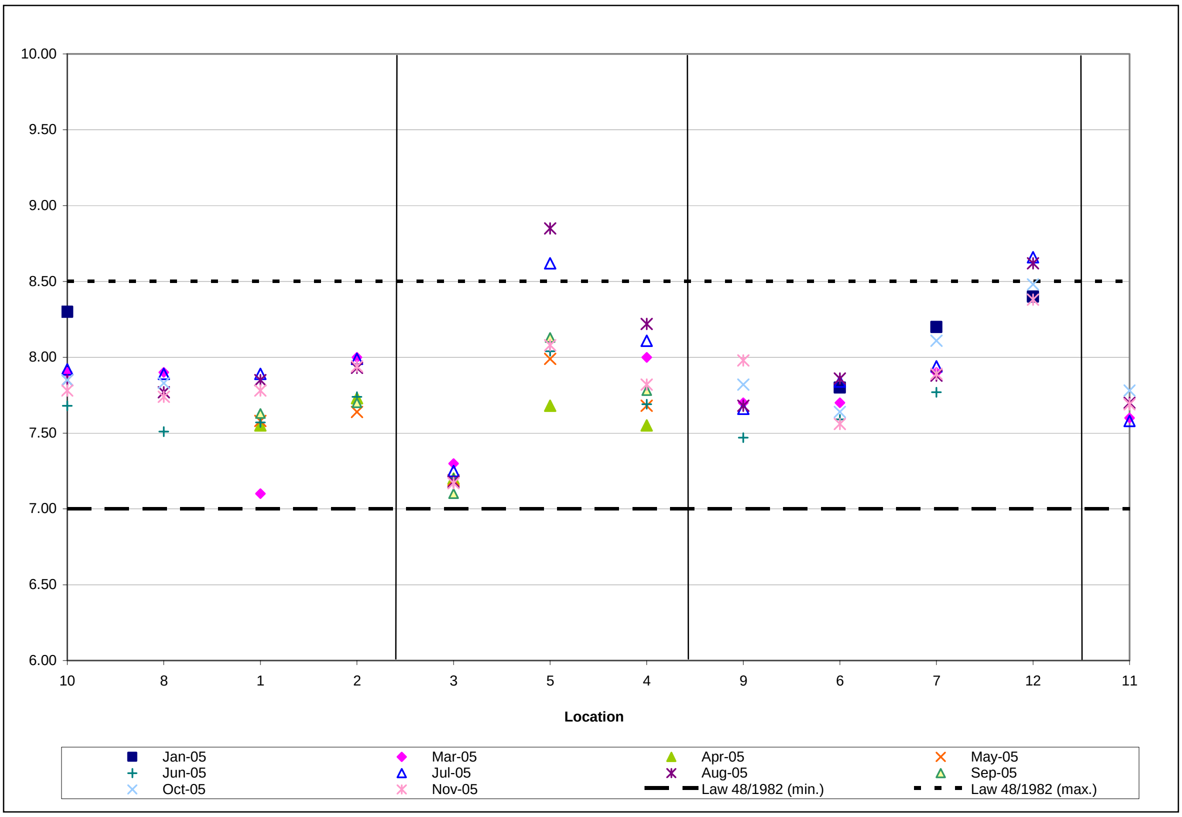
Temperature does not show any significant spatial variation. This parameter certainly affects the quality of the samples taken and the behaviour of the other studied parameters. As a result, variations between sites are mainly influenced by non atmospheric factors and links with agricultural practices or other sources of pollution will have to be considered as main issues to be referred to in this study.

As far as the pH is concerned, the values observed are almost all within the law 48/1982 range, generally showing slightly alkaline waters – particularly for drainage water. However, a clear spatial variation can be identified particularly at drains (locations 3 & 5; respectively maize and cotton collectors) and in the Wadi Rayan Lake as shown on figure 4.20.

Values at the collector near the maize field are consistently nearly neutral (pH = 7) but the highest values were observed at location 5 next to the cotton field. Such behaviour may be attributed to the

relationship between the type of crop grown, the soils and agricultural practices (such as use of manure). Confirming such influences would require further study but may be justified by the values observed at the main drain (location 4) where the pH remains in between the values observed at the collectors highlighting the effect of mixing waters coming out of locations 3 and 5. Additional agronomical studies would enable to clarify the relationship between the type of crop and pH which may affect the water quality.

Figure 4.20: Spatial variation of pH

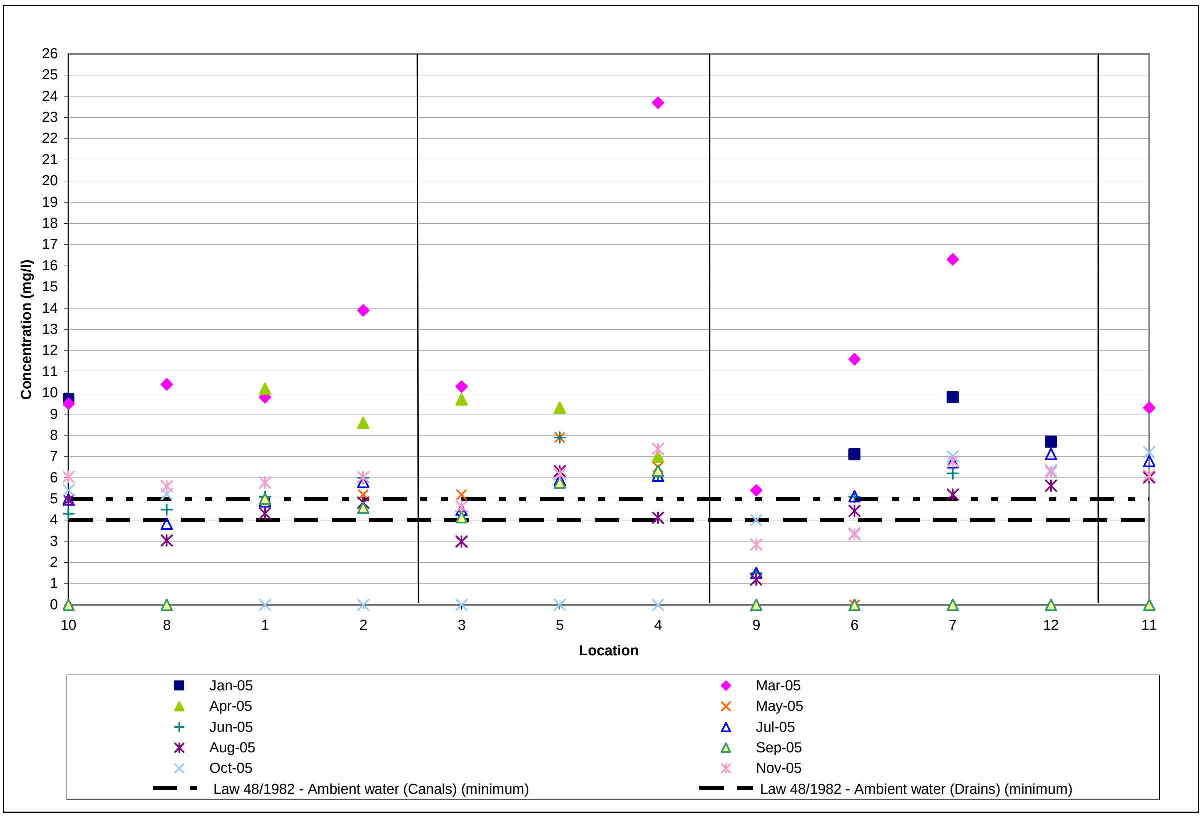


The pH values appear to increase down the system from location 9 to 12 (from the start of the Rayan drain to the second Wadi Rayan Lake). The origins of this increase are not absolutely clear, but it can be seen that drainage water in the detailed study area has a higher pH than the incoming canal water and hence, the Wadi Ryan Lake has highest pH values, sometimes over the limits fixed by the law 48/1982. The NAWQAM data confirms this observation that agriculture has an increasing effect on the pH values. This is important since the pH can trigger bio-chemical reactions directly influencing the biodegradation of pesticides and nutrients.

(ii) Dissolved Oxygen (DO)

Variations in DO down the system need to be considered in the context of *in-situ* parameters as DO is highly dependant on temperature and other parameters - particularly flow velocity. Trends in DO are plotted in figure Figure 4.21 below.

Figure 4.21: Spatial variation in dissolved oxygen



Analysing spatial effect on DO brings interesting results, although seasonal variations are rather greater. Local regulations (Law 48/1982) define the minimum acceptable values for ambient waters (drains and canals). However, trends in DO amounts down the system are all similar for both primary and secondary canals (locations 10, 8, 1, 2). The values observed show roughly constant levels of water oxygenation from the entrance into the system to Hanna Habib, albeit with seasonal variations which result in critical values in some summer months.

Oxygenation increases significantly down the system. Location 9, at the start of the drain has a very low DO, but levels increase further downstream. The water at location 9 is diverted from the Wadi Qarun drain and can be expected to be affected by municipal and industrial pollution from Fayoum city. The water quality thus improves as it is diluted by agricultural effluent.

Both locations 3 and 5 involved sampling in collectors located next to maize and cotton field respectively whereas location 4 is the main drain. This shows the poor water quality in the drains of the detailed study area, in terms of oxygenation, and indicates that no aerobic degradation of organic matter and nutrients is possible. The figures also show that there is an influence of cropped field on the amount of dissolved oxygen present after drainage. It appears that, in most cases throughout the monitoring campaign, maize planted fields have higher oxygen consumption resulting in lower DO values than cotton cropped fields. No direct relations can be established at this stage between the type of crop and evolution of dissolved oxygen in drainage water: the combined effects of rooting zone biological activity, ph, nutrients and salinity would probably affect the amount of oxygen dissolved in drainage waters. However, the influence of agricultural practices on DO values in drainage water is worthy of further investigation. Values observed at location 4 are mainly in between the

concentrations measured at the two collectors and illustrate the result of mixing together two waters with very low DO concentrations.

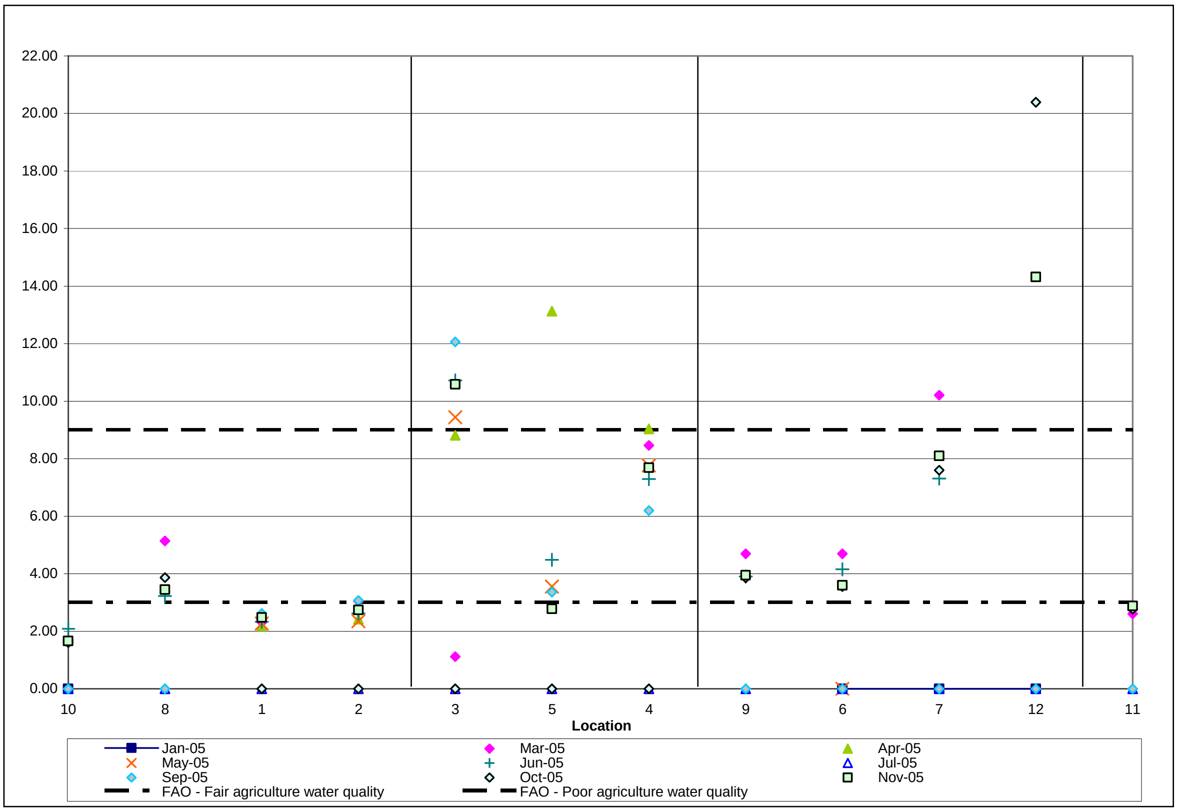
As would be expected, drinking water (location 11) has a slightly higher DO that the raw water source that it is derived from (at Nazla, location 8).

(iii) Salinity

Salinity was studied through the variations of both TDS and SAR. These two parameters are closely dependant and as would be expected show similar patterns.

As would be expected in the study area, where the reuse of drainage water is needed for irrigation and evaporation is very high, accumulation of salts in soils becomes clearly visible. Indeed, when comparing the SAR at the entrance of the system to those observed in drainage water, drainage water shows higher values. There are again differences between the maize and the cotton collector, reflecting the probable effect of the crop type on the quality of the water coming out of drains (with location 4 again showing the impact of the mix between the two types of water). Soils under maize crops seem to release more salts which are not consumed by the plants or adsorbed on soils particles. Comparison with the NAWQAM data reveals the same patterns.

Figure 4.22: Spatial variation in Sodium adsorption ratio



Almost inevitably, the Wadi Rayan lakes show the highest salinity, illustrating the accumulation of salts in this closed environment which is severely affected by the amounts of salts brought by the system, the high evaporation rates and negligible fresh water input from rainfall. These salts may

become potentially toxic to the aquatic fauna and flora present in the lake (as has been observed in Lake Qarun). These trends in salinity are confirmed by the NAWQAM data, which also shows that values in both drainage and canal water were roughly constant until 2004, but then an increasing trend has started

(iv) Nutrients

The study of nutrients and their spatial variations is important for understanding and finding ways to mitigate diffuse pollution. We will describe the evolution of both nitrogen and phosphorus compounds. The limits used as reference in this case are the law 48/1982 on Ambient Waters (canals), Drinking water standards defined both in Egypt and by the WHO, and the standards fixed by the FAO under severe restrictions.

Figure 4.23: Spatial Variations in Nitrate

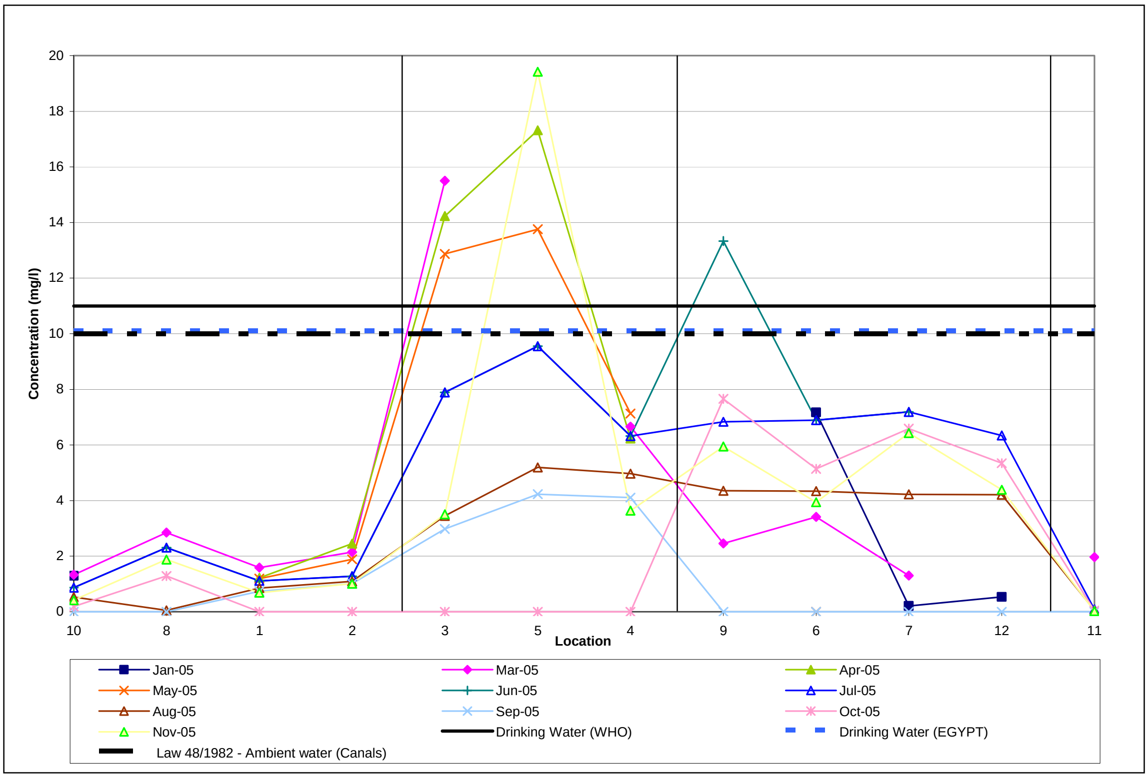
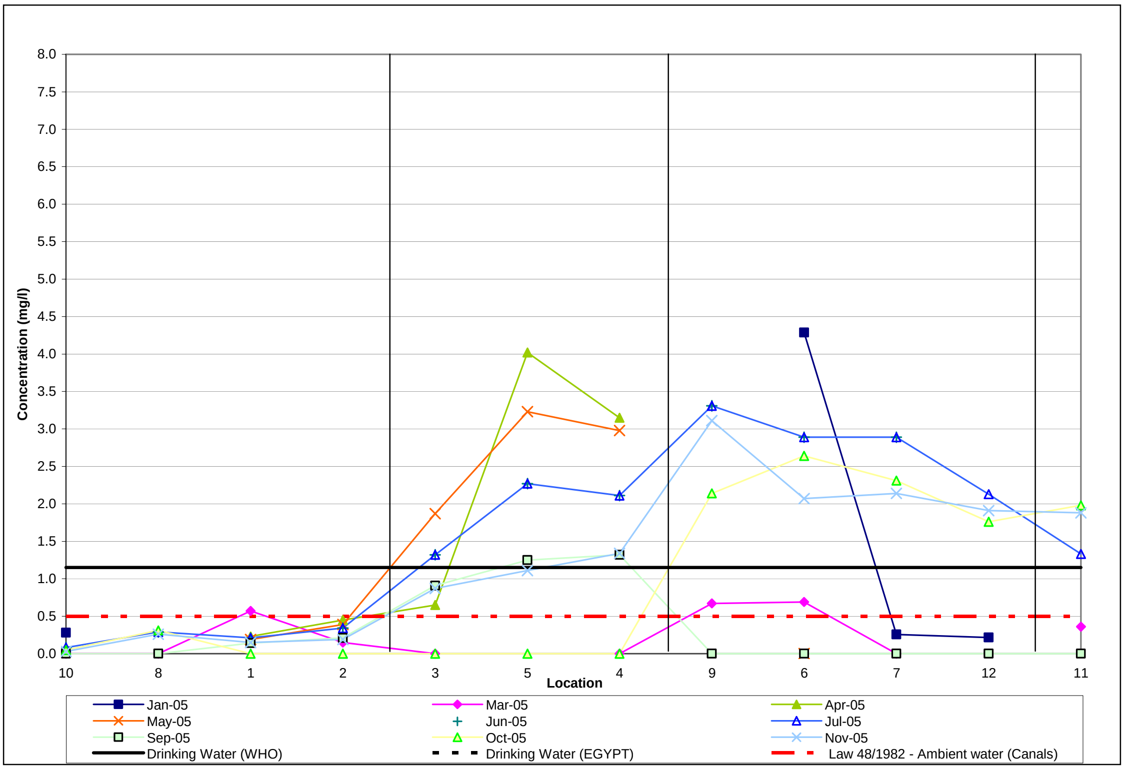


Figure 4.24: Spatial variations in ammonium



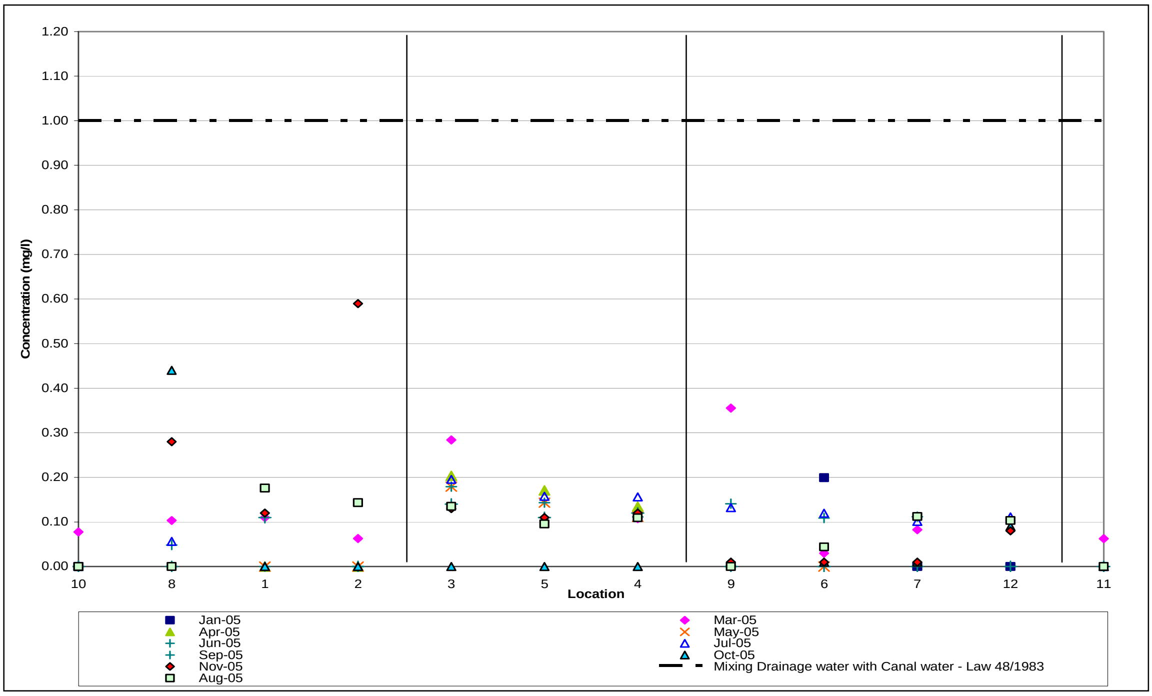
As stated in section 4.4.1, the evolution of nitrate and ammonium are closely dependant and related to the nitrogen cycle in soil and water. There are constant low values in the primary and secondary canals as this water is not influenced by agricultural activities. But the concentrations in the small drains after Hanna Habib (at locations 3, 5 and 4) are much higher and are well over the limits for most of the year. These figures clearly highlight the effect of field drainage on water quality - a clear impact of agricultural pollution. Water coming out from the fields contains higher concentrations of NO_3-N and NH_4-N which are dissolved when water passes through the soil. In addition, poor levels of organic matter combined with large quantities of added nitrates well limit the ability of the soil to retain nitrates - which are instead directly dissolved into the water.

The figures also show a significant influence from the type of crop grown. The collector from the cotton field show higher concentrations than the one next to the maize field: this reflects the higher applications of nutrients. Concentrations are again low further downstream, underlining the dilution effects brought by the mix with drainage water from other areas which had fertiliser applied at other times. At location 9, at the start of the drain, no significant nitrate concentrations are visible (although ammonia levels were high, presumably due to municipal pollution from Fayoum) and these remain low as far as Wadi Rayan Lake.

No nutrients were detected in drinking water – this confirms the efficiency of water treatment works , as can be seen by comparing the concentrations with Nazla (location 8) where raw water is collected upstream the drinking water production plants.

As far as phosphorus compounds are concerned, there is only a very slight increase in total phosphate concentration at drainage sites (Figure 4.25).

Figure 4.25: Spatial variations in phosphate



In this case the concentrations of total phosphate measured at the collector next to the maize field are slightly higher than the ones measured at the collector located next to the cotton field. This is the reverse pattern to that noted for nitrogen compounds trends. This may be due to the amount of nutrients applied to the fields being significantly different between crops, but it will also reflect other pollutants such as the use of soap from which residues may reach drainage water. The precise reasons for this small difference cannot be categorically determined from the present study.

Nitrate, nitrite and ammonium applied to the field as fertilizers (Urea and other forms) are important pollutants of drainage water. Even if the standards are not exceeded, the constant nitrogen contributions cause poor water quality in the drains, and are potential threats towards the Wadi Rayan Lakes. Phosphorus concentrations are much lower than those observed for nitrates, no direct threat is apparent but continuous monitoring as phosphorus compounds are the main contributors to eutrophication in fresh water. Further, the Wadi Rayan lakes are very shallow and "young" and thus no eutrophication processes are visible for now. But with the regular contribution of nitrogen and phosphorus into these water bodies, conditions may be met to start the eutrophication processes and has to be considered as a potential threat towards these water bodies. Managing the agricultural practices in order to increase the amount of organic matter in the soils could be used as means to reduce the surplus residual of nitrogenous fertilizers and phosphorus compounds present at the collectors.

(v) Pesticides and metals

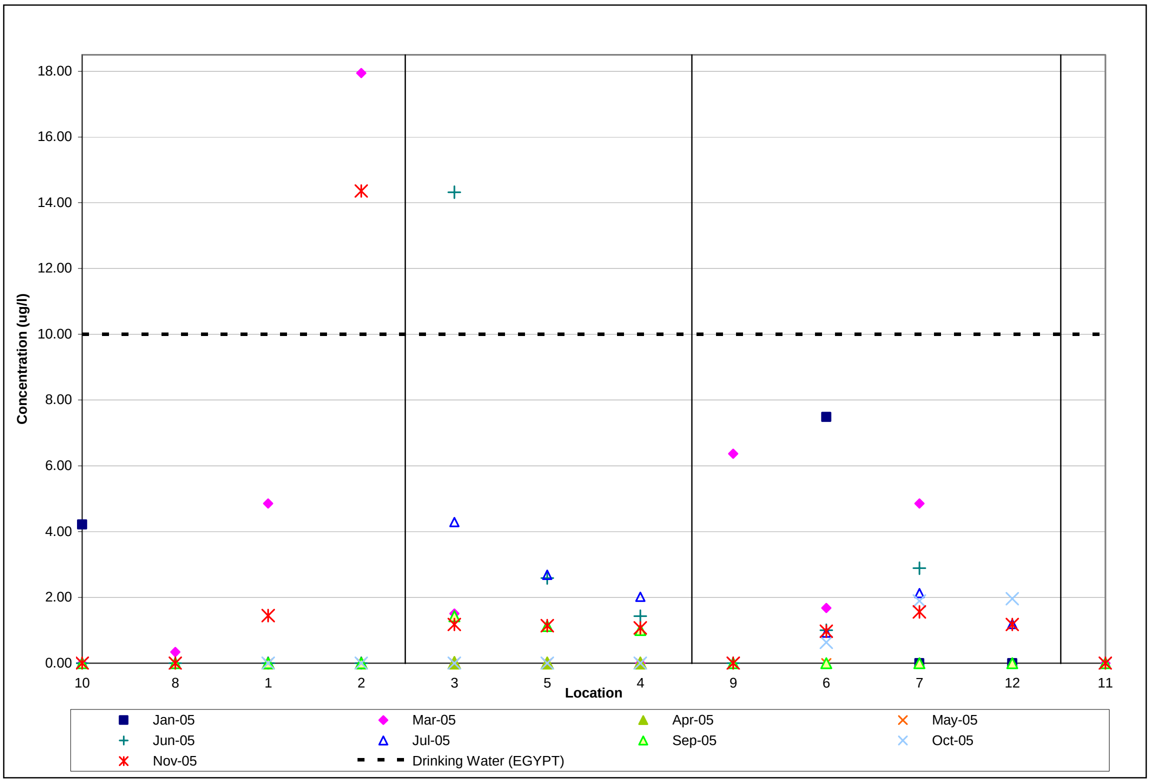
Referring back to the Table 4.8 (see section 4.4.1), we may establish the spatial variations of pesticides concentrations found in water. Although some of the values obtained are most of the time below detection limits, the others remain significant. The majority of the considered locations show quite important pesticides concentrations in March whereas values obtained the rest of the year are much

lower. The presence of pesticides in irrigation water is certainly due to agricultural practices over the study area; seven types of biocides have been detected in March in samples taken next to the maize collector even if concentrations are below the limit of the methods of analysis.

Iron values are constant throughout the system, apart from exceptional values related to the system shut down in winter months. As a consequence, very little effects of agricultural practices are to be considered as far as iron variations are concerned. Moreover the higher values observed are those at the main drains (location 9). These illustrate the probable effect of industries and municipal waste present upstream the sampling point and thus not linked to agriculture. But when zinc and copper are concerned, values shown by locations 3, 4 and 5 (see Appendix F) are higher than the other locations particularly for the zinc which is applied for agricultural purposes.

As far as arsenic is concerned, the available data show obvious spatial variation of this element. Even if found in water at very low concentrations, this heavy metal constitutes an issue as it is not degradable and may accumulate in water, sediments and living organisms causing threat towards health issues. As in figure 4.26, two major remarks may be made. On the one hand the values observed in March are the highest of the monitoring campaign where samples taken at Hanna Habib seem to be the more problematic: the concentrations found are high and above Egyptian drinking water standards even though high dilution would be expected in canals. Similar remark can be made about the values obtained in November at this location. On the other hand, drainage sites show interesting results. Indeed, as from the drains, the concentrations of Arsenic are higher than the ones found at the entrance points and remain constant down the system.

Figure 4.26: Spatial variations in arsenic



The origins of arsenic in the study area are not certain at this stage. It is known that this element may be a component of pesticides[30] which would explain its presence in drainage water. However, the geochemical signature of the soils in the study area has to be taken into consideration as the presence of arsenic could be due to natural conditions in soils, as well as the effects of industries located upstream the Fayoum Area. The low concentrations observed are not to be considered as immediate danger towards uses of water for irrigation but this heavy metal is not degradable and its potential bio-accumulation has to be taken into consideration when monitoring the evolution of the Wadi Rayan Lakes.

4.4.3 Relationship between water quality and agricultural practices

NAWQAM has been monitoring the study area from 1997 to 2005 using some of the same sampling points as those chosen in our study. The data obtained from their monitoring is useful for compare the historical values of parameters in the study area with the more detailed data obtained in our monitoring campaign. Most results obtained from the NAWQAM monitoring do not show any extreme changes since 1997, but there is the important exception of sharp changes in Nitrate, Ammonium, COD and BOD from August 2002 where values shift from uniform low values behaviour to much higher and more variable ones. We are not aware of any reason which could have caused this dramatic change.

The water quality monitoring campaign shows both temporal and spatial variation in the status of parameters. Some variations are certainly linked to agricultural practices the summer season is the time when crops have the highest water demand, resulting in poorer water quality - particularly in the period from May to August. These irrigation water supply means are of important interest in maintaining cropped field thought the whole year, but negatively affect the water quality. The "cleaning" effect of the Nili season has disappeared resulting in poor water quality in these months. In addition, as far as nutrients are concerned, it seems that the highest values observed are those measured in January when there is little dilution as the canals are closed: winter months correspond are a time poor water quality, probably related to thecontribution of nutrients on the field added to crops in excess of their ability to use nutrients.

The impact of agricultural practices is evident by comparing water quality in different types of water body, with the highest concentrations being observed in small drains. There is a this risk that agriculture will lead to the degradation of water resources, with impacts on public health and the ecosystem. The overall effect of agriculture practices on water quality is, however, still small as the limits laid down in the standards are reached very few times and only under particular conditions. But the effects remain clearly visible (particularly when nutrients are concerned) after taking into consideration the links between cropping calendar, pattern, fertilising schedule, etc. There is evidently also an impact resulting from the choice of crop cultivated: drains from maize generally have a better water quality than from cotton. However, in many respects agricultural effluent is less serious a pollutant that upstream towns and industries. Thus despite the poor quality of agricultural waste it may still improve the quality of water in drains which originate from urban areas.

[30] http://www.atsdr.cdc.gov/HEC/CSEM/arsenic/exposure_pathways.html

4.5 Livelihoods

4.5.1 Introduction

The extreme climate and environment makes water a critical asset for residents of the Fayoum. They are dependent, directly or indirectly, on water diverted from the Nile for all uses – including crop production, drinking and cooking, other domestic uses, fisheries, livestock, and other environmental requirements. Water is often the limiting resource: agriculture is constrained more by access to water than to land. Agriculture is the dominant livelihood strategy, but there is some local off-farm income-earning activity - in Yuqab Yussuf, for example, 8% of adult men have public sector jobs. However, temporary out-migration of young men, who work on building sites in Cairo or for oil companies in other parts of Egypt, is an important livelihood activity in the district, and not only for the poorest section. A reported 2% of adult men in Yuqab Yussuf work outside the village as building labourers or some other form of manual labour.

The purpose of this section of the report is to examine the role of water in livelihoods, the importance of the quality of this water, and the impact that changes in water quality have had or are likely to have. The consequences for livelihoods are likely to be subtle, and perhaps not yet recognised by the local population. These studies focused on villages within the detailed study area, but these are put into a regional and national context by reference to literature.

4.5.2 Role of water in livelihoods

(i) Agriculture

Intensive irrigated agriculture, growing crops and vegetables for sale and subsistence, is by far the most important livelihood activity in the study area and is entirely dependent on irrigation water. The amount of land needed to remain economically independent was often said to be 1 feddan – those who own less have to rent or sharecrop land, or work as agricultural labourers. All the farmers' groups interviewed during the field study identified the availability of irrigation water as a key factor influencing both their livelihood *strategies* and livelihood *outcomes.*

The availability of irrigation water in the summer influences their choice of what to grow and so helps to shape their strategies, although it is only one of many factors, and is a key factor in their livelihood outcomes. The main crops, by area, are wheat and berseen (grown during winter), maize and cotton (grown during summer). Farmers here are forbidden by the government to grow rice, but they say they would not be able to in any case, as there is insufficient irrigation water available. Tomatoes, grown mainly in the winter, are now one the most important crops in terms of income. However, it is a relatively new crop, prices fluctuate markedly and it is thus a slightly risky. There has been a significant change away from the traditional crops over the past five years.

Table 4.10 is a fair copy of a matrix ranking diagram compiled by a group of farmers in the village of Sha'lan. It shows what they grow, the factors they take into consideration when choosing what to grow and how they rank different crops against these criteria, with an aggregate ranking for each crop. Water salinity is a significant factor, but other aspects of water quality are not regarded as of any importance.

Table 4.10: Matrix ranking of crops in Sha'lan (by male farmers)

Influencing factors	Berseem (Clover)	Onions	Medicinal plants	Cotton	Maize (grain)	Maize (fodder)	Wheat	Tom-atoes
Income	4	6	5	3	7	8	2	1
Soil type	7	2	8	4	3	6	5	1
Costs	7	3	8	2	4	5	6	1
Cattle on land	1	6	6	5	2	3	4	6
Amount of water	8	3	2	7	6	5	4	1
Weeds present on land	6	2	5	4	6	6	3	1
Water salinity	7	2	4	5	3	7	6	1
Aggregate ranking	7	2	6	3	5	6	3	1

Note: 1 represents highest value, 7 lowest value

(ii) Livestock

There are no large livestock enterprises in the study area[31], but many households in the study area keep a small number of cattle, which can often be seen tethered near canals. Livestock are watered from canals and, in a few cases, drains. Most drains are too deeply incised to be accessible for watering animals, but they do use drain water in some places such as Zalatiya and Koliya where canal supplies are particularly inadequate. Households consume the meat and milk themselves and use the manure as fertilizer, which increases yields and reduces dependency on expensive artificial fertilisers. Most households with cattle sell calves and those with a lot of cattle also sell milk. Although livestock play a relatively small part in livelihood strategies in the study area, any deterioration in their animals' health would have an impact on farmers' livelihood outcomes. There is no natural grazing land, and thus farmers grow berseem and maize as fodder crops. These are crops which are relatively non-intensive in terms of agro-chemical use, so the net effect of keeping cattle is neutral or perhaps beneficial for water quality.

(iii) Fishing in Wadi Rayan

For a small but significant group, perhaps 2,000 men, fishing in El Rayan Lake is a key element in their livelihood strategies. Interviews suggest that these are landless men who fish in the lake 5 days per week. Reportedly, there are about 140 fishing boats operating on the lake. Each boat is owned by a small association of fishermen; for instance, one group said that their association numbered 14 fishermen. There are four main types of fish in the lake and fishermen report an average catch of 7-8 kilo per day. The price ranges from 2-18 Egyptian pounds a kilo, depending on species and season.[32] For three months of the year, they are forbidden from fishing while the lakes are re-stocked.

According to one of the two fishermen's groups interviewed, gross incomes per boat range from 140-7,000 Egyptian pounds a week, which is split between association members. One group claimed their boat had made a profit of 380 Egyptian pounds the previous week, which was split between the 14

[31] There are a small number of large livestock enterprises in the Fayoum as a whole, with about 10 with more than 100 head of cattle including one reported to have 500 head. This is located in Ash-Shawashnah, downstream of the study area.
[32] Lates nilotics, tilapia, solea solea and mugil cephalus.

association members, giving them 27 Egyptian pounds each; this does not take into account purchase and maintenance of equipment. Their catch is sold to an agent of the fishing cooperative, who retains 5% of the value of the catch in return for annually restocking the lake.

(iv) Fishing in canals and drains

Several people reported occasionally taking fish by hook and line from the canals and drains for household consumption. Few people fish often in these channels – rarely more than once a week - and it is almost always for their own consumption; for instance, one farmer mentioned fishing in this way once every couple of months. Tilapia and catfish were the species mentioned. According to several farmers, catches tend to be small, between 1-2 kilograms in weight. All interviewees reported that the numbers of fish had declined in recent years, due to the introduction of *stachosa*, a type of crayfish that is used to control the snails that cause bilharzia. Few people in this district eat this crayfish, although it is edible.

Occasionally, a few people use pesticides to kill fish in the drains, which they then sell in the market. In one group interview, it was said that this happens about three times a year. The use of an electric current to kill fish was also mentioned; apparently this is done in January, when the irrigation system is closed down for maintenance.

Fish caught in this way are also reported to be small in size, and in general fishing in canals seems now to be an insignificant element in the livelihoods mix.

(v) Domestic and recreational uses of water

The canal system is the source of drinking water. This is treated in 'compact units' and delivered through pipes to household or village taps - not every household has its own tap. People also usually wash in water from the taps. They try to avoid washing in canals because of bilharzia, but we observed many women and girls using canals to wash pots, dishes and laundry. Drains are not used much, even for washing, because of salinity and problems of access. Boys swim in the canals, and sometimes in the drains, during the summer, despite the risk from bilharzia.

4.5.3 Water as a livelihood asset

The discussion above demonstrates the critical role than water plays in livelihoods strategies. It is a scarce resource and there is considerable competition for access to it. The only sources of water are canals and drains: there are no natural streams; there is no usable groundwater and no rainfall. Drainage water tends to be saline, but, some farmers reported that they have to use water from drains for irrigation during the summer months (June –August), as canal water is in short supply during that period. In fact, farmers were observed pumping irrigation water from the drains during the first field study visit, which took place in February-March, indicating that water shortages for some farmers at least are not restricted to the summer months. The proportion of farmers resorting to irrigating from the drains is not clear; the *omda* (headman) of Sha'lan village put it at about 10% of farmers.

The shortage of irrigation water is a particular problem in parts of the study area located at the tail of canals. In some locations, such as the hamlets of Abu Bokr and Zalatiya, it is damaging livelihoods. Here, farmers are working land at the end of the Faragala branch canal, which transports water from

Bahr El-Banat via Kaser el-Gebaly. They complain of severe shortages of irrigation water, especially during the summer. They try to alleviate this by digging ponds to store water drawn from the canal when it is plentiful. They say they cannot irrigate from the drain because its level is too low, which suggests they cannot afford private pumps, although other farmers in this area do use pumps.

In addition to informal use of drainage water by individual farmers, there is a formal system for reusing water by pumping water from the Wadi Rayan drain into the main canals. This is limited to a relatively small amount in order to ensure that the salinity of the mixed water is still acceptable for irrigation. Although this affects the water quality, the salinity is monitored by the FID and the farmers do not consider the quality to be a problem.

For the fishermen working on Wadi Rayan, irrigation water is as much an essential element in their livelihood strategies as for farmers. Because the lake is fed by the Rayan drain, any deterioration in water quality caused by diffuse agricultural pollution might be expected to impact on their livelihoods. They complain of falling water levels in the lake due to water being pumped to a newly-settled area reclaimed from the desert, and a new fish farm. They claim this affects their catches, although the link between lower water levels and reduced catches is not clear-cut – reduced levels make fishing easier but result in lower total yields.

4.5.4 Factors influencing access to good quality water

Access to water is thus a critical component of livelihoods in the study area. However, this is influenced by many factors, which we discuss briefly here using the asset categories of the livelihoods framework. It is important to note that some of these factors influence access to good quality water for themselves, whereas other factors influence access to or quality of water for other users (generally further downstream)

Skills in water management and awareness of the factors influencing good water management have an important influence on access to water. Our interviews showed that people from all wealth categories had an understanding of the impact of using poor quality water – they chose crops that suited the quality of water (ie salinity) that is available to them, and avoided unnecessary exposure to bilharzia from bathing in canals and drains. We did not investigate their knowledge of water management at field level to control salinity through leaching as it is outside the scope of this project and has been studied elsewhere. Interviewees did not consider that any other aspect of water quality was important for agriculture, and the results of the water quality testing (chapter 6) confirm this.

However we did observe their management of water in relation to fertiliser applications. This revealed that farmers do not take account of the likely impact of fertiliser applications on drainage water quality and did not consider this an important topic. Since we have shown that downstream water quality has generally a low concentration of nitrates (see chapter 6), this is a valid belief. However, we also found that their applications of fertiliser were below the recommendations and were sometimes applied at times that did not match the requirements. This would result in wastage of nutrients and thus a reduction in yield below that which the farmer could expect.

We also observed their skills and practices in applying pesticides, and could see that workers were exposed unnecessarily to pesticides, thereby causing a threat to their health. They also did not consider the impact of these application techniques and quantities on pollution of watercourses further downstream with pesticides.

We observed a strong system of sharing water on a time basis (*motarfa* system) although we did not investigate this in detail as it has been studied elsewhere and is largely outside the scope of this project. It is, however, significant in that it demonstrates strong cooperative arrangements exist for ensuring access to water, which could be built on should changes in water management be needed in the longer term for reasons of water quality management. As a note of caution, however, it should be pointed out that those potentially affected by pollution are generally located further downstream in villages which upstream farmers would not otherwise have close social relations with.

Water quality is declining because of increased reuse of drainage water, resulting in increasing salinity. This further limits its suitability for irrigation, and mainly affects those who pump water directly from drains. Soil salinity is related to salinity of irrigation water, but can be kept within acceptable limits by careful leaching - the entire area is provided with an effective network of sub-surface drains although we did observe some areas where drains have failed causing problems of waterlogging and salinity

The separation of canals and drainage system coupled with the high salinity means that there is less recycling of drainage water than would otherwise be expected. After the main reuse pump stations on Bahr el Nazla and Bahr el Banat, drainage water is used almost exclusively for fisheries and environmental purposes. The drains are deeply incised and highly saline except in the extreme upper reaches making it physically difficult to use this water. The impact of poor quality water is thus essentially transferred to the lakes, where dilution and sedimentation has so far mitigated the impact of pollution there.

Domestic water supplies are taken from the canal and treated by filtration and/or chlorination. This is sometimes inadequate to ensure adequate water supplies of good quality but bacteriological treatment is the main concern. The systems do not reach every household and thus there is a strong demand for extending the systems and for improving the quality of treatment. However, despite these shortfalls no one drinks untreated canal water. Sewage is disposed in septic tanks, or more commonly in trenches which are cleaned out periodically for disposal in the desert. This system evidently causes some contamination of canals

4.5.5 Understanding and perceptions of water quality issues

During interviews, the following problems were mentioned in relation to canal water; shortage of irrigation water in the summer, salinity of irrigation water, dirtiness caused by domestic rubbish being thrown in, seepage from household sanitation trenches and a bad smell in the summer. It was notable how often the problem of salinity was mentioned. However, this is not related to agricultural pollution but is caused by evaporation and mixing of water from drains into canals. Not everyone perceives canal water to be dirty.

During these discussions, none of the interviewees expressed any concern about diffuse agrochemical pollution. This fits with the water quality tests, which indicate that water quality in the study area is generally good. So, taken together, the study findings strongly indicate that diffuse agrochemical pollution does not yet impact on livelihoods in the study area. A few people attribute a perceived increase in liver and kidney problems to use of pesticides. There is, however, no data to either support or disprove this belief. If it were true, it is more likely to be due to poor application techniques than to consumption of polluted water.

4.5.6 Vulnerability to deteriorating water quality

People living in the study area would be vulnerable if there were a marked decline in water quality due to agrochemical pollution. Table 4.11 shows how the water use pattern in the study area links to this potential vulnerability.

Table 4.11: Vulnerability to poor water quality in study area

Uses of water in study district	Possible impact in situation of poor water quality
Irrigated agriculture	No direct impact, unless associated with a change of volume available (due to restrictions on access, or increase in salinity)
Livestock	Animal health could be adversely affected through both drinking and being washed in polluted water
Fishing in Wadi Rayan	Reduced fish yields Ban on sale of fish for public health reasons
Fishing in canals and drains	Reduced fish yields Health risk of eating contaminate fish End to fishing and loss of food source, due to perceived or actual health risks
Domestic drinking water	Human health adversely affected (diarrhoea)
Bathing and washing dishes etc.	Human health adversely affected (bilharzia, skin diseases, diarrhoea)

4.5.7 Impact of water quality on livelihood outcomes

Water quality in the study area could indirectly impact on human health, thus adversely affecting livelihood outcomes, through domestic drinking, bathing, washing dishes, pots and laundry and through swimming for leisure. Any adverse impacts on human health from drinking water would be expected to affect men and women, girls and boys equally. However, because of gendered cultural norms, adverse effects on health from bathing and swimming in canals and drains would be expected to affect boys and perhaps adult men, whereas adverse health effects from contact during washing pots, dishes and laundry would be expected to affect women and girls. Bilharzia is prevalent in the area, and thus swimming and other direct contact with water in the canals is discouraged although it is almost inevitably very common.

The water in the taps is taken from both Bahr el Banat and Nazla canals (which includes water mixed from Rayan drain) and then treated at small plants. Several people complained about the poor quality of the drinking water, saying it contained ‘impurities’. They say that staff at the treatment plant on Nazla canal are not well qualified for their jobs, and that the amounts of chlorine and ammonia they use to treat the water are too high. Some interviewees also complained that the water only goes through one stage of treatment whereas it should go through three stages. We did detect some pesticides in the canals which are used as raw water sources for drinking water supply schemes, and

thus a failure of the treatment system could result in some contamination of the drinking water. This is small threat to human health (compared to the more immediate risks due to bacteriological pollution) but it highlights the need to control contamination of canals. We presume that this is largely due to washing of sprayers etc, but a more detailed study would be necessary to confirm that.

The main group whose livelihoods would be threatened are fishermen, if water quality deteriorated to the extent that fish could no longer be marketed. This will be a gradual process but pollutants will build up in sediments and concentrated in the food chain, and it will be exacerbated by the problems of water shortage which dilute the pollutants.

If water quality in the study area were to deteriorate sufficiently, people's vulnerability could give rise to various negative impacts on livelihood outcomes (Table 4.12).

Table 4.12: Livelihood outcomes of deteriorating water quality

Uses of water in study area	Source of water	Possible impact in situation of poor water quality	Risk	Livelihood outcome
Irrigated agriculture	Canals	Reduced crop yields, due to increasing drainage reuse and hence salinity; reduction in net amount available for irrigation to allow for higher leaching percentages	Moderate, but unrelated to agro-chemicals	Farmers' incomes reduced
	Drains	Reduced crop yields, due to salinity	Moderate, but unrelated to agro-chemicals	Farmers' incomes reduced
Livestock	Canals/Drains	Animal health could be adversely affected through both drinking and being washed in polluted water	Low	Farmers' subsistence use of milk and meat reduced, income from sale of milk and calves reduced
Fishing in Wadi Rayan		Reduced fish yields	Low	Fishermen's income reduced
		Ban on sale of fish for public health reasons	Moderate	Fishing abandoned as an economic activity.
Fishing in canals and drains		Reduced fish yields	Low	Farming households might lose this occasional supplement to livelihoods, but with minor impact.
		End to fishing due to perceived or actual health risks	Low	
Domestic drinking water		Human health adversely affected	Low	Health and hence livelihood outcomes adversely affected
Bathing, swimming, washing dishes and clothes in canals and drains		Human health adversely affected	High risk due to bilharzia, but very low risk due to agro-chemicals	Health and hence livelihood outcomes adversely affected

5 Sri Lanka Case Study

5.1 Description of Case Study Site

Kachchigal *Ara* has a catchment area of 185 km^2, and is situated within the Ruhuna Basin[33] in the dry zone in the south of Sri Lanka (Figure 3.1). The catchment is dominated by extensive, irrigated lowland agriculture, is typical of many parts of Sri Lanka and lies in the far west of the Hambantota District. It drains into Kalametiya lagoon, a coastal wetland lagoon system, which supports a bird sanctuary, fisheries and farming communities, as well as having ecological importance. This has an additional catchment of 50 km^2 – which is drained by various small channels and *aras* which enter Lunama and Kalametiya lagoons directly

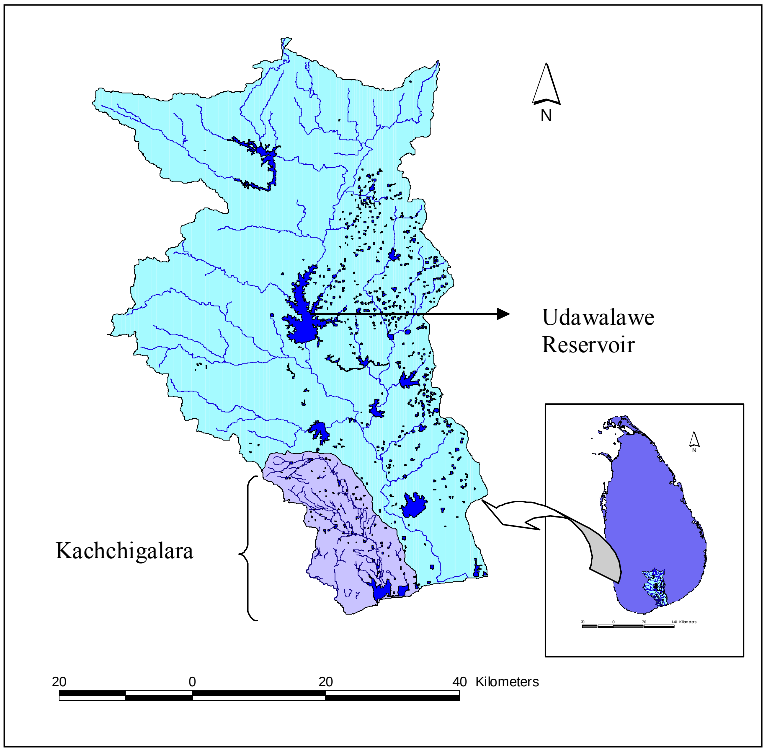


Figure 5.1: Location of Kachchigala *ara*

The majority of water resources are diverted through irrigation schemes for agricultural production. The basin has a population of over a million people and has experienced major drought problems in recent years. Agriculture is mainly managed by individual families or family-run co-operatives, with sixty percent of the crop being paddy. A report on the overall Ruhuna Basin, from the UNESCO World Water Assessment programme (UNESCO 1998) concludes that during the dry months "water quality is poor due to the presence of agrochemicals" – although this statement is not substantiated in the report.

Kachchigal *Ara* contains no urban areas of any significant size. The population is almost entirely comprised of rural farming and fishing communities, who use water from tanks, canals and *aras* for agriculture, bathing, washing, livestock, fisheries, home garden cultivation and the environment, as is typical of most areas in Sri Lanka (Senaratne & Milner-Gulland, 2002; Bakker et al, 1999).

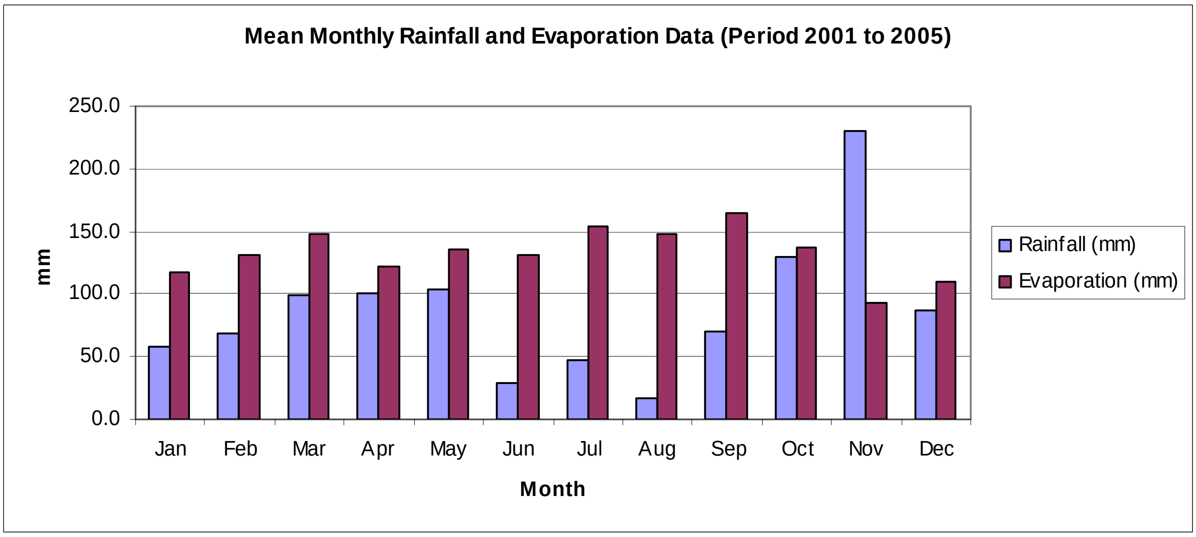
Although originally a separate small, perennial river basin, the Kachchigala *Ara* has been linked to the adjacent Walawe basin, following construction of the Uda Walawe Reservoir on the Walawe Ganga, which was completed in 1967. Water is released into two irrigation canals: the right bank main canal

[33] Strictly speaking this is a group of basins, of which the Walawe (catchment area 2,500 km$^{2)}$ and Kirindi Oya are the largest. Kachigal ara drains to the sea just west of the Walawe. The Ruhuna Basin is one of the international case study catchments for the United Nations World Water Assessment Programme.

(RBMC) and the left bank main canal (LBMC). The Kachchigala *Ara* catchment includes the most downstream blocks on the RB canal, which crosses the Kachchigal *Ara* at the Kachchigala wewa. Although water is not released directly to the *ara*, this link canal alters the Kachchigala *ara* hydrology fundamentally since branch canals irrigate land on either side of the Kachchigal Ara. Water then drains from these lands into the Kachchigal *Ara*.

Sri Lanka has three agro-ecologically defined zones (wet, intermediate and dry) (Poonrajah 1984; McCall 1990), within which the Kachigal Ara catchment is in the dry zone.The rainfall is typically bimodal, but with a pronounced variation in amount, duration and onset of season. Kachchigala *ara* is at the western end of the district and thus has a significantly higher rainfall than most of the dry zone, with an annual average rainfall ranging from 1200-1550mm in two main seasons: *Maha* (wet) from October to January and *Yala* (dry) from March to September. The highest monthly rainfall is reported in November and December (about 150-200mm), and the lowest rainfall in June to August. In general, evaporation (100 to 150 mm per month) is higher than rainfall, making irrigation essential for agriculture.

Figure 5.2: Average rainfall and evaporation



Source: Angunakolapalassa crop research centre

Drainage into the Kachigal *Ara* and thence to the sea through Kalametiya Lagoon comes from two main sources.

- Natural runoff from upstream parts of the catchment (north of RMBC, mainly from Kachchigala *ara* upstream of Kachchigala *wewa*, and Booveli *ara* NW of RMBC) which is influenced to a small extent by minor tanks and *chena* agriculture; and
- Flows diverted from Walawe basin, mainly from RBMC, but also from the earlier lower Walawe system which takes water from Liyangastota *anicut*: these are the dominant flows.

The total land area of the KA catchment is about 18,400 ha, of which 4,700 ha are upstream of Kachchigala wewa. A further 1,500 ha are highlands draining into the Booveli ara, outside the main irrigated area (but which drain into KA near to Angunakolapelassa. The gross area under the various irrigation systems is thus 12,200 ha (this is the area roughly bounded by the RBMC, Mamadala and Gajamangama branch canals and draining into Kalametiya lagoon just south of Hungama), and is

referred to in this report as the study area. The upstream areas, totalling 6,200 ha, comprise a mix of highland, chena and very small areas irrigated by minor tanks, of which Hingura is the largest. The net irrigated area (ie excluding highlands, villages, home gardens, roads, canals etc) in major and minor irrigation schemes is about 6,900 ha (see section 3.6.1 for details of this). The unirrigated land in the study area is thus 5,300 ha (45% of the gross area).

Previously there were just small tank systems irrigating about 400 ha (less than 5% of the catchment) – mainly for paddy - that were fed by Kachchigala *Ara* and its tributaries. The dominant land uses then were forest and scrub jungles within which there were patches of *chena* (slash and burn cultivation) and residential areas with home-gardens – this remains the case in the upper catchment apart from in the tank command areas.

The tank catchment areas were covered with forest or scrub jungle – including some *chena* lands. The forest cover in the upstream areas of these small tanks served eco-system functions such as arresting soil erosion which would otherwise lead to sedimentation and water pollution of tanks. An extract from the diary of Leonard Woolf (1908-1911) illustrates the situation in the area in the past: "Here or just past it is a fine piece of forest showing what magnificent country this must have been before *chenas* ruined it …… Just through the jungle is Metigatwala wewa, a really magnificent village tank with a bund as good as many a major work can boast. There are 45 amunus under this tank and I believe the whole extent belongs to Mulkirigala Vihare. The Kachchigala *Ara* flows into it …" (Woolf 1997). The water in the small tanks as well as in *Ara* was relatively unpolluted and it was the main source of drinking water of the communities living in the area.

The area underwent massive changes due to large-scale irrigation development (Molle et al, 2005). The forest and scrub jungle areas were cleared and turned in to irrigated fields, new settlements were created for settler families brought from outside, leading to a dramatic population growth in the area.

The hydrology of the area was also changed due to the large inflows of irrigation and drainage water from Uda Walawe system to Kachchigala *Ara* basin. There are some smaller inflows from other basins – notably the Murutawela scheme which brings in a small amount of water from the west. The flow pattern is still influenced by the numerous small tanks on minor natural drainage channels. But unlike in the past, the total storage in these is now negligible compared to the flow in the Kachchigala ara.

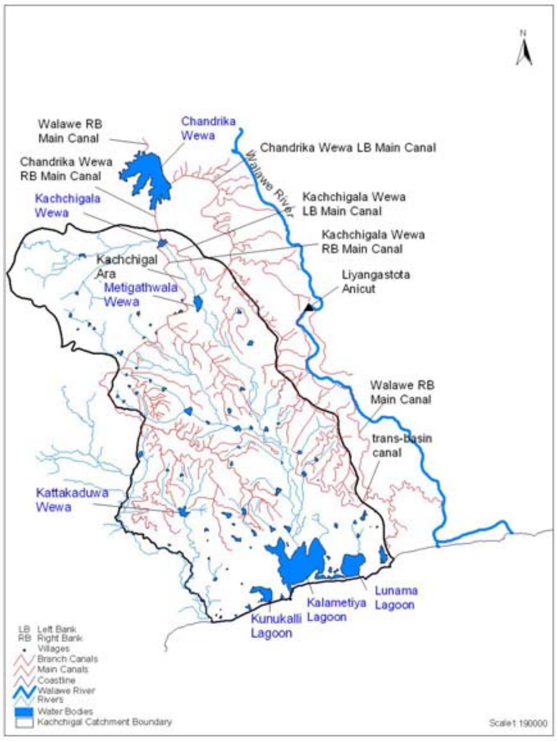


Figure 5.3: Natural river system and irrigation canals

The accompanied changes in Kachchigala Ara, especially in the area below Kachchigala tank are noteworthy. A tank bund was built on the *ara* at Kachchigala wewa, so that the RBMC can flow across the *ara*. Thus the natural flows in the *ara* are intercepted by the RBMC. Water for tanks and anicuts further downstream is thus now provided by drainage from the RBMC irrigation system rather than from upstream parts of the *ara* (except, very rarely, at times of high rainfall when water spills over the Kachchigala bund into the Kachchigala ara). This has resulted in a large increase over the natural flow since the irrigation duty is very high in upstream areas of Uda Walawe command (and efficiency of use is low, partly due to the soils and partly due to management efficiency). This excess has caused problems of flooding and water logging in parts of the downstream end of the catchment. The irrigation and drainage system is illustrated in Figure 5.3.

Irrigation management is carried out by under three institutional arrangements. The larger systems are managed by the Mahaweli Authority of Sri Lanka or the Department of Irrigation. Land under the small tanks is privately owned[34] and these are managed by the farmers with support from the Agrarian Services Department. The areas are summarised in Table 5.1.

A major point of contention is that water management is focussed towards agriculture and aimed at increasing efficient cultivation, without due consideration to other water users and the environment (Statkraft Groner, 2000). In the Kirindi Oya system to the east of the Walawe system the Project Management Committee that makes decisions on water allocation does not include fishermen and though it has been modified to include livestock owners they are still not effectively involved.

Water allocation for drinking supplies does however take priority over irrigation: a minimum requirement that must be met (Matsuno, 1998). The tanks are increasingly supplying water for piped water supplies, for which the water is either chlorinated, filtered or both. Currently, most rural communities in this area do not receive piped domestic supplies of water and therefore rely heavily on groundwater[35], or deliveries by “water bowsers”. Drinking untreated surface water would pose a health risk due to bacteriological contamination, but the irrigation canals, tanks, *ara* and coastal lagoon are used for other domestic uses. However, the government objective is to provide safe drinking water to the entire population by 2025, through small-scale community schemes (Ariyabandu and Aheeyar, 2004).

The upper parts of the major systems are managed directly by the relevant government agency, but field-level management has been devolved to farmer organisations (FOs). These are responsible for O&M within a distributory canal, which typically irrigates about 40 ha or less via a number of field channels. Water is supplied on a rotational basis to farmers, and each is entitled to water once a week during the crop growth stage. Water supply is continuous during the land preparation / sowing stages. Retention times for water within the fields are dependent upon weather conditions, irrigation water releases to and from the irrigation canals, local management practices, and the personal preferences of the farmer.

[34] Much of the land under Metigatwalawewa – one of the largest tanks - is owned by Mulkirigala temple and rented out to farmers

[35] despite its high natural fluoride concentrations (100-200 ppm) due to the deposits of serpentine, which makes the groundwater unsuitable for direct consumption in many areas

The commencement of cultivation is controlled by the irrigation schedule drawn up by the Mahaweli Authority of Sri Lanka (MASL) or the Irrigation Department, which allocates water according to rainfall, other water requirements (including domestic and hydroelectric power considerations) and existing water levels in the reservoirs. However, the cultivation schedule can be highly variable due to the unpredictability of the onset and amount of rainfall that will be received.

In the Mahaweli area, each family was allocated 2.5 acres (1 ha) of land, with 0.5 acres as a home garden. Farmers were given the right to use this land, but not ownership, so they can rent the land in or out but cannot buy or sell it. This differs from land under small tanks, where farmers have ownership rights: farms within small tank commands typically vary from 0.25-3.0 acres, with the majority of farms being less than 1 acre of land. In non-Mahaweli areas home gardens also range in size from 0.5 aces to 2 acres. The existing land use pattern is illustrated in the map below.

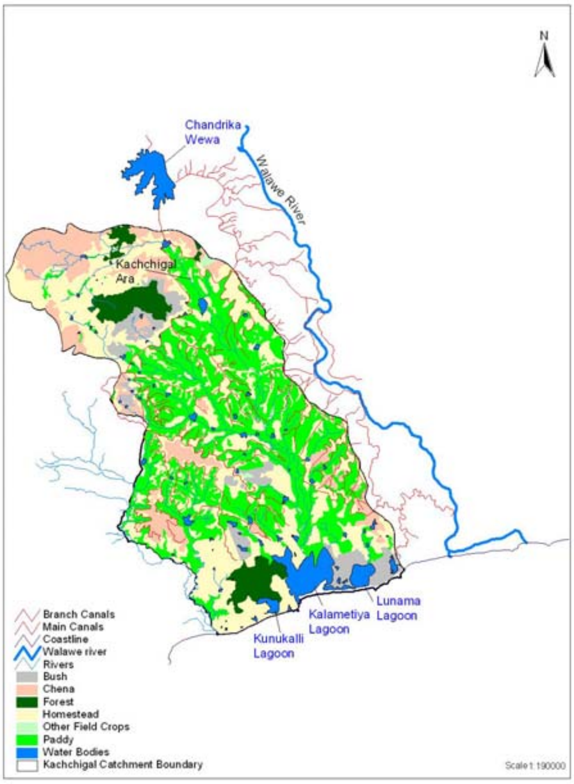
The composition of irrigated land is shown in Table 5.1 below:

Table 5.1: Irrigated land and crops in study area

Institute Name	Canal Name	Paddy (Ha)	OFC (Ha)	Total (Ha)
Mahaweli Authority	Walawe canals	4,080	1,895	5,975
Irrigation Department - Lunama	Liyangastota canal	425	70	495
Irrigation Department	Murutawela Canal	40	10	50
Agrarian-service centre	Small tank	415	0	415
Total		4,960	1,975	6,935

Source: MASL, Agriculture Department

The majority of the soils (55%) are Reddish Brown Earths (McCall, 1990). The Upper Catena is low in nitrogen and phosphorus, but provides a good supply of potassium, calcium and magnesium and has good cation exchange capacity. Its depth, texture and drainage are generally satisfactory for a wide range of cereals, pulses, oil seeds and fruit crops, but it becomes impossible to cultivate when it is too dry or too wet. The Mid and Lower Catena are imperfect with poorly drained soils, excellent for irrigated paddy. The remaining land (about 45%), comprises low humic gleys which are suitable for paddy cultivation. Significantly they are known to adsorb pesticides (J Handewela, former Director Angunakolapelessa Research Station, pers comm.).



The KA system is not only used for irrigation water distribution and drainage collection, but serves many other functions of great socioeconomic and ecological importance. Consequently, irrigation development has also provided an important source of water for purposes other than agricultural production, especially in dry zone areas (Steele, Konradsen and Imbulana, 1997) where studies have shown that irrigation tanks and canals are used for a multitude of domestic purposes including bathing, laundry, recreation and in a few cases drinking (Bakker *et al.*, 1999). Livestock needs, home garden cultivation, fishing and wastewater disposal are included in the list of multiple uses.

Kalametiya lagoon is also an important natural resource, supporting fishery activity, ecosystems and the bird sanctuary. Socio-economic research around the Lagoon, which is at the downstream end of the KA, has revealed that the upstream irrigation interventions made thirty years ago have destroyed the brackish water coastal lagoon fisheries and damaged coastal paddy lands which relied on local sources and drainage flows from the much older Liyangastota irrigation scheme. The only effective solution (to divert drainage water westwards away from the lagoon) was too large a scheme to be considered and would have impacted negatively on many other communities. Thus these two coastal communities attempted local partial solutions, and had conflicting ideas for how to resolve the problem (Senaratne and Clemett, 2004).

The study area falls within 3 Divisional Secretary (DS) divisions, Ambalathota, Anguna-kolapallassa and Embilipitiya. The total population in these divisions is about 49,107 and the number of families is around 11,369 (Table 5.2).

Table 5.2: Demographic data for the study area

DS Division	Nos Families	Total Population	Total Male	Total Female
Ambalantota	4,114	14,615	7,321	7,294
Angunakolapalassa	6,114	29,932	12,539	13,793
Embilipitiya	1,140	4,560	2,245	2,315
Total	11,368	49,107	22,105	23,402

5.2 Institutional Context and Stakeholder Analysis

5.2.1 Key stakeholders in the study area

A summary stakeholder analysis is presented in Table 5-3

Table 5-3: Key stakeholders identified within the Kachchigal *Ara* Catchment

Stakeholder Group	Interests	Likely impact of pollution control	Relative priorities of interest
Primary Stakeholders			
Individual farmers	Irrigation water from Walawe scheme Irrigation water from small tanks Irrigation water from *ara* Enhanced, sustainable crop production	+/-	1

Stakeholder Group	Interests	Likely impact of pollution control	Relative priorities of interest
Lagoon fishermen	Fish and crustacean (food) resources from Kalametiya Lagoon	+	4
Tank fishermen	Fish, crustacea (food) and other natural resources from the small tanks	+	3
Ara fishermen	Fish for food from drainage channels/canals	+	3
Livestock farmers	Tanks for livestock watering and bathing Grazing land	+	1
Rural communities[36]	Agriculture, Livestock and Fisheries and other natural resources as outlined above Surface water supply for domestic uses and recreation Groundwater for drinking and other domestic use Safe raw water sources for small urban and rural domestic supplies	+	1
Ecotourism (e.g. Kalametiya Bird Sanctuary)	Enhanced aquatic environment and associated biodiversity	+	4
Secondary Stakeholders			
Mahaweli Authority of Sri Lanka (Walawe)	Sustainable management of water resources Technical capacity building Collaboration in management of fisheries	+	3
Department of Irrigation	Sustainable management of water resources for all uses	+	2
NARA	research on management of lagoon resources Aquaculture Monitoring and improvement of water quality and aquatic environment	+	2
Department of Agriculture	Agricultural research and extension related to agrochemicals and agricultural productivity; administration of specific legislation	+/-	3
Department of Agrarian Services	Agrarian services including management of minor irrigation	+/-	3
Department of fisheries and aquatic resources	Aquaculture development and improvement of aquatic environment	+	4
National Water Supply and Drainage Board (NWSDB)	Provision/technical support for water supply Monitoring and managing water quality for domestic purposes	+	3
Central Environ-mental Authority	Regulation of impacts on the environment Sustainable management of water resources Development of wetland conservation management plans; enhanced aquatic ecosystems	+	4
Pradesheeya Sabhas	Rural domestic water supply	+	2
Farmer Organisations (canal-based)	Local management of agriculture and irrigation	+/-	1
Fisheries Societies (tank-based)	Management of fishing in lagoon and tanks	+	3
Interim National Water Resources Authority	Water resources policy and legislation	+	4
Various NGOs/CBOs	Support for local projects and initiatives	+	2

[36] including small towns

5.2.2 Legislation related to water resources

Key legislation related to water resources is summarised in Table 5.4 covering the major laws and regulations relating to the management of surface water and groundwater resources and pollution control in Sri Lanka (adapted from Bakker *et al.* 1999; WRCS 2000; Sakthivadivel *et al.* 2001; Garaway 2002; Somaratne *et al.* 2003).

Table 5.4: Key legislation related to water resources

Enactment	Date	Key Provisions	Agency/agencies responsible for implementing legal provisions
The Irrigation Ordinance No. 32 (as amended)	1946	The Irrigation Ordinance consolidates the law relating to irrigation. It provides the regulations for the Divisional Secretaries (DSs) to prepare plans for new minor irrigation schemes or introducing changes to the existing ones. The approval of the Minister is required for plans for the major irrigation schemes. It provides for holding cultivation meetings in major irrigation schemes, and for seasonal cultivation decisions to be taken at a special meeting of an Irrigation Management Division (IMD) Project Committee (PC) attended by the DS. The Ordinance may override the State Land Ordinance in specific cases. The mechanisms for water allocation associated with this Ordinance do not require consideration of fisheries (or other water uses), and are subject to review and alteration by the government through the Minister.	Minister of Irrigation, DSs dealing with farmer organisations, IMD PC
The Crown Land Ordinance (The State Lands Ordinance No. 8)	1947	The right to the use, flow, management and control of any public waterbody is vested in the state under this Ordinance. It makes a distinction between public water and private waters. Part IX of the Ordinance provides for the regulation and control of public waters and streams through a system of permits. Water for irrigation is exempt from license requirements (the ordinance is overridden by the Irrigation Ordinance with respect to the need for permits for the irrigation sector). Also, the Crown Land Ordinance does not address allocation issues (including allocations for social and environmental uses) or mandate planning systems (e.g. in times of water scarcity or in the long term).	DS
The Electricity Act No. 19 (as amended)	1950	This Act provides for the licensing of installations for the generation of electricity. Licenses confer all rights necessary for the purpose of electricity generation, including the right to use water.	Ministry of Irrigation and Power
The Soil and Water Conservation Act	1951	This Act empowers the Minister of Agriculture to declare areas subjected to soil erosion as erodible areas. The Minister may make regulations applicable to these areas requiring the owners of land to take measures to afforest the banks or watercourses or to maintain a strip of land along the banks of water courses free from cultivation.	The Minister of Agriculture
The Ceylon Electricity Board Act No. 17 (as amended)	1969	Describes the duty of the Board to develop and operate the nation's system for the supply of electricity. The Board is exempt from the requirement to obtain a licence under the Electricity Act, but the right to use	The Ceylon Electricity Board

Enactment	Date	Key Provisions	Agency/agencies responsible for implementing legal provisions
		water for hydropower is granted under a later amendment to the Electricity Act.	
The National Water Supply and Drainage Board Act No. 2 (as amended)	1974	This Act empowers the National Water Supply and Drainage Board (NWSDB) to direct and use water to provide water supply for public, domestic and industrial purposes without other approval.	The NWSDB
The Agrarian Service Act (an amendment and continuation of the Paddy Land Act No. 1 of 1958)	1979	Provides for tenure security in irrigated lands and sound management of agricultural activities and water in small tank systems through Agrarian Service Committees and Farmer Organisations. Directly concerned with the devolution of power from central level, with respect to water resources development and management.	Commissioner of Agrarian Services
The Mahaweli Authority of Sri Lanka Act No. 23 (as amended)	1979	The MASL and Agencies were created under this Act. The Act empowers MASL to use and develop the water resources of the Mahaweli River. It does not provide principles or procedures governing the allocation of water.	The Mahaweli Authority of Sri Lanka
Thirteenth Amendment to the Constitution	1987	Devolves a number of powers with respect to water resources development and management from central level, including irrigation other than within inter-provincial schemes, to the level of Provincial Councils and the administrative bodies, organisations and institutions formed under the provincial administration. List III makes inland fisheries and other irrigation, flood control and irrigation water resource planning a joint responsibility of the national and provincial governments. Provincial Councils are active in irrigation management, particularly with respect to minor schemes. There is, however, no provincial legislation concerning the allocation of water among various sub-sectors.	Parliament
The National Environment Act (as amended)	1988	Provides provisions for environmental pollution control, including the pollution of water, and protection of sensitive wetlands. Note: Authority over some activities has been delegated to the Provincial Environmental Authority	The National Environmental Authority (or Central Environmental Authority).
Participatory Irrigation Management Policy	1988	Provides direction for handing over of full responsibilities for operation and maintenance of and resource mobilisation below distributary canals to Farmer Organisations.	Irrigation Management Division and Department of Irrigation
Mines and Mineral Act	1992	Section 30 of the Act provides provisions for imposing restrictions on the issue of mining licenses if the mining is to take place in the proximity of waterbodies.	Geographical Survey and Mines Bureau
The Fisheries and Aquatic Resources Act No. 2	1996	Provides for the licensing of fisheries and aquaculture operations. The licensing of inland fisheries constitutes an allocation of water required to execute the approved operation. Conflicts may occur however with respect to other water users, especially as the Act affords no power with respect to influencing such users.	Minister of Fisheries and Ocean Resources

5.2.3 Policies, legislation and institutional arrangements

(i) Water resources

The policy and institutional arrangements for water resources development and management in Sri Lanka are in a complex state of transition at present, with significant developments liable to continue to occur into the near future. The foundations of the National Water Resources Policy are discussed at length in WRCS (*op. cit.*). Importantly, all surface and groundwater are legally state-owned and managed by the government in partnership with water users, on behalf of all Sri Lankans (Bakker *et al*. 1999; WRCS *op. cit.*). There is no government-recognised system of individual or group water rights. Major objectives within the policy pertinent to the current study include, among others, recognition of the "national importance of water allocation to the irrigation sector", improvement of standards in the "maintenance of safe quality of water sources required for various water users" and ensuring a "healthy environment and sustainable use of both surface and groundwater resources using a comprehensive, river basin-oriented approach". The new policy also recognises the need to protect the water required for environmental and social needs (including fisheries), especially since these uses are not recognised in policy and no mechanisms exist to safeguard the requisite allocations (WRCS *op. cit.*).

The new Water Resources Policy and Water Resources Act are, however, still constrained by the lack of cohesion, overlap, redundancies and gaps in the institutional framework presented below. Moreover, the management of water resources *per se* has been a lesser priority than simply developing and using the resources for the services they provide. Consequently, there has been little progress in alleviating problems such as agriculture-linked water pollution and general watershed degradation.

Typically, there is a mismatch between administrative and hydrological basin boundaries, and few administrative structures exist at basin scale (Hoogendam 1995, cited in Bakker *et al.* 1999). In several instances, the same activities in water resource management are carried out by a number of different agencies. Although the agencies may in effect be serving different geographical areas, there is often much duplication of effort. These kinds of constraints are recognised as leading to the potential for conflict and overuse of water. Importantly, they result also in a lack of environmental protection.

As comprehensively detailed in Somaratne *et al*. (2003), the general administration, institutional and organisational mechanisms and structures available for water and other natural resource management are highly complex in Sri Lanka. Prior to the establishment of provincial governments, administrative functions and law enforcement for natural resource management were implemented by the central government at the district level (there are 9 provinces in Sri Lanka and 25 districts). For example, this was achieved through representatives ranging from government agents representing government at district level, to field level extension officers of the Department of Agriculture (DOA), cultivation officers, field level officers of the Department of Agrarian Services (ASD), and grass roots officers of *Grama Sevakas* (responsible for village level administrative functions). Following the 13^{th} amendment to the Constitution (detailed in Appendix A), there was the gradual devolution of power from central level to provincial level, through the setting up of provincial councils, establishment of different coordinating committee systems (e.g. District Divisional Secretariat level Agricultural Committees, Agrarian Service Committees, etc.), as described at length in Somaratne *et al*. (*op. cit*.). However the process has been lagging, contributing to various water resource problems, such as water pollution. In light of such problems, the government of Sri Lanka set up the new policies and

institutional arrangements described in WRCS (2000), and outlined above, which are in the implementation phase at present.

(ii) Water quality

There are no institutionalised systems in existence in the country for monitoring or management of water quality for any of the water resources. (Garaway 2002)

The NWSDB is the principal national agency responsible for domestic (and the main channel for investment in the sector) and industrial water supply, and sewage and surface drainage (WRCS 2000; Somaratne *et al*. 2003). The NWSDB investigates water sources for water supply systems and sanitation (waste disposal) schemes, and is involved in their operation and maintenance. It undertakes water quality monitoring at the intakes to the water supply schemes and for treated water, in relation to established water quality standards (see below), and associated research and development activities. It focuses on the provision of domestic water supply (quantity and quality) to local urban centres. There are regular monitoring systems for the large river systems that are supplying water to urban areas like Colombo (e.g. Kelani Ganga). Although there is no such regular and institutionalised monitoring in place for other small-scale systems also managed by the NWSDB, *ad hoc* monitoring is carried out at the request of the users. If complaints come from the users (who pay for drinking water) about the quality of water of a source they use (rivers, groundwater, etc.) the NWSDB attends to monitoring.

Local government authorities established under the 13th amendment of the Constitution of the country are also responsible for monitoring the quality of water they are supposed to supply to the communities living in their jurisdictions (Municipal councils (MC), Urban councils (UC) and Pradesheeya Sabhas (PS)), with assistance from the NWSDB. The local government authorities are within the provincial organizational structure of the country (Ministry of Local Government at the national level and Provincial Councils at provincial level, and MCs for large towns, UCs for medium-sized towns and PSs in the rural areas, etc.). Some of these local government authorities have their own water supply systems which they themselves constructed and manage, where they carry out systematic monitoring (although there are problems related to monitoring). Also, some local government authorities operate the water supply systems constructed by the NWSDB - local government authorities have willingly taken over the responsibility of operation of the systems to supply water for the communities living in their jurisdiction.

As a rural area, the Kachchigala *ara* catchment comes under the Thunkama PS, and the supply of water for domestic use is the responsibility of the PS. For drinking, rural communities use groundwater (from wells) that is not monitored by any agency. As mentioned below, some parts of the catchment also fall under Mahaweli Authority of Sri Lanka (MASL), where MASL releases water in the canal system for domestic use. The NWSDB is responsible for the offtakes, storage and piping of drinking water to Angulakolapelassa, Ranna and Hungama towns within the catchment.

When new projects are planned within a basin, the qualities of particular potential water sources are monitored to assess the water quality for the use of particular projects. Although the NWSDB is not considering the Kachchigala *ara* system for large-scale drinking water supply projects, it actively provides the necessary technical and administrative support for small-scale drinking water projects in the catchment. Such Community Water Supply and Sanitation Projects (CWSSP), which address both water quantity and quality, largely fall under the jurisdiction of the NWSDB as a state sector body.

Environmental issues, including those in terms of water quality (i.e. the potential detrimental effects of diffuse pollution from agriculture), are dealt with broadly under the Central Environmental Authority (CEA), within the Ministry of Environment and Natural Resources. The interests of wildlife specifically are represented by the Department of Wildlife Conservation (DWLC), as well as various non-government organisations (NGOs). The Department of Coastal Conservation is the agency responsible for the protection of the environment and natural resources in the coastal areas (and may be in part involved in management of Kalametiya Lagoon within the lower Kachchigala ara).

The CEA is the institution responsible for the enforcement of laws, regulations and rules of the Environment Act (Table B1) controlling the pollution of water and other natural resources. It checks effluent quality at discharge points (but mainly for industries), and is also involved in the development of ambient quality standards for selected waterbodies and limited surface water quality monitoring (WRCS 2000). Although the power vested in the CEA has been delegated to the Provincial Council, hereby enabling the provincial authority to play a key role in environmental protection (Somaratne *et al*. 2003), there is probably little or no management of water quality and other environmental issues at local scale within a small catchment such as Kachchigala ara, with relatively low population density and no National Parks/specially protected areas.

The National Aquatic Resources and Development Agency (NARA) is involved in monitoring the effects of pollution, including that from agriculture, on the downstream environment of only Kalametiya Lagoon within the Kachchigala *ara* catchment. The NARA undertakes this role as part of its involvement in the development of a coastal lagoon Management Plan for the southern region and for the purposes of assessing impacts of altered water quality on fish/crustacean food resources.

(iii) Agriculture, with specific reference to irrigation management

There is a wide range of organisations playing a role in the control of agricultural practises, including irrigation, from central government to village levels (Somaratne *et al*. 2003). Several of these organisations are of central importance in representing the needs of farmers, and have shared or overlapping responsibilities. A focused comparative assessment of such institutional issues specific to the irrigation and fisheries sectors is provided in Garaway (2002).

The Ministry of Agriculture, Livestock and Samurdhi is centrally involved in agriculture, including irrigation. The Ministry also includes a series of departments and statutory institutions responsible for other aspects of agriculture in its broadest context, *inter alia,* livestock and fertilizer enterprises. Of particular relevance to this project are the following functions: formulation of programmes/projects based on national policy in respect of agricultural development and direction of the implementation of such programmes/projects; agricultural research, extension, training and education; administration and operation of various acts and ordinances (see below); and enhancement of agricultural productivity.

Within the Ministry, agriculture (including irrigation) is the primary responsibility of the Department of Agriculture (DOA). The DOA functions both at central government and provincial level, and has its own network of offices throughout the country to carry out its functions within irrigation schemes, including those of the Kachchigala *ara* catchment. These functions include, among others, agricultural research and the provision of extension services to farmers, and dissemination and implementation of new agriculture-related technologies. The DOA also provides a list of pesticides registered in Sri Lanka (insecticides, fungicides, and herbicides) and specific recommendations for crops in Sri Lanka in terms of the three broad categories of pesticides.

The Mahaweli Authority of Sri Lanka (MASL) is a national organisation under the Ministry of Irrigation and Water Management with broad functions and powers under its legislation to implement the Mahaweli Ganga Development Scheme, and to promote integrated development in declared special areas (such as the Walawe Basin). It is responsible for the provision of water resources of appropriate quantity and quality for local agriculture and other uses, the planning and implementation of water and hydropower infrastructure, collection of hydrological data, and so on (WRCS 2000). It addresses the management and operation of agricultural practices and irrigation systems in designated Mahaweli areas, but Garaway (2002) observed that MASL's dual role as water regulator and water user is weakly defined. It has now launched a restructuring programme to transform itself into a River Basin Management Agency.

The principal management responsibility for irrigated agriculture, and thus water, in the Kachchigala *ara* catchment is borne by the MASL. The Headworks Administration, Operation and Maintenance Division of MASL is responsible for water releases from the Uda Walawe Reservoir in the adjoining Walawe Catchment (which supplies much of the irrigation water for use in the Kachchigala *ara* catchment). Within the Kachchigala *ara* catchment, the greater part of the existing irrigation system (i.e. from the top of the catchment to the *anicut* downstream of Ethbatuwa) is managed and operated by the MASL. Specifically, the MASL office in Embilipitiya (located in the neighbouring Walawe Basin) is responsible for activities such as water issues, water quality (though they do not carry out monitoring themselves, they need to give permission for any monitoring and to be kept informed of activities and results), and the rehabilitation of canals and structures within this part of the system. The Resident Project Manager (RPM) is responsible for the entire Uda Walawe area, which includes the area of paddy irrigation below Kachchigala wewa. The RPM is assisted by Deputy RPMs responsible for irrigation (including scheduling water releases), agriculture and land (Buysse 2002).

The Ministry of Irrigation and Water Management houses the national-level Department of Irrigation (ID). As is the case with MASL, the ID is also responsible for the provision of acceptable quantities of water for irrigation, collection of hydrological and irrigation data, as well as for the operation and maintenance of the main and secondary systems within irrigation schemes. It has an Irrigation Engineer for each irrigation division. In medium irrigation systems, technical assistants of the ID handle operation and management of the system, as well as institutional development activities, and are responsible for obtaining farmer participation. They act as project managers for joint scheme management.

Within the KA Catchment, the ID manages the irrigation system in the southeast corner of the catchment below Liyangastota Anicut. In times of no irrigation, the ID supplies water in the canal system for domestic purposes.

The Agrarian Services Department (ASD) is a key stakeholder organization involved directly in agriculture, housed within the Ministry of Agriculture, Livestock and Samurdhi. The ASD is responsible for providing legal recognition to the country's Farmer Organisations (FOs). It also has a key role to play in the management of small-scale agriculture (specifically paddy cultivation) under small tank systems (irrigating less than 85 ha).

Within the Kachchigala *ara* catchment, the local Agrarian Service Centre is the branch of the ASD that delivers various kinds of services required for the farmers in their jurisdiction to execute agricultural activities, including the initiation of cultivation meetings, and provision of agrochemicals, seeds, fertilizers, farming equipment and other inputs. Attached to each Agrarian Service Centre is an Agrarian Service Committee (Somaratne *et al.* 2003). The committee comprises field level officers of

the various line agencies (e.g. provincial level of DOA, Department of Animal Production and Health) and a limited number of farmer representatives from FOs.

A major function of the Divisional Secretariat (DS) responsible for the Kachchigala *ara* catchment is the management of crown lands and coordinating agriculture (and other development activities) within the DS division. There are typically also District Agricultural Committees and DS level agricultural committees, which enable inter-agency coordination at both levels for the implementation of agricultural plans and work on agriculture-related issues.

Within the Kachchigala *ara* area, as is the case elsewhere in the country, canal-based FOs comprise a vital component of the institutional framework for local management of rural agriculture practices, in collaboration with the MASL, ID and others (see above and Somaratne *et al*. 2003 for details). The farmers in discussion with local agencies, at Kanna meetings, jointly decide on the planning, implementation and monitoring of seasonal agricultural programmes (e.g. timings of water delivery for crops, applications of agrochemicals) and other issues pertaining to agriculture through such committee-based arrangements. The FOs, which are formed and initiated by the Irrigation Management Division (IMD), are responsible for the operation and management functions, as well as maintenance, of the tertiary irrigation system (including distributary and field level canals) and small tank systems; they may take on additional functions. Above this level of functioning, FOs are generally weak and do not play a significant role in system operation and maintenance (Garaway 2002).

(iv) Fisheries

Inland fisheries are a relatively recent phenomenon in Sri Lanka and are largely confined to artificial lake systems, such as tanks. As Renwick (2001) observes, presently such "fisheries are not recognized in water management and allocation decisions", in spite of their established importance for local livelihoods and poverty alleviation. Further efforts are recognised as essential in fully developing an effective and integrated institutional framework in Sri Lanka that considers fisheries from all perspectives (including, for example, responsibilities for monitoring the effects of bioaccumulation of chemicals on fish as a food source) (Renwick 2001).

A far more limited number of organisations are responsible for inland fishing and aquaculture practices, as compared with agriculture, and in representing fishermen and fish-farmers.

Several departments and statutory institutions come under the Ministry of Fisheries and Ocean Resources. Probably of most relevance to the study are the Department of Fisheries and Aquatic Resources, the National Aquatic Resources Research and Development Agency (NARA) and the National Aquaculture Department Authority. The Department of Fisheries and Aquatic Resources is the organisation principally responsible for all aspects of freshwater (inland) fisheries management. However, it is not directly involved in actual fishing activities. NARA is involved actively in coastal fisheries research and management, including the coastal lagoon at the downstream end of the Kachchigala *ara* system. The MASL also has a limited role to play in collaborating in the management of inland fisheries through its management of local water storages (small tanks) for irrigation water supply.

Inland fishing is carried out by community based fisheries organizations in large tanks and sometimes in medium-scale tanks. In small tanks (and *aras*), individual farmers in the respective areas are also

involved in fishing. In most of the tanks, fishermen have established organisations for coordination and regulation of activities (including stocking) and also for collective marketing of the fish. Such tank-based Fisheries Cooperative Societies are found within the Kachchigala *ara* Catchment, organised on a tank-specific basis, for a number of tanks (e.g. Kachchigala wewa, Mahajandura wewa). They are also associated with the lagoonal fisheries established within Kalametiya Lagoon. However, these societies are not fully operational requires, and typically they are not involved in water use planning or management at any level. They have a far weaker voice than farmers and are unable to fit easily into the existing administrative and decision-making structures. Furthermore, it appears that the committees established for the district and local level coordination of agricultural activities (see above) do not include any representatives from the fisheries societies.

The policy and legislative framework supporting fisheries is much weaker than that pertaining to agriculture and irrigation. As a result, it appears that fishermen who are adversely impacted by irrigation schemes/agricultural practices have no legal basis to address issues of concern (Garaway 2002). For instance, there is no mechanism to legally safeguard tank water levels critical for fisheries. As Garaway (*op. cit.*) observes, the lack of incentives for irrigators to conserve water and the lack of monitoring of water quality (and enforcement of standards) exacerbates the situation for fishermen.

5.3 Agricultural policies and Practices

5.3.1 Agricultural policies

(i) Policies and their influences on main crops grown

Since time immemorial agriculture has been playing the most significant role in the Sri Lankan economy and livelihood systems. A large number of irrigation systems, large and small, built by the ancient kings in the dry zone parts of the country bear evidence to their significance for agriculture in the country. Rice, the staple food of the country has been the main crop cultivated under these systems. Besides cultivating rice in irrigation systems, the people practiced shifting cultivation - popularly known as *chena* - to grow grains and other vegetables during the *maha* season. This dual agriculture system was the predominant practice in the dry zone covering nearly two-thirds of the country: although the annual rainfall is about 1200-1500 mm, it has high spatial and temporal variations making agriculture very dependent on irrigation water supply.

During the post-independence period (after 1948) paddy cultivation was further promoted by constructing large-scale irrigated agriculture settlements to address the problems related to food supply for the growing population and find solutions to the unemployment problem in the country. The successive governments after independence provided incentives to farmers to grow paddy (fertilizer and agriculture equipment subsidies, and purchasing of paddy by the government at fixed price).

The third era of the agriculture policy started with the left-oriented government in 1970s which pursued an agricultural self-sufficiency policy in the country. It introduced a food import substitute policy under which import of rice and other food items were restricted and a massive agriculture development program called “cultivation war” (*vaga sangramaya)* was implemented. The goal of this program was to establish household food security. Farmers were encouraged to cultivate crops such as Sorghum, Green gram, Manioc, Kurakkan (millet), chillies etc. in irrigated lands as well as in highlands under this program. In spite of these attempts, the country still needed to import a

substantial quantity of rice to feed the increasing population. The new government in 1977 aimed to increase the irrigated area through developing all possible land under the Mahaweli river basin in the country. These Mahaweli irrigation systems cover about one third of the irrigated area of the country.

In 2003 the government introduced a policy called "Granary area program" that had been introduced in countries like Malaysia to improve the productivity of certain crops that can be grown well in certain regions (areas) of the country. Seven districts (areas) including Hambanthota where this study site is located were selected as main paddy growing districts and attempts were made in them to increase yield from 4.5t to 6 t /ha.

In 2004 the government focused at improving the productivity in small irrigation schemes where cropping intensity and yield had been very low. The strategy chosen was to rehabilitate 10,000 small irrigation schemes and improve the yield and cropping intensity.

(ii) Subsidies and grants available to farmers influencing crop choice

Every government since post-independence have implemented programs to provide subsidies and grants for the farming communities to improve agriculture productivity in the country. Commonly grant subsidies and other agriculture related assistance is as follows:

- Fertilizer subsidy (almost all the governments granted subsidies for Urea)
- Subsidies for improved seeds
- Low interest agriculture credit schemes through state banks
- Obtain the services of organizations such as FAO, World food program to implement demonstration programs on integrated pest management and so on for the farmers.
- Construction of new irrigation systems and rehabilitation of existing irrigation schemes.
- Institutional strengthening for productivity improvement (Irrigation Management division of the irrigation ministry and various programs of the department of agrarian services and agriculture)

(iii) Policies influencing the use of agro-chemicals

The ultimate objectives of the policy and programs planned and implemented by various government was to improve the productivity of agriculture. The pressure to improve productivity leads to:

- Attempt at expanding the cultivation area (cropping intensity)
- Attempt at increasing the crop yield. For this purpose, the governments introduced high yielding varieties. These new varieties were susceptible to disease and pest attack and very responsive to fertilizer. With the introduction of green revolution technologies, use of improved seed, fertilizer and agro chemicals became predominant practices among agricultural communities. It replaced their traditional environmental friendly farming practices.

- Attempt at increasing the crop area with other field crops (vegetables), in order to reduce the requirement for water

Each of these led to an increase in the use of agro-chemicals. The Fertilizer Secretariat established under the Ministry of agriculture is responsible to decide the import policies of fertilizer and also making recommendations and implementation of fertilizer subsidy policies of the government. The Department of agriculture is responsible for making recommendations for quantity of fertilizer to be applied to crops.

The Ministry of Agriculture is responsible for pesticide application policies of the country. Several acts have been passed by the parliament to manage pesticide usage of the country. The Pesticide Act prescribed the types of pesticide approved and banned in the country giving the trade names and active ingredient of each pesticide. According to the government law each pesticide used in the country should be registered under the pesticide registration section of the department of agriculture. The pesticide registration section maintains a list of pesticide being used in the country with the names of pesticides being banned from time to time for various reasons ((Act No 33 of 1980). The pesticide registration section of the department of agriculture published the list of approved pesticide from time for dissemination among the public. The office of the pesticide registration issues registration guide for the traders who intend to get in to the pesticide trade.

(iv) Significant changes in agricultural policy over the last 10 years

In the last 10 years, irrigation and agriculture sector have undergone several significant changes. The key changes observed are as follows:

- The irrigation investment policy has changed and the government is concerned to invest resources for improving the productivity of existing irrigation schemes rather than creating new irrigation schemes that are not economically feasible. This trend has resulted in improving the agronomic practices, water management practices and other input use to increase the cropping intensity and crop yields of the existing irrigation schemes.

- Policy of Granary area program (2003) - This policy is also more or less related to the new policy on irrigation investment. Seven districts have been designated as the area where productivity of paddy is to be increased up to the potential level, from 4.4 t/h to 6.0 t/h. To achieve these targets it needs to increase the input use such as fertilizer and agro-chemicals and other agronomic practices.

- Commercialization of agriculture to improve the income of marginal farmers in irrigation systems. (Policy of government in 1994). The government initiated two pilot projects in two irrigation systems to test this policy by establishing two farmer companies with the share capital of farmers (2002 IWMI Ridibandiela Farmer Company). . The farmer companies were established to improve the marketing linkages and coordination of agriculture inputs and linkages with the private companies in the country. The farmer companies were initiated to cultivate high value crops to increase their income in the small holding sector. The high value crops such as chillies and various vegetables need increased use of agro-chemicals and fertilizer.

Apart from the national level program to increase the productivity of agriculture through use of increased synthetic inputs such as fertilizer and agrochemical, there is very clear and increasing trend is observed in practising organic farming in many irrigation schemes by individual farmers.

Unfortunately these experiments are not being monitored or documented, although there is anecdotal evidence from visits to various irrigation schemes: NGOs and the Department of Agriculture encourage farmers to reduce synthetic inputs and increase use of organic fertilizer such as paddy straw and other organic matter. The extension programs of the Agriculture Department include demonstrations and training to motivate farmers for organic farming.

(v) Environmental policies

The water resources are covered under the policies and acts related to natural resources as a whole, and there are no environmental policies developed specifically for water resources management. Various enactments on managing natural resources in the country and the provisions under each enactment are shown in annex 1.

The Central Environmental Authority (CEA) is the institution responsible of exercising most of the environmental acts (enactments) but at the same time there are specific agencies also responsible for managing specific resources. Such specific line agencies and the role they play are given in Table 5.5

Table 5.5: The institutes responsible for legal enactments.

Natural Resource	Institution	Provisions
Domestic water	National Water Supply and Drainage Board	To monitor the quality of water and take measures to deliver water with quality acceptable to the national standard prescribed
Forests	Department of Forest	Protection and enhancement of forest resources of the country
Wildlife	Department of Wildlife Conservation	Protection and enhancement of wild life of the country
Mineral resources	Geological Mines Bureau	Monitoring and protection of mineral resources
Coastal resources	Department of Coast Conservation	Protection of coastal resources

There are no particular institutions responsible for monitoring, protection and management of some critical natural resources such as soil and water. The Government of Sri Lanka is attempting at establishing exclusive policies and acts for the management of water resources, but this is proving very controversial. The Department of Agriculture is playing some roles to mange land resources to protect and enhance soil resources through various means for preserving soil erosions.

5.3.2 The Agricultural Extension service

As described in section 5.2.3(iii), the Ministry of Agriculture is the institution responsible for agricultural development and management in the country, with the Department of Agriculture (DOA) as its development arm. The DOA has established specialised divisions under its purview to implement the various services required for agricultural development. The division on agriculture extension is one such specialised section. The central office of the agriculture extension division is located in Peradeniya, but it has established an institutional network over the country.

The extension service is different in Mahaweli and non-Mahaweli areas. The non-Mahaweli system is described first.

Agricultural officers of the DOA are attached to each Agrarian Services Division. The agricultural officers are assisted by a large number of grass root level extension officers at village level. The situation in Kachchigala *Ara* catchment is as follows:

- There are agrarian services centres in Angunokolapelassa, Ambalathota, Lunama, and Embilipitiya, with one or two Agriculture Instructors are attached to each Agrarian centre;

- Agriculture research and extension officers (grass root level officers) - 52 persons are attached to Ambalathota agrarian service division - other agrarian services divisions are similar.

The agriculture extension system in Mahaweli managed area of Kachchigal *Ara* is somewhat different. This is managed by the Mahaweli block offices, of which to cover the area of the Kachchigal Ara catchment. Each block office has one Agriculture officer and about 5-6 Unit managers and the same number of field assistants to carry out agriculture extension and water management activities.

5.3.3 Agricultural practices

(i) Crop pattern and yields

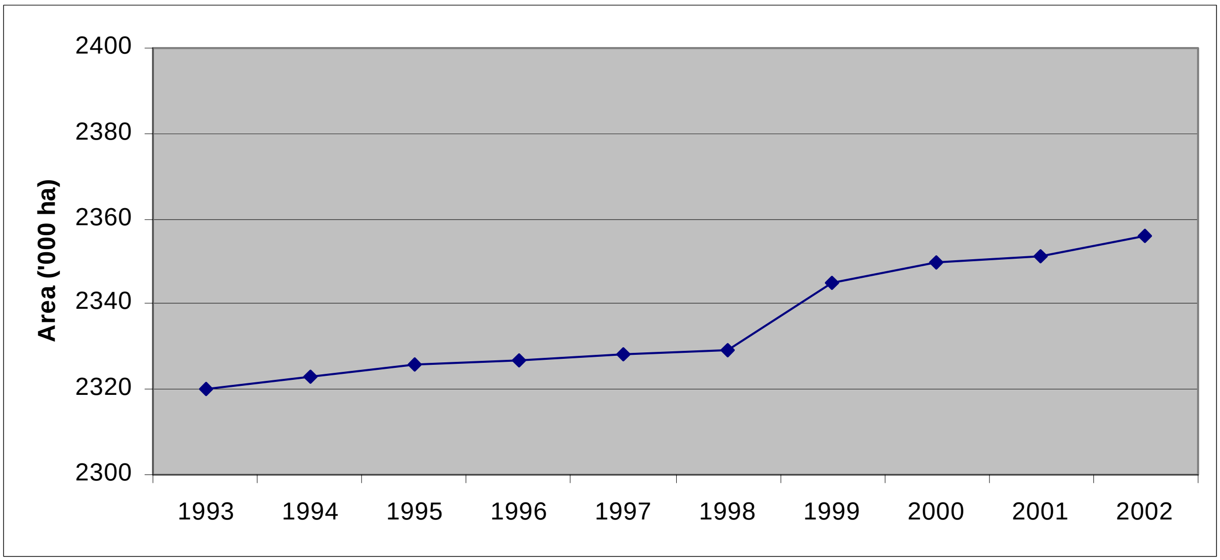
About 30 % of Sri Lanka's 6.5 million ha land area is utilised for agriculture but the per capita cultivated land area is low (0.1 ha/person), which increases pressure for food production. The main food crop is rice and important plantation crops include tea, rubber and coconut (Nugaliyadde et al. 2003) although the latter are not important in the study area.

In this section we look at the current situation and trends both in the detailed study areas and at district and national level. Paddy is the dominant crop at all levels. The other main crop locally is bananas, which are semi-permanent and have a very low requirement for inputs: carbofuran is applied before planting (ie perhaps only once or twice so far in the history of the scheme); and occasional low applications of fertiliser are made. There are other permanent crops (coconut, cashew, jackfruit etc), but no inputs are used on these. Vegetables have much higher requirements for inputs, but cover a small part of the study area – perhaps 3% of the area.

Crop areas

At a national level, there has been a small increase in crop areas over the past decade to the current total of around 2.4 million hectares, at a rate of about 1% per year, as land has been developed. This is as shown in Figure 5.4

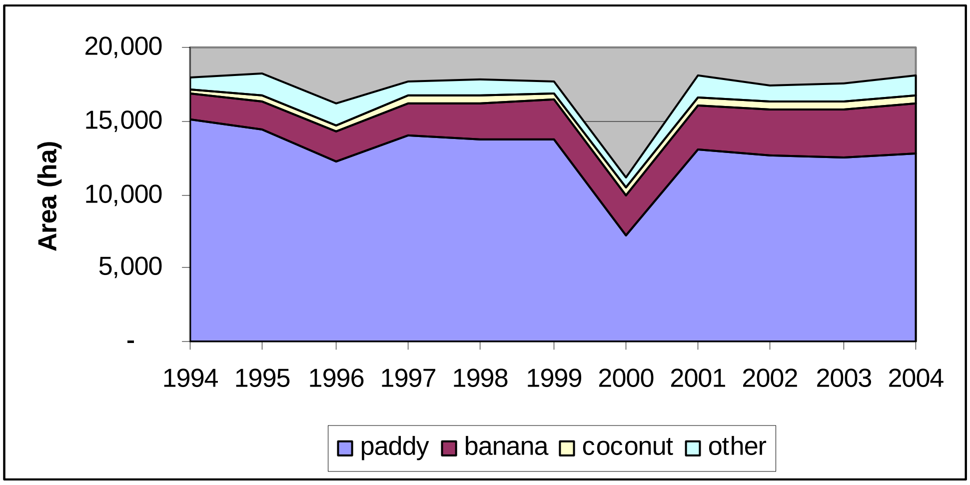
Figure 5.4: Trends in crop areas (national level)



Source: FAOSTAT

There has been less change in crop areas at Walawe, and the total crop has been virtually unchanged except in maha 2000/01 when there was virtually no paddy grown. This is presented in Figure 5.5, giving the annual total crop area (ie the sum of yala and maha season crop areas, with the exception of perennial crops such as coconut and banana). 'Other crops' here includes a mixture of vegetables and other perennial crops such as jackfruit or cashews. The most significant change is the increase in bananas at the expense of paddy, which has decreased at 3% per annum. Bananas now cover over 30% of the area, as compared to 18% in 1994 – although this is most pronounced in the northern part of the scheme. The proportion of bananas in Embilipitiya district increased from 20% to 55% of the area over the decade as compared to an increase from 15% to 20% in the study area.

Figure 5.5: Crop areas at Walawe



The breakdown in crop areas in the detailed study areas is presented in Table 5.6 and Table 5.7. Paddy is the main crop with small areas of bananas, vegetables and permanent crops (such as coconuts,

jackfruit and cashews) being cultivated. .Ethbatuwa is probably most representative of the mix of crops grown in the area as a whole, whereas Metigatwala is representative of conditions where paddy is the dominant crop.

Table 5.6: Summary of crops grown and areas of 30 farmers in Ethbatuwa

Ethbatuwa	Area (ha)	No. farmers cultivating crop	% of land cultivated	% of farmers cultivating
Paddy	18.7	30	76	100
Vegetables	1.1	5	5	17
Permanent crops	2.7	9	11	30
Bananas	2.1	9	9	30
Total	24.6	30		

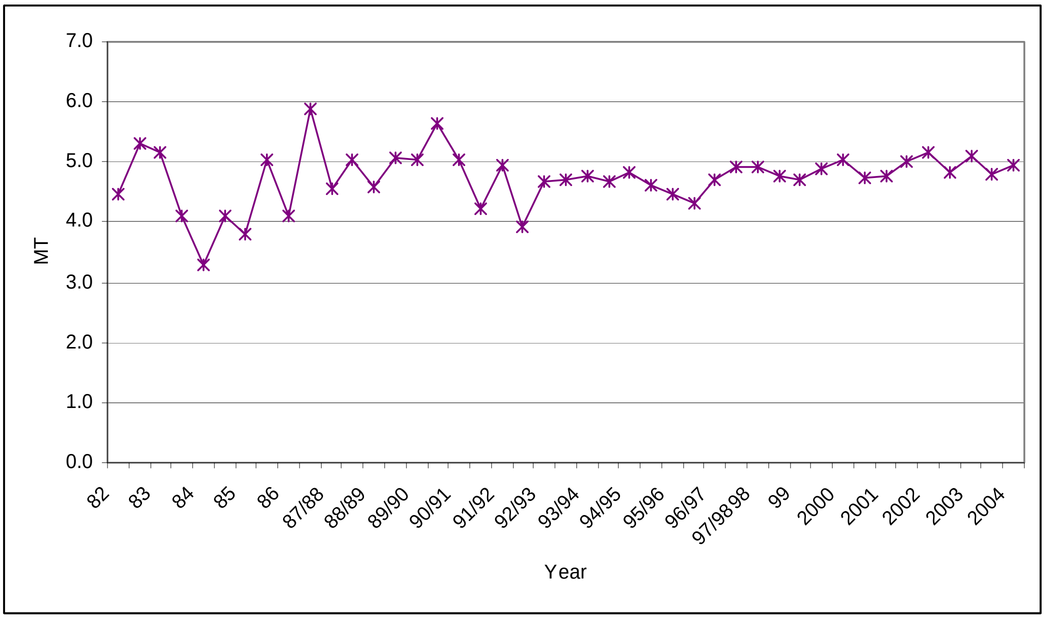
Table 5.7: Summary of crops grown and areas of 40 farmers in Matgathwala

Matgathwala	Area (ha)	No. farmers cultivating crop	% of land cultivated	% of farmers cultivating
Paddy	26	40	97	100
Vegetables	0.3	2	1	7
Permanent crops	0.2	1	1	3
Bananas	0.2	1	1	3
Total	26.7	40		

Paddy yields

Average rice yields at Walawe are slightly better than national average yields of 3.78 t/ha. Trends in yield data for paddy from 1982 to 2004 in the Uda Walawe irrigation scheme are shown in Figure 5.6. It is possible that yields in areas irrigated by the small tanks have slightly higher yields as the water is available earlier and is more reliably available.

Figure 5.6: Paddy yield in Uda Walawe irrigation scheme – Mt/ha.



Source: MASL Project office Embilipitiya

The yields in the *yala* season (2005) in the study area were slightly lower than these (4.6 Mt/ha in Metigalawalawewa and 3.8 Mt/ha in Ethbatuwa). The reasons for this are likely to be in the different methodologies used for estimating yield, and should not be compared directly with the overall MASL data – although as will be discussed later, fertiliser use in these areas is less than recommendations (averaging about 65% of recommended total nutrients per hectare), and less than the averages reported on a block level by MASL. The lower yield in Ethbatuwa (despite using, on average, more fertiliser) is likely to be due to the poor water supply at the extreme tail of the system.

Table 5.8: Paddy yields (kg/ha) in detailed study areas

Area	Mean	Min	Max
Metigatwalawewa	4,632	3,044	8,340
Ethbatuwa	3,798	2,266	6,342

(ii) Fertiliser use

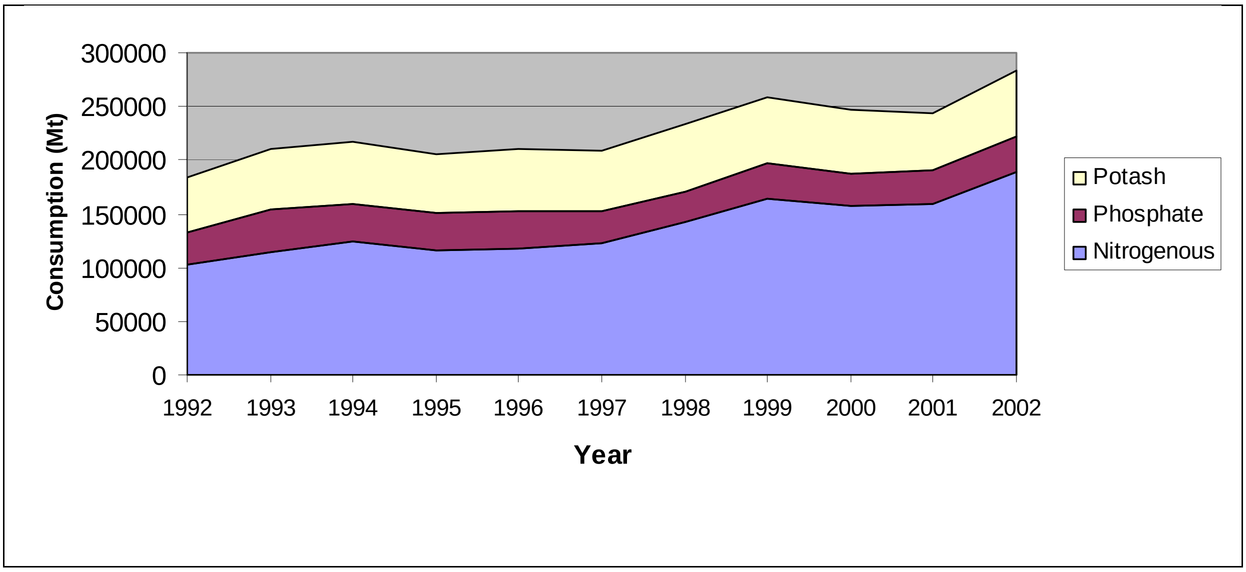
National level

The total fertiliser consumption (i.e. nitrogen, potassium and potash fertilisers combined) in Sri Lanka (FAO, 2005) increased by 55% in the decade to 2002 (from 183,657 to 284,218 tonnes) as shown in Figure 5.7. There has been little change in cultivated area over this period (Figure 5.4, which just indicates an increase of about 12,000ha - around 1%), The increase in total consumption of fertilisers is almost entirely due an increase in fertiliser use per unit area of agricultural land. At the national

level the amount of total fertiliser per unit area of agricultural land has increased from 78 kg / ha to 121 kg / ha (a 55% increase)[37].

As in Egypt the increasing consumption of fertilisers appears to reflect the strategy of the Sri Lankan government to increase agricultural productivity, although there does appear to be a fundamental difference in Sri Lanka - fertiliser subsidies are provided for urea. Other reasons for increased fertiliser consumption in Sri Lanka include the expansion of agricultural area (mainly in the 1970's and 80's with the development of the Mawaheli scheme); the introduction of high yielding cultivars; and the provision of low interest loans to farmers to enable them to purchase agro-chemicals.

Figure 5.7: Fertiliser consumption in Sri Lanka



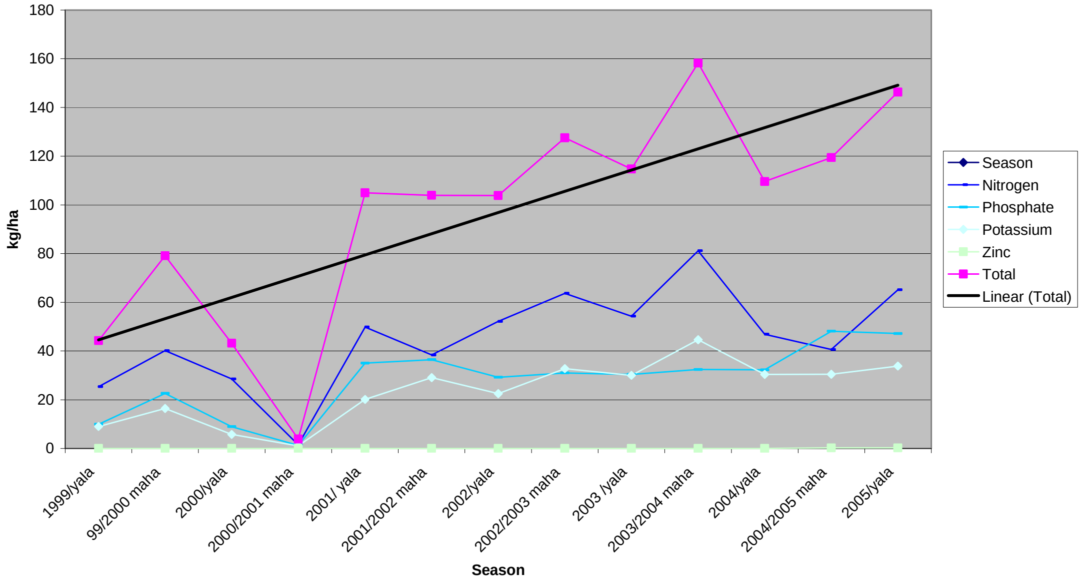
Source: FAO, 2005

Local level – Uda Walawe system area

The information on fertilizer use by the Mahaweli farmers was obtained from Murawashihena and Angunokolapelassa block offices, which are representative of a large portion of the study area. The trends of fertilizer use in paddy cultivation is shown in the figure below.

[37] Fertiliser consumption represents *partial* nutrient inputs to the agricultural system (the other main inputs being applications of manures and slurries, and atmospheric nitrogen deposition). Consumption figures provide an overview of the intensity of fertiliser use per unit agricultural area and represent the total of nitrogen (N), phosphorus (P) and potassium (K) applied in a variety of mineral forms.

Figure 5.8: Fertiliser usage at Uda Walawe



source: Murawashihena block office

The total amount of reported fertiliser use in Uda Walawe (Figure 5.8) shows a general increase over the six-year period from 1999 – 2005 which also reflects the changes seen at the national level (Figure 5.7). Discussions with agro-chemical retailers in the project study area also indicates an increasing demand for inorganic fertiliser for paddy, vegetables and bananas. Care must be taken in interpreting this data since the retailers surveyed do not only supply farmers in this area. However, of the 15 retailers questioned, 13 reported that there fertiliser sales had increased by about 10% over the last 5 years for paddy; 12 reported that fertiliser demand had increased by about 8% for banana production over the last 5 years; and 14 reported an increase of about 14% in fertiliser sales for vegetable production.

Urea is the most commonly used fertiliser in the two blocks - probably because of the associated fertiliser subsidy. In April 2005, it was reported that the Sri Lankan Government was importing fertilisers at $340 tonne and supplying to farmers at $110 tonne[38]. At the national level other reasons for increased fertiliser use, include an increase in cultivated area, favourable product prices for plantation crops such as tea and coconut, and favourable weather conditions for crop production (UNESCAP, 2002). These are less important factors in the study area, where the major changes in crop area occurred some time ago, plantation and vegetable crops are less important than paddy. The major recent cropping change locally is from paddy to banana which is associated with a decrease in fertiliser applications.

While there is no simple linear relationship between amounts of fertiliser applied and subsequent nutrient loss, increasing fertiliser use is associated with N and P enrichment of waters. There is evidence of this occurring in the EU (EEA, 2003) and it is reasonable to conclude that the increase in fertiliser consumption in Sri Lanka will give rise to greater environmental pressure – particularly in

[38] See Oryza - the rice trade industry portal report (April 2005): http://oryza.com/asia/srilanka/index.shtml

those parts of Sri Lanka where agricultural activity is intense or the environment more vunerable (for example the permeable sandy soils in the Kalpitya Peninsula, or the vegetable-growing areas around Nuwara Eliya).

Local level – recommendations and applications in the detailed study areas

The DOA provides recommendations for fertiliser use in each agro-climatic zone of the country for three target yields (high, medium and low). These are presented in Table 5.9 for the dry zone, including the Walawe area, for the low yield situation (target 5Mt/ha, which corresponds most closely to actual yields), and will be compared with actual use by the 70 farmers in the detailed study areas.

Table 5.9: Fertiliser Recommendations for Paddy

Application	Weeks after sowing	Nutrients Kg/ha			Fertiliser Kg/ac			
		N	P_2O_5	K_2O	Urea	TSP	MOP	$ZnS0_4$
Basal		5	30	20	5	25	15	2
1st top dressing	2	30	-		25	-	-	-
2nd top dressing	5	45	-		40	-	-	-
3rd top dressing	7	20	-	15	20	-	10	-
Total		100	30	35	90	25	25	2

At Walawe, agricultural advice is provided by MASL rather than DOA, but they provide the same recommendations. There is a set of slightly different fertiliser recommendations given by National Fertiliser Secretariat (2002) which were also prepared in conjunction with DOA (with assistance from FAO). These roughly correspond to the 'high yield' recommendations made by DOA, but they recommend a slightly higher basal dressing (20 kg cf 5 kg N/ha), which is reflected in a slightly higher total for the season (160 kg cf 140 kg N/ha).

In practice farmers in the study areas apply considerably less than this.The general pattern is to apply a basal dressing of Vmix (4:30:12 N:P:K) followed by Urea (46:0:0) 3-4 weeks after sowing and TDM (Top Dress Mixture – a blend of NPK 30:0:20), but most farmers omit one or more of these applications. Vmix (and TDM) are mixed by local retailers, but it is reported that they are not always correctly mixed. Urea is the cheapest component (because of subsidies) and thus retailers can save money by using more urea and lower quantites of other fertilisers[39]. The farmer's preference appears to be to apply 50kg (1 bag) per acre, but most farmers apply less than this. Observed practices in the two detailed study areas are given in Table 5.10 and Table 5.11.

Table 5.10: Fertiliser Applications in Detailed Study Areas.

	Units	Vmix	Urea	TDM
Nos farmers applying		51	53	35
Total number of farmers		69	69	69

[39] anecdotal reports by local officers, who comment that farmers are able to distinguish different types visually

% applying		74%	77%	51%
Quantity applied	kg	3,635	3,845	1,700
Area fertiliser applied on	ac	75.25	82.25	55
Rate of application by those who use fertiliser	kg/ac	48	47	31
Total area cultivated	ac	107.75	107.75	107.75
%of area applied on		70%	76%	51%
average rate over whole area	kg/ac	34	36	16

Source: field observations

Table 5.11: Kg nutrients per hectare of paddy

	Actual	Recommended	Percentage of recommendations
Nitrogen	56	100	56%
Phosphorus	25	30	84%
Pottasium	18	35	50%
Aggregate	99	165	60%

Cropping, and thus fertiliser application, is staggered over several weeks. Land preparation for paddy cultivation was undertaken around the same time in both areas, generally starting in late April or early May with ploughing of the paddy field by two wheeled tractor and plough. Farmers plant the rice by transplanting rice seedlings or broadcasting pregerminated seed, and fertiliser is broadcast (scattered) by hand. The actual timing of fertilizer use of 70 sample farmers in Ethbatuwa and Metigatwala study area during Yala 2005 is shown in Table 5.12.

During Yala 2005 the average total fertiliser application in both Blocks was highest during May and declined during the cropping season with no fertiliser applied in August in Matgathwala and 13.8 kg/ha of urea N applied in August in Ethbatuwa . Phosphate and potash fertiliser applications were on average highest in May and, since these fertilisers are largely associated with paddy cultivation in the study area, this is expected since they are usually applied as a basal dressing prior to sowing. Nitrogen fertiliser application was highest on average in June this being associated with the first and second top dressings after sowing.

Table 5.12: Timing of nutrient applications in detailed study areas

Area	**Nutrient**	**Nutrient applications Kg per ha total paddy land**				
		May	**June**	**July**	**August**	**Total**
Metigatwala	N	4.4	36.7	0.4	0.0	49.5
	P	22.9	0.6	0.0	0.0	23.5
	K	9.2	2.0	5.6	0.0	16.8
Ethbatuwa	N	23.5	39.2	2.1	0.0	64.8
	P	27.2	0.0	0.0	0.0	27.2
	K	10.9	7.5	0.0	0.0	18.4

Area	Nutrient	Nutrient applications Kg per ha total paddy land				
		May	June	July	August	Total
Combined	N	12.5	37.8	5.7	0.0	56.0
	P	24.7	0.3	0.0	0.0	25.1
	K	9.9	3.2	3.2	0.0	17.5

Farm survey data

Average nutrient applications from in-organic fertilisers were below recommended quantities in both areas. Three farmers in Matgathwala reported using no in-organic fertilisers although two of them used organic amendments and yet were still able to record rice yields ranging from 3,398 kg / ha to 4,950 kg / ha, whilst all the farmers in Ethbatuwa applied some inorganic fertiliser. There were no farmers in Ethbatuwa Block who acheved the N fertiliser recommendations (taken here to be within ±5 kg of the recommended amount, ie 100 kg/ha for 5T/ha yield), whilst two farmers exceeded the recommended quantity of N fertiliser (121 kg/ha and 137 kg/ha) for the yield that they achieved. In Matgathwala two farmers achieved the recommended N fertiliser quantity and one farmer exceeded the recommendation (218 kg / ha, but achieved a yield of only 5.8T/ha). One farmer applied 150kg/ha, but achieved a yield of over 8T/ha. Average phosphorous consumption was similar to the recommended rates in both areas, but barely half of the recommended rate for potash was used.

In both areas farmers reported applying split applications of fertilisers (i.e. applying fertiliser at different times during the cropping season) in line with recommendations. This better matches the crop requirements and reduces the chances of losses through leaching, surface runoff and volatalisation. In both cases there were some farmers who only applied fertiliser once (15 farmers in Matgathwala Block and 4 farmers in Ethbatuwa Block) and this seems to relate to the fact that they applied very small quantities and only used one type of fertiliser (either urea or Vmix). The exact reason for this is unclear but is likely to be related to cashflow problems or farmers simply not being able to afford to purchase the recommended amount of fertiliser (such comments were made during field interviews).

In addition to inorganic fertilisers, many farmers use organic amendments On average 300 kg / ha of straw were applied by farmers in Matgathwala Block and 125 kg / ha of cow dung although there were 12 farmers who did not apply any organic amendments. In Ethbatuwa Block 242 kg / ha of straw was applied but no cow dung. In both cases the application of organic amendments was below recommended quantities. The amount of organic amemdments applied are low compared to recommendations of National Fertiliser Secretariat (2002) who suggest at the first ploughing rice straw should be applied (the entire quantity of straw from the previous season rice crop is recommended – not less than 7 t / ha) and, after second ploughing 4 t / ha of cow dung should be applied. These recommendations would however be difficult to achieve given the numbers of cattle kept, and the way they are grazed.

Farmers also apply fertiliser to bananas, although none were applied in the yala season to the banana crop in the Matgathwala study area. No fertiliser was applied to permanent crops in the detailed study areas.

Summary

In summary, at the national level there is an increasing trend in fertiliser consumption and this trend is also seen over the last 5 years in the Murawashihena and Angunokolapallassa Blocks which are consider representative of a large portion of the study area. The increasing consumption of fertilisers, especially urea, is associated with fertiliser subsidies, access to low interest credit to enable farmers to purchase agro-chemicals and the introduction of high yielding cultivars.

Despite this increase, fertiliser consumption in the study area during the Yala 2005 season indicated that on average fertiliser rates applied to paddy were below recommended levels with five farmers not applying any fertiliser. Although farmers had a good knowledge of the recommended fertiliser rates, the survey data and field interviews suggest that farmers under-apply fertilisers. The exact reasons for this are unclear but are believed to be essentially financial. Many of the surveyed farmers used organic amendments to supplement inorganic fertiliser and many stated that they are increasingly making use of rice straw, husks and animal manure as a fertiliser source.

Rice yields, on average, are higher than the national average although they are less than the target levels set by MOA. Given these observations it seems reasonable to conclude that, despite the increasing risk of pressure on the environment from rising fertiliser consumption at the national and regional level, the environmental pressure resulting from excess nutrients in the study area is still likely to be small.

(iii) Pesticide use

Introduction

There has been an increase in fertilizer and pesticide use in Sri Lanka over the past 30 years that coincides with the increase in irrigated land, greater cropping intensity and mono-cropping, and the move away from *chena* (shifting or “slash and burn”) cultivation which traditionally relied on rain water and few agrochemicals. Rice, the main crop in Sri Lanka, is estimated to consume about 70 % of the pesticide, mostly weedicides, imported into the country (NARESA, 1991). The high potential yield loss from plant pests, estimated to be around 10-15 % of total yields (Kudagamage, Senarath and Fernando, 1992), with losses being greatest in horticultural crops such as flowers, vegetables and fruits, is also a factor (Steele, Konradsen and Imbulana, 1997). Furthermore, the use of agro-chemicals has also been encouraged by commercial enterprises improving access to, and promoting, agro-chemicals, as well as providing credit facilities and according to van der Hoek and Konradsen (2002) this has not been counteracted by an agricultural extension service (in Smit, 2002).

Pesticide consumption data is available from the Pesticide Registrar Sri Lanka. Products are available in different forms and concentrations, and thus a direct comparison of aggregate total quantities of all pesticides is not very meaningful: it is more useful to consider the quantity of active ingredients (a.i.). However, even this approach has its limitations when combining quantities of different tyoes of pesticides. The total active ingredient quantity does provide a broad indication of pesticide loading, but it overlooks factors governing pesticide fate that are often key parameters for determining long term environmental impact. Total active ingredient values also do not discriminate between pesticides with transitory effects and those with characteristically longer residence times in the environment which may pose a greater risk to environmental and ecological quality objectives. The Alliance for Sustainable Food and Farming (Sustain) provide a good overview of the complexities associated with the development of an indicator for pesticides for the reasons outlined above - variations in toxicity,

persistence and mobility; variations in formulation and concentration of active ingredients; and geographical factors, soil type, and application method. These can all affect the degree of environmental impact.

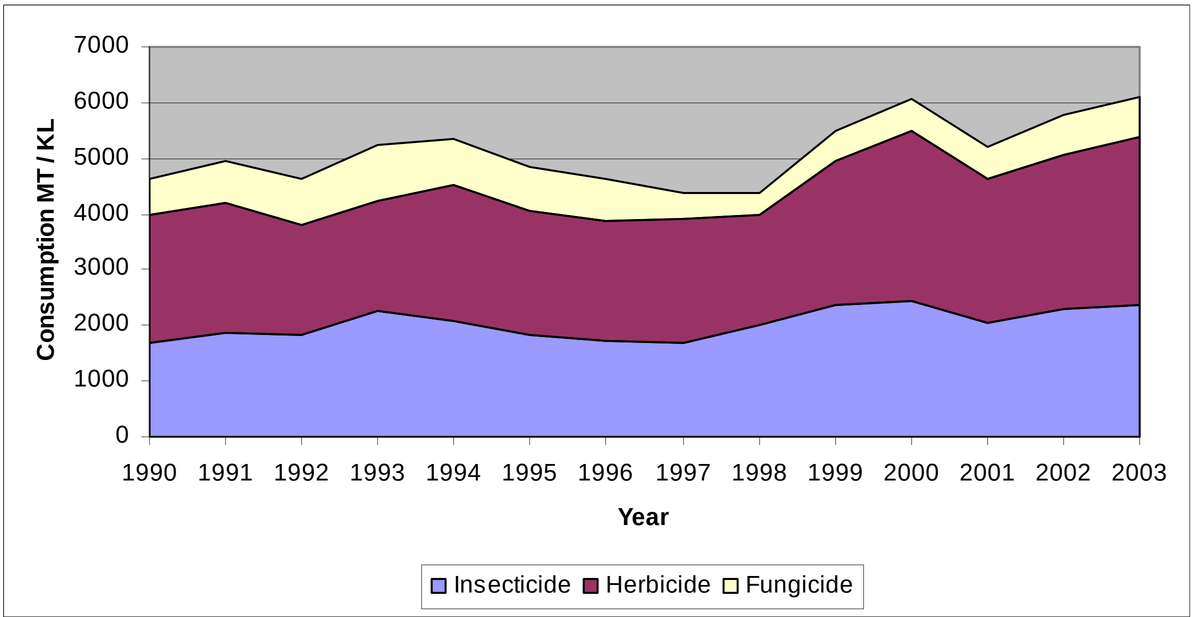
The indicators used in this study i.e. pesticide inputs, in order to assess the pressure on the environment, are also used by Defra and the EEA, the choice being largely governed by the availability of data. Other useful information to consider is the type of farming system prevalent in the area of study e.g. organic verses conventional (in this context meaning reliant on agro-chemicals) since organic agriculture uses zero (or minimal) pesticides. Our observations in the study area suggest that whilst the concept of organic farming was familiar to farmers and extension officers there were no examples where farmers formally followed the practice. There are some farmers who are beginning to adopt more environmentally benign farming practices such as IPM, use of organic amendments as a substitute to inorganic fertilisers. A more common reason for low or zero application of fertilisers is, however, the fact that farmers cannot afford them.

Water quality data can be a means of quantifying the amount of pesticide reaching the aquatic environment although the actual impact will depend on their chemical and physical properties, environmental conditions and biological conditions. The state of the terrestrial and aquatic ecosystems through the use of an indicator species or using an index of biodiversity will also give an insight into the impact of agro-chemicals on the environment.

National level data

According to statistics maintained by the Sri Lankan Pesticide Registrar over the period covering 1990 – 2003 inclusive, there has been an overall increase in pesticide consumption (fungicides, herbicides and insecticides) of 32% (Figure 5.9).

Figure 5.9: Pesticide consumption (total volume)

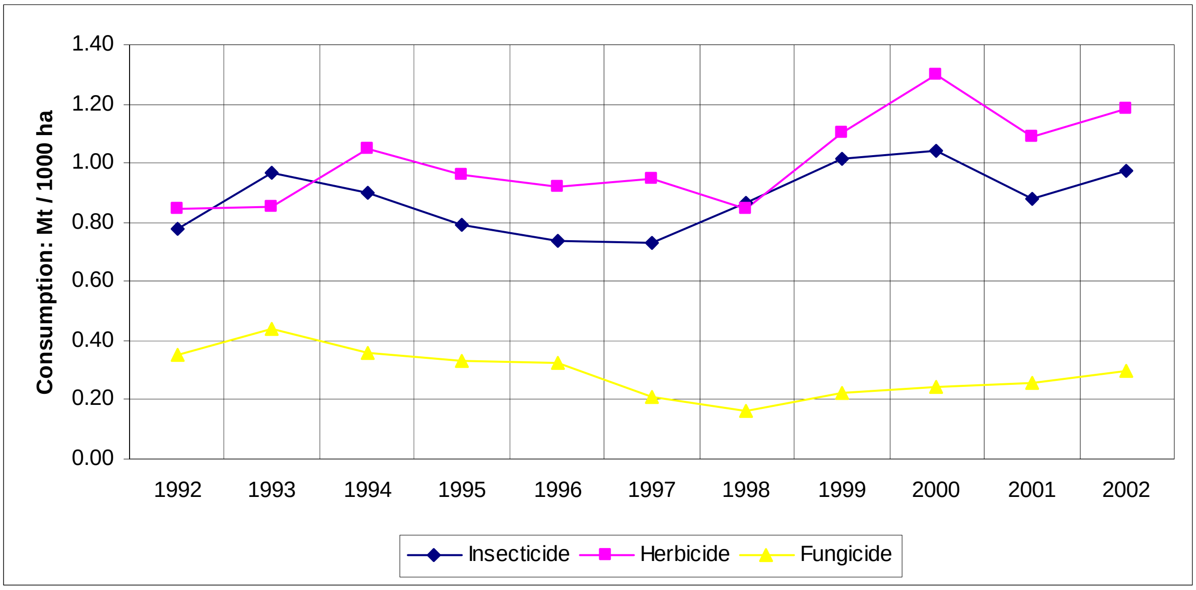


Source: Pesticide Registrar, Sri Lanka

Comparing the situation in 2003 with that in 1990, it can be seen that there have been increases in insecticides (41%), herbicides (30%) and fungicides (14%) and, in terms of actual weight pesticides have increased from 4,637 mt to 6103 mt. The exact reason for the increase in pesticide consumption is unclear but is likely to be linked to government's policy to support the agricultural sector - for example through provision of subsidised credit, although there has also been a modest increase in agricultural area (according to FAO statistics there has been an increase of about 12,000 ha – about 1% over the past decade – so this is a small influence).

There are large annual variations in pesticide use, probably reflecting changes in the registration of and hence availability of different types of pesticides. However, considering a regression line for the decade 1992 to 2002, we can see that there has been an annual increase of 1.5% in insecticide consumption per unit area of agricultural land, a 3.3% annual increase for herbicides and a decline of 1.5% for fungicides (Figure 5.10). Considering the past five years alone, there has been a more pronounced increase (with increases of 4%, 6% and 2% per annum respectively), but the variations are too great to conclude whether this indicates an accelerating trend towards greated pesticide use, or is just a short-term fluctuation.

Figure 5.10: Pesticide consumption per unit area

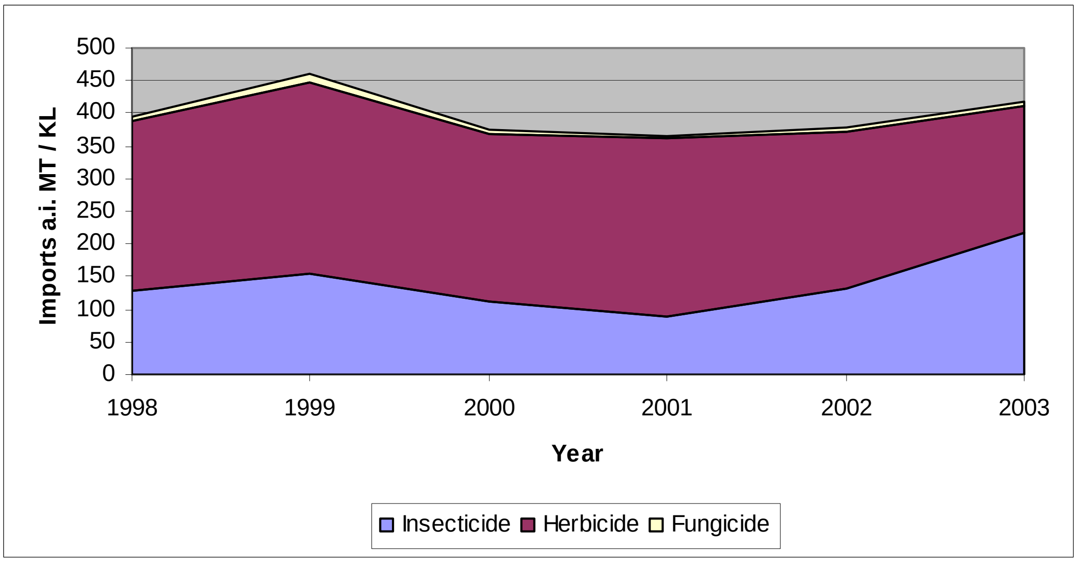


Source: Pesticide Registrar, Sri Lanka and FAOSTAT

The pesticides registrar also keeps data on imports of pesticides. In this case the data is presented in terms of active ingredient (a.i.). Again there is a significant annual variation, but there has been a marginal overall reduction over the past five years – a trend line shows an overall decline of about 0.5% per year. Considering the various types of pesticides, there has been an increase of 8% pa for insecticides, and a decrease of 5% p.a. for herbicides and 10% p.a. for fungicides (

Figure 5.11).

Figure 5.11: Pesticide imports (active ingredients)



Source: Pesticide Registrar, Sri Lanka

Again there is no clear reason why these changes have occurred although for insecticides this may be associated with a greater demand to control pests associated with vegetables, or for malaria control; the decline in herbicides and fungicides may be associated with the more selective use of these chemicals and the introduction of a.i. that require very low doses (as small as 5 g/ha) in contrast to loadings of active ingredients of more than 2 kg/ha in older pesticide formulations such as isoproturon.

Despite the apparent increase in pesticide consumption at the national level and the increasing rates of use per unit area of land Sri Lanka has, since the FAO's publication of Code of Conduct on the Distribution of and Use of Pesticides actively assessed the role of pesticides and regulated their use (Roberts, 2003[40]). Roberts (2003) summarises the steps taken by Sri Lanka in regulating pesticides and removing WHO Class I pesticides and some Class II pesticides such as endosulfan and the introduction of farming practices that rely less on pesticides such as IPM. Notwithstanding this, the increase in pesticide consumption reflects an increasing reliance on pesticides reflected in the steady increase in the application rate of insecticides and herbicides, and, on the basis of this an increasing pressure on the environment.

Local statistics

We were able to obtain some information on weedicide application by farmers in Murawashihena block which covers a large part of the study area, and is generally typical of the area as a whole. This appears to be the only systematic pesticide data at the local level, and was collected by the MASL Block Office Murawesihena. This data covers the post emergence herbicides M.C.P.A. and Propanil (3-4 D.P.A.) used to control weeds in paddy (Figure 5.12). M.C.P.A[41] is almost totally degraded in

[40] Roberts, DM, Karunarathna A., Buckley NA, Manuweera G, Sheriff MHR and Eddleston M (2003). Influence of pesticide regulation on acute poisoning deaths in Sri Lanka. Bulletin of the World Health Organisation, 81 (11), pp. 789 – 798.

[41] According to list of agricultural pesticides registered under the Control of Pesticides Act, January 2002. Office of Registrar of Pesticides, Sri Lanka.

rice paddy by aquatic micro-organisms in less than 2 weeks (Etoxnet); propanil and breaks down rapidly in water due to microbial activity in about 2 days in aerobic conditions and 2 – 3 days in anaerobic conditions and in soils breaks down rapidly in about 1 – 3 days (Etoxnet).

Figure 5.12: Herbicide use in Muravasihena block (*yala* season)

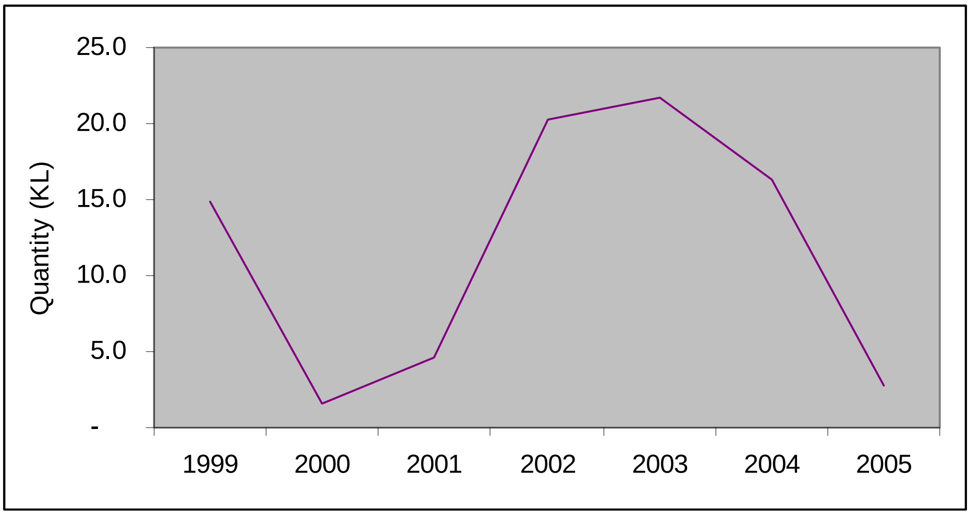


Figure 5.13: Herbicide use in Muravasihena block (*yala* season)

There does not appear to be any obvious trend in consumption of these pesticides. Consumption is apparently greater in most *yala* seasons. The very large fluctuations are hard to understand, and may reflect errors in the database – oxadiazon is a commonly used herbicide, but is not included in these statistics: most farmers use herbicide, and there does not appear to be any changing trend in herbicide use. The variability is much larger than the variation in the area of paddy cultivated, but may be related to the availability and affordability of the pesticide or a combination of all of these variables. The low figures for yala 2005 may reflect incomplete data as they are not consistent with our other observations in this study.

Sales reported by retailers

A sample of 15 major retailers was selected and interviewed as described in chapter 3. A summary of the survey is presented in Table 5.13. The retailers all said that sales of insecticide for use on paddy had declined over the last five years (generally by over 50%), whereas sales for vegetables had increased by 15-30%. Given the magnitude of sales and the fact that about 5% of the catchment is under vegetables, these figures equate to a small decline in total sales of around 5%. These data are summarised in

Table 5.14 covering insecticide, herbicide and fungicide sales, converted into litres of active ingredient.

Table 5.13: Summary of agro-chemical retailer survey showing perceived changes in agro-chemical sales over 5 years

Change	Paddy			Banana			Vegetables		
	Insecti-cide	Herbi-cide	Fungi-cide	Insecti-cide	Herbi-cide	Fungi-cide	Insecti-cide	Herbi-cide	Fungi-cide
Increasing	✓ (1)	-	-	-	-	-	✓✓ (12)	✓ (1)	✓✓ (14)
Decreasing	✓✓ (12)	-	✓✓ (11)	-	✓ (1)	-	✓ (1)	-	-
No change	(1)	(14)		-	-	-	(1)	(1)	(4)
Av. change	- 41%	0%	- 19%	0%	- 1%	0%	+ 19%	+ 4%	+ 7%

Key: ✓change reported; () indicates number of retailers expressing change

Care must be taken in interpreting this data since the retailers surveyed do not only supply farmers in this area, but also others in neighbouring areas. However, the majority of retailers stated that sales of insecticide for paddy cultivation had decreased (on average this was perceived to be by 41%), with no change in herbicides and a slight decrease in fungicides. Sales of pesticides for banana cultivation have not changed, whilst there has been an increase in sales of insecticide and fungicides for vegetables. The changes in sales may be due to a number of variables, including the increase in vegetable production, 13 out of the 15 retailers attributed the decline in insecticide and fungicide use in paddy to the introduction of IPM. However, the term IPM should be interpreted broadly in this context: related general improvements - in awareness of pesticides, restrictions on use of particular pesticides etc - are likely to be referred to as IPM.

The retailers mentioned that due to introduction IPM (see below) by the farmers the following trends are observable

- 13 out of 15 retailers say that their insecticide sale has decreased by 5 to 40 %
- 11 out of 15 retailers say that their fungicide sale has decreased by 5 to 30 %

As would be expected, IPM has had no effect on the sales of herbicide and fertilizer.

Table 5.14: Insecticide sales (litres)

Chemical	Concen-tration	Sales (a.i) *Maha* 04/5	Sales (a.i) *Yala* 2005	WHO toxicity	Class	persistance in soil (days half-life)	Persistence in water (days half-life)
Fungicides							
Carbendazim	50%	227.3	168.8	U	Carbamate		
Edifenfos	30%	108.6	90.9	1b	OP		
Hexaconazole	50%	324.0	257.5	U			
Herbicide							
Bispyribac	100%	436.0	378.0	U			
Fenoxaprop-p-Ethyl	20%	182.2	130.2	Obs			
Glyphosate	36%	1,379.5	1,010.3	U	OP	47	12-70
Oxadiazon	80%	3,049.6	2,406.4	U	BP		
Paraquat	20%	621.0	541.0	II	BP	>1000	160
Pretilachlor	30%			U			
Propanil	36%	5,929.4	4,462.8	II	acetanilide	1-3	2-3
Thiobencarb	20%	1,994.8	1,605.2		TC		
Insecticide							
Acephate	75%	340.1	243.8	III	OP	6	?
Carbosulfan	50%	340.8	278.9	II	Carbamate	?	?
Chlorofluazuron	50%	58.8	47.2	U		?	?
Chlorpyrifos	40%	923.1	764.8	II	OP	60-120	5-80
Diazinon	50%	111.0	92.5	II			
Dimethoate	40%	411.2	329.3	II	OP	20	8
Fenubucarb	60%	239.9	177.0	II	Carbamate	?	?
Fipronil	50%	36.7	31.6	II		2-20	1-5
Imidocloprid	20%	51.0	42.8	II	Chloro-nicotinyl	50-190	>>30
Profenofos	50%	62.3	49.2	II	OP	2-3	100
Quinalphos	25%	68.1	57.6	II	OP	?	?
Thiodicarb	38%	14.8	12.6	II	Carbamate	?	?

Notes: toxicity (1b= highly hazardous, II= moderately hazardous, III= slightly hazardous, U= unlikely to cause acute hazard in normal use); classification (OP= organophosphate, BP= bipyiridyl, TC= thiocarbamate)

Source: Retailer survey Kachchigala Basin

Despite the limitations of this survey, it does seem that there is a trend for farmers to use less on pesticides on paddy and more on vegetables. The wider variability in cropping at the catchment scale means that we cannot quantify the magnitude of this change. There is a small trend towards vegetable cultivation, which may result in a significant local increase in environmental pressure, but this is unlikely to replicated over the entire catchment. There has been a reduction in pesticide use on paddy, but as usage is now very low, this trend cannot continue for long. There is even a possibility that improved knowledge as a result of IPM programmes would result in an increase in pesticide usage if this is found necessary to increase yields in a cost-effective manner.

Farmer survey

Of the 70 farmers surveyed in Metigatwala and Ethbatuwa a total of 4 (2 in each farmer group) reported not to applying any pesticides. In Ethbatuwa 25 farmers reported using herbicides and 9 reported using insecticides in paddy cultivation; of these 8 reported that they used a combination of herbicides and insecticides, whilst 1 farmer used only insecticides. With the exception of 2 farmers, herbicides were applied during May to control weed growth after emergence of the rice crop and 2 farmers applied herbicide during the first week of June In Ethbatuwa. Some farmers applied herbicides twice, and a few applied insecticides more than once. Insecticides were mainly applied during June or July as the crop developed, although some farmers applied in May – including Endosulphan which was banned in 1998. The data on pesticide use on paddy is summarised in Table 5.15

Table 5.15: Pesticide use on paddy by 70 farmers

Chemical	May		June		July		Overall		Total	
	Area sprayed	Vol	Area sprayed	Vol	Area sprayed	Vol	Nos farmers	Nos appliers	Area	Vol/ha
Ethbatuwa										
Herbicide	17.6	74,400	1.2	480			30	28	18.5	4,050
Insecticide	0.8	200	2.2	13,200	3.2	1,200	30	9	18.5	790
Fungicide										0
Metigatwala										
Herbicide	5.0	14,800	11.7	31,420	2.0	160	40	27	25	1,855
Insecticide	3.0	620	14.4	15,500	4.4	11.9	40	26	25	830
Fungicide										0

The most commonly used herbicide, in terms of number of farmers reporting using the pesticide (11 reported using this herbicide), used for paddy cultivation was propanil – which is consistent with the information from the retailers mentioned above.

The most commonly used insecticide used in paddy cultivation was Dimethoate (4 farmers used this pesticide). Dimethoate has a low persistence in soil (representative half-life of 20 days) and is rapidly broken down in soils by soil micro-organisms and is broken down faster in moist soils; in water dimethoate has a half-life of 8 days and disappears due to micro-organisms or chemical degradation (Ecotoxnet[42]).

No herbicides were reported to be used in vegetables and only 4 farmers reported using an insecticide. The Ethbatuwa farmers did not report using any pesticides in banana production or permanent crops. Only 3 farmers reported using "modern" IPM techniques.

In Metigatwala 27 farmers reported using herbicides and 26 using insecticides in paddy cultivation, and of these farmers 13 reported using both herbicides and insecticides and 12 using only insecticides. Two herbicides were most commonly used by farmers in Metigatwala namely, propanil (7 farmers)

[42] Extoxnet. Pesticide information profiles. Information downloaded during September 2005. http://extoxnet.orst.edu/pips/ghindex.html

and Shofit (7 farmers) and these were mainly applied in May or June. It appears that farmers only applied the herbicide once during the period of cultivation. The most commonly used insecticide used in paddy cultivation was Dimethoate (12 farmers reported used this pesticide). No pesticides were reportedly used in banana or permanent crop cultivation and no herbicides were used in vegetable cultivation. Only 2 farmers used insecticides on vegetables. Curiously, despite 17 farmers in Metigatwala reportedly practicing modern IPM techniques, there were 3 times more farmers using insecticides compared to Ethbatuwa farmers.

In summary, of the 70 farmers, 55 farmers used herbicides (mostly propanil, which breaks down rapidly) in paddy cultivation to control weeds. 34 farmers reported using insecticides in paddy cultivation of which dimethoate was most commonly used. IPM seems to be sparsely practiced in the study area, 20 farmers reporting to use modern IPM techniques. However, in the Metigatwala group whose farmers reported practising IPM techniques more widely insecticide use was higher compared to the Ethbatuwa group. There is no clear reason why this difference exists and it seems odd that even where IPM is more widely practiced insecticide use is also relatively high.

Vegetable production is not very extensive in the study area (accounting for 2.75 ha in Ethbatuwa and 0.75 ha in Metigawala, as compared to 18.5 ha and 25 ha paddy respectively), but those who did grow vegetables used much higher rates than for paddy (1.9 l/ha in Metigatwala and and 2.6 l/ha in Ethbatuwa). Neither banana cultivation nor permanent crops received any agro-chemicals.

(iv) Water use

Flows into Mamadala branch canal irrigating part of the study area are presented in Figure 5.14, showing actual and planned flows (around 4- 5m3/sec for an area of 2,715 ha of which 75% are paddy) together with rainfall. Rainfall is low and irrigation releases do not take account of it. Actual releases are significantly greater than the plan – typically by 20%, but by a much larger factor at the end of the season. The excess at the end of the season alone accounts for 25% of the planned delivery for the season and indicates considerable potential for improved irrigation management. The potential benefits are immediately apparently since the subsequent maha season was delayed by a month due to a shortage of water in the reservoir.

Figure 5.14: Canal discharge and rainfall – Mamadala branch canal: *yala* 2005

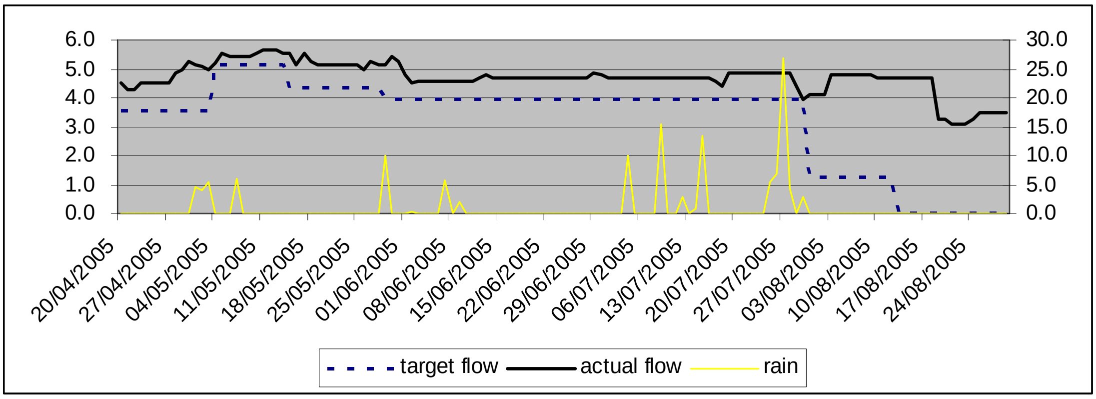
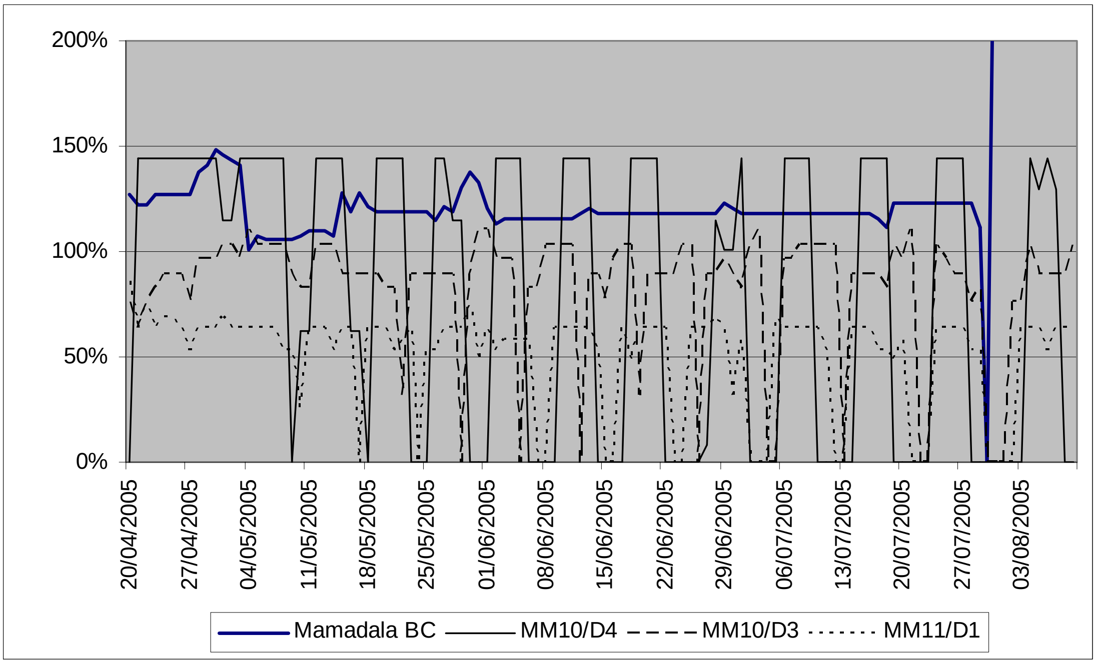


Table 5.16: Variation in Distributary canal flows – Ethbatuwa: *yala* 2005



This excess water is not uniformly distributed amongst the command area. The discharge, expressed as a percentage of design in the three distributary canals in the Ethbatuwa study area at the tail of the branch canal show very different pictures MM10/D4 receives up to almost 150% of design, whereas flows in MM11/D1 rarely exceed 60%. These canals are intended to be operated on rotation, but both the magnitude of the flow and the duration of the rotation is very variable. Per unit area, MM10/D4 receives 85% and MM11/D1 60% of the flow entering MM10/D4. The average flow over the season is thus 1.9 l/sec/ha – substantially greater than the crop water requirement, calculated by Mott MacDonald (1992) to be equivalent to 0.67 l/sec/ha. Some of these losses are inevitable – because of the nature of the soil – but some could be reduced in the future if standards of management were improved.

This information together with the fertiliser data to calculate an approximate nutrient balance for this area, as follows:

Table 5.17: Nitrogen balance: Ethbatuwa

Parameter	Value	Unit	Source
Actual fertiliser N applied to crop	63	kg N/ha	Field observations
Mean harvest yield	3,800	kg/ha	
Grain protein content	1.26	%	IPNS training manual
Protein to nitrogen conversion	5.7	kg N/kg protein	
Nitrogen Harvest Index (NHI)	0.74	kg grain N/kg shoot N	IPNS training manual
Nitrogen Use Efficiency	0.6	kg shoot N/kg	Typical value

Parameter	Value	Unit	Source
		available N	
Total crop N demand	19	kg N/ha	Includes all sources[43]:
Fertiliser N applied which is unused by crop	25	kg N/ha	
Gaseous loss as proportion of fertiliser N applied	30	%	Typical value[44]
Estimated gaseous loss (as NH_3, N_2O, NO_2)	19	kg N/ha	
Unused fertiliser N remaining available for leaching	6	kg N/ha	After deduction of gaseous losses
Average seasonal irrigation water supplied	1.9	l/sec/ha	Field measurements, Mott MacDonald (1992)[45]
Average crop water requirement/evaporative losses	0.67	l/sec/ha	
Annual drainage volume related to the cited crop	12,800	m^3/year	
Mean annual concentration of drainage water leaving soil root zone	**2.2**	**mg nitrate/litre**	

This value may seem very low but is higher than concentrations measured in drainage water However, this is a preliminary calculation and some uncertainty in some of the above estimates and assumptions must be acknowledged. Presumably the sampling dates did not coincide with peak losses from the fields and thus recorded less than the average actual concentration.

The impact on the aquatic system is thus low but this could increase significantly if this dilution factor is reduced in the future (e.g. due to water shortages as the left bank is developed). Such shortages might lead to a change in cropping to more input intensive crops such as vegetables and thus greatly increase the concentrations in agricultural drainage waters and thereby pose an environmental issue.

(v) Impact of IPM programmes

MASL have an established programme for introducing Integrated Pest Management (IPM) to the Walawe irrigation system area, and now most farmers have had some access to IPM – particularly in the northern end of the system. Coverage at Ethbatuwa is much lower than at Metigatwalawewa, and farmers are less likely to follow the recommendations

Table 5.18: Progress with IPM programme

	Ethbatuwa	Metigatwala
Total number of farmers	30	40
Number trained	13	27
Number using IPM	8	25
Changes in yield (%)	5-10%	10-15%

70 farmers' survey

43 fertiliser, manure, atmospheric deposition, and net soil and crop residue mineralisation
44 e.g. Harrison and Webb, 2001, Advances in Agronomy. Actual gaseous losses may be greater than the typical 30% value estimated here due to enhanced denitrification in the subsoil resulting from the periodic flood irrigation events
45 Walawe Irrigation Improvement Project: Assessment of right bank water requirements

This programme follows the community IPM model widely promoted throughout the world by FAO (Tripp et al, 2004). Many farmers in the study area reported that they were aware of and used IPM methods, and this is cited by agro-chemical retailers in the region as a reason for the decline in their insecticide sales over the last 5 years. Roberts et al. (2003[46]) made a similar observation and he stated that less pesticides are used in some paddy cultivation areas of Sri Lanka (these areas are not specified) due to the introduction of IPM techniques (and phasing out of WHO Class I pesticides). Van den Berg (2002[47]) states that there are four principles introduced through IPM Field Schools to the farmers – namely that they should:

- grow a healthy crop;
- observe the field regularly;
- conserve natural enemies; and
- farmers become expert in their own fields.

We undertook a survey of the 70 farmers to help understand the uptake and application of IPM in the study area. In summary, 32 farmers (46%) reported using IPM techniques, but twelve of these reported only using traditional IPM techniques. These include:

- Reading / reciting charms / magic to "chase" the pest away from the crops (based on cultural and religious beliefs with no intention of killing the pest);
- Lighting of oil lamps (oil extracted from flowers of some traditional trees and also coconut oil) is a deterrent to pests and, is also know to deter wild animals;
- Hanging branches of coconut trees in areas of the cultivated land to attract birds which also eat the pest found in the crop;
- Use of winnowing fans and coconut ropes covered in gums extracted from trees that attract pests and then stick to the gum;
- Apply liquid extracted from neem trees to the crops to kill / or deter pests; and
- Timely establishment of the crop to coincide with favourable weather conditions to control pests.

17 farmers said they just used modern IPM techniques whilst 5 said that they practised a combination of both. Farmers reported that the modern IPM techniques that they practiced in the study area include:

- Timely establishment of crops to coincide with favourable weather conditions to control pests (although considered a traditional method this is considered part of the "package" used in modern IPM);
- Spraying of agro-chemicals according to the pest population (for example, if the value of pest damage to the crop is more than the cost of the agro-chemical to be applied it is recommended to apply agro-chemical, whilst the converse might apply if pest infestation is low relative to the anticipated damage to the crop the pest may cause);
- Frequent field observations and attempt to understand the magnitude of the pest population;

[46] Roberts, DM, Karunarathna A., Buckley NA, Manuweera G, Sheriff MHR and Eddleston M (2003). Influence of pesticide regulation on acute poisoning deaths in Sri Lanka. Bulletin of the World Health Organisation, 81 (11), pp. 789 – 798.

[47] Van den Berg H (2002). Integrated Pest Management: an alternative to high-input agriculture. In Smit LAM (ed.). 2002. Pesticides: Health impacts and alternatives. Proceedings of a workshop held in Colombo, 24 January, 2002. Working paper 45. Colombo, Sri Lanka. IWMI. ISBN 92-9090-487-9.

- Application of liquids extracted from trees such as neem (traditional method).

Rice straw is the most widely used organic manure (40% farmers) and 2 farmers (3%) reported using goat manure. The 35 farmers who used organic amendments believed that they could use less inorganic fertiliser as a result (on average the perceived reduction was 11% with a maximum of 30% and a minimum of 3%).

The introduction or use of IPM techniques is to encourage farmers to be less dependent on agro-chemicals in their farming practices and therefore an indicator of the uptake of such techniques would be a change in the use of agro-chemicals. Table 5.19 below summaries the changes in agro-chemical use following the introduction of IPM techniques undertaken by the farmers who reported they practiced IPM in the study area.

Table 5.19: Changes in agro-chemical use following uptake of IPM

	Inorganic fertiliser	Fungicide	Insecticide	Herbicide
Before IPM introduced	33 farmers applied 3 times	3 applied x 1 26 applied x 1 or 2; 3 applied x 3	3 did not apply 4 applied x 3 28 applied x 4	35 x 1
After IPM introduced	33 farmers applied 3 times	22 never used 11 applied x 1 2 applied x 1 or 2	12 did not apply 12 applied x 1 11 applied x 2	35 x 1
Change	No change	Reduced	Reduced	No change

According to farmers in the study area who practiced IPM they continued to split fertiliser application three times during the season. Although not clear from the survey results the fertiliser applications are probably to do with paddy cultivation and therefore the split applications will follow recommendations associated with basal dressing prior to sowing and top dressings following planting. Where herbicides are applied these are only applied once and are likely to be associated with control of weeds in paddy cultivation – further reductions in herbicide use could be made if weeds are removed manually. However, this traditional method may not be feasible due to the cost or scarcity of labour. The number of times insecticides and fungicides are applied has reduced, to the extent that farmers reported they did not apply either of these pesticides more than twice during a season, whilst prior to the uptake of IPM, farmers applied these pesticides 3 or 4 times in a season. Furthermore, of the 35 farmers practicing IPM they reported a perceived reduction of insecticide use by on average 83%.

Care must be taken in interpreting these results since there could be considerable seasonal variation in pesticide consumption depending on the magnitude of pest outbreaks. Nonetheless, the results do suggest that where farmers have used IPM techniques they have been able to reduce the number of times they apply insecticides and fungicides and, this has resulted in an average reduction of insecticide use of 83%. Both of these changes are likely to have a reduced pressure on the environment as well as potentially reducing operator exposure to pesticides. Another benefit reported by farmers practicing IPM was an increase in crop yields (exactly which crops are not mentioned) of on average 13% which, assuming favourable market prices, should result in higher crop gross margins.

These observations i.e. the uptake of IPM translating into increased yields and reduction in insecticide consumption is consistent with observations made by van den Berg (2002[48]) who illustrated the increase in yields and savings in pesticides in a number of districts in Sri Lanka as well as a reduction of the average number of insecticide applications after a Farmer Field School (FFS). Tripp et al. (2004[49]) identifies the FFS as a successful means of introducing and encouraging the uptake of IPM in rice cultivation stating that the "most important effort by (*agricultural*) extension to reduce insecticide use has been the FFS programme" which has been part of a long-term commitment to IPM in Sri Lanka by the FAO since the mid-1980's with the main activity of the FFS was between 1995 – 2002 when more than 600 FFS were organised throughout the country. According to Tripp (op. cit.) working in Southern Province of Sri Lanka, including sites in Hambantota and Matara, the impact of the FFS programme has resulted in farmers using only a third of insecticides compared to other farmers and they are less dependant on fungicides. Besides this, FFS farmers make better use of organic amendments such as straw to improve soil fertility and are more inclined to use single nutrient fertilisers. Interestingly, Tripp seems to say that the FFS enabled farmers to gain a greater understanding of certain ecological relationships (exactly what is not stated) and therefore gives them the confidence to reduce their use of insecticides but only in so much that it gives them a more informed approach to insecticide use i.e. evidence of other forms of insect control are consistently applied was not apparent. Even though this may be the case Tripp considers farmer awareness of the problems caused by insecticides and by over-reliance on synthetic fertilisers has increased although "there is little evidence for the emergence of any type of 'green' farmer".

(vi) Livestock

Livestock numbers reflect the intensity of livestock production systems. Livestock numbers can be a major component of nutrient loadings and balances at field and farm scale. Intensive livestock husbandry systems increase the risk of soil erosion and degradation on vulnerable soils (e.g. sloping land), and can increase poaching risk around feeding or watering troughs and around areas where animals have access to canals and drains. Intensive animal husbandry systems which combine high livestock numbers with limited agricultural land areas can increase the risk of soil erosion, sediment loss, and pollution of nutrients to water bodies (e.g. from slurry). Cows, buffalo and chicken are the main livestock raised in Sri Lanka, as well as some pigs, sheep and goats.

Cattle and buffalo – national and local trends and impacts

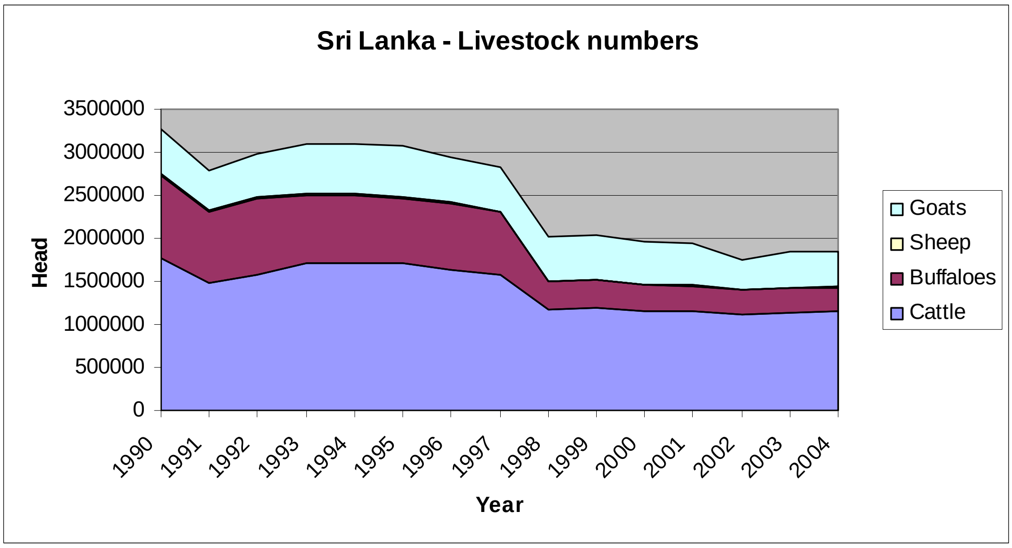
Cattle and buffalo are important for milk and for curd production, which is an important industry in Sri Lanka, especially in Hambantota District, as well as for meat with smallholder farming or subsistence based farming tending to dominate local milk production. Whilst there appears to be a decline in cattle numbers in Sri Lanka over the last 14 years (Figure 5.15) the government has encouraged investment and development of exotic (non-native) dairy cattle such as Holstein or Friesian breeds through breeding programmes to improve the genetic stock and increase milk production and reduce the dependency on imports of dairy products.

[48] Van den Berg H (2002). Integrated Pest Management: an alternative to high-input agriculture. In Smit LAM (ed.). 2002. Pesticides: Health impacts and alternatives. Proceedings of a workshop held in Colombo, 24 January, 2002. Working paper 45. Colombo, Sri Lanka. IWMI. ISBN 92-9090-487-9.

[49] Tripp R., Wijeratne M and Hiroshini P (2004). After School: the outcome of farmer field schools in Southern Sri Lanka. Draft for review only. www.odi.org.uk/rpeg/research/ natural_resources/LEITpapers/**srilanka**.pdf. Downloaded December 2004.

Even with this investment in production specialist dairy units are not as common compared to the more dominantly smallholder mixed crop–livestock farming operation with farmers mostly feeding their animals on natural grasses available in common lands such as on road sides, railway banks, fallow paddy fields, tank beds and other vacant lots, all maintained under rain fed conditions. Dairy production plays an important role in maintaining sustainability and crop yields in most smallholder mixed farming systems and has provided farmers with a source of regular daily income from dairy based products (Bandara[50] points out that very few farmers milk their buffalo cows, but gives no explanation as to why this is the case) and a way of cushioning the risk of crop and market failures.

Figure 5.15: Livestock numbers in Sri Lanka



Source: FAOSTAT

The total estimated number of cattle and buffalo in Sri Lanka in 2004 based on the 2002 Agricultural Census was 1,160,900 and 301,500 respectively, with little variation in cattle and buffalo numbers between 1998 and 2004 (Table 5-20).

[50] Bandara. The current status of smallholder dairy systems in Sri Lanka. http://www.ilri.cgiar.org/InfoServ/Webpub/Fulldocs/South_South/ch07.htm Downloaded November, 2005.

Table 5-20: Cattle and Buffalo Population and Milk Production 1998-2004

YEAR	Cattle				Buffaloes			
	Total Number of Cattle	Cows Milking at present	Average Daily Milk Production Litres	Average Monthly Milk Production Litres	Total Number of Buffaloes	Cows Milking at present	Average Daily Milk Production Litres	Average Monthly Milk Production Litres
2004	1,160,900	216,050	443,600	13,308,000	301,500	53,060	85,000	2,550,000
2003	1,138,700	211,800	434,850	13,045,500	280,480	51,560	84,050	2,521,500
2002	1,112,948	207,110	424,558	12,736,740	282,087	51,656	84,317	2,529,510
2001	1,153,200	214,600	424,347	12,730,400	290,300	53,400	84,063	2,521,900
2000	1,147,600	213,600	420,127	12,603,800	304,500	53,300	84,317	2,517,512
1999	1,191,500	221,700	424,558	12,473,900	319,500	55,400	83,880	2,516,400
1998	1,178,400	219,300	409,393	12,281,800	316,400	53,300	82,521	2,475,620

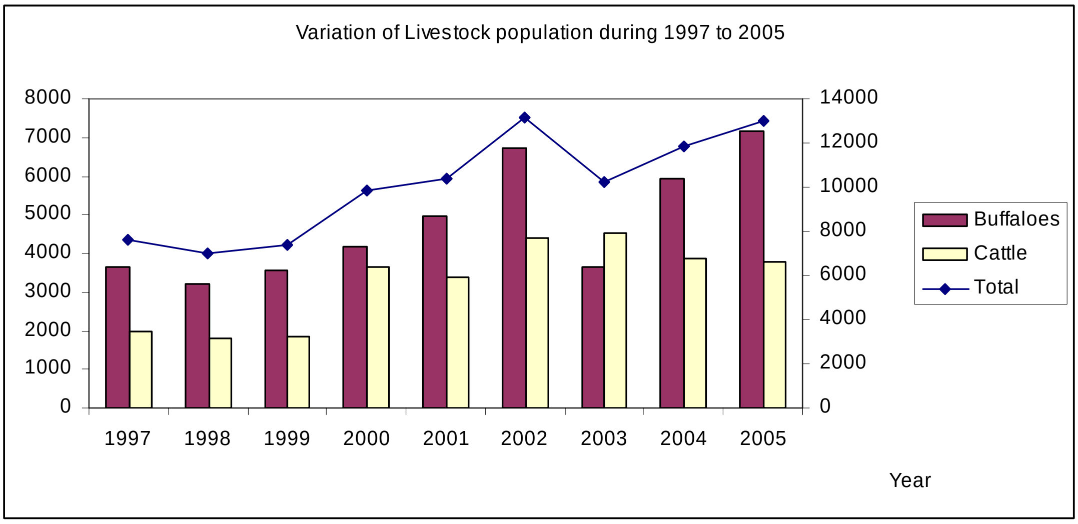
Revised Series of Estimates Based on Census of Agriculture 2002

Over longer term there has been a larger reduction in numbers, as reported by FAO (Figure 5.15), indicating decline in cattle, sheep and goat numbers. The large reduction in the 1990s may reflect the loss of grazing land, as land is reclaimed for agriculture under the Mahaweli programmes, but the full reasons behind the differences in available published statistics are not clear – particularly the large drop in numbers between 1990 and 1991 and again between 1997 and 1998.

There are a number of possible additional reasons, apart from the lack of grazing land (discussed elsewhere in this report) for the decline in dairy livestock numbers including too few breeding buffalo, very little artificial breeding of buffalo, ineffective dairy breeding programmes, under developed milk collection and processing facilities and no regulatory system in place to ensure the quality of milk collected and marketed (Bandara, 2005).

Curiously, livestock data available for Walawe (Figure 5.16) shows the opposite trend in numbers. Numbers of cattle numbers have been fairly stable over the last 5 years (2000 – 2005) but there was a large increase reported over the 1990s. Buffalo numbers have been more variable and appear to have almost doubled over the past 10 years. There are some strange large inter-annual variations – particularly 2002-2004 – which may reflect pressures to report numbers incorrectly noted elsewhere in this report. This upward trend in buffalo numbers perhaps reflects the fact that the region is a traditional curd producing areas.

Figure 5.16: Livestock population at Walawe



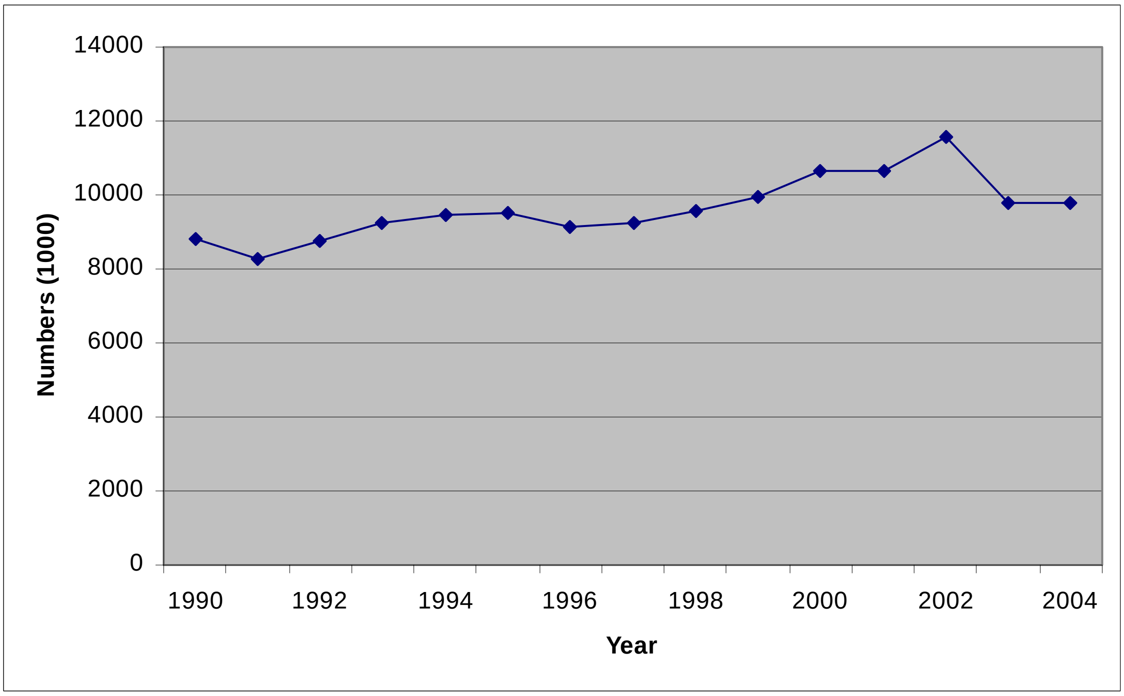
The overall decline in cattle numbers at the national level would indicate a decreasing pressure on the environment although that the statistics suggest that the reverse is true at a local level. Field observations suggest that, despite the increases, livestock density does not threaten the environment except in some 'hotspots'. Such locations include around tanks where buffalo wallow and drink: rural communities in field interview complained that the tank became contaminated and was then not suitable for washing or bathing in.

We found no evidence of large manure or slurry storage issues which might pose a pollution threat from effluent run-off. Some farmers report that they used animal manure to fertilise paddy, although this was not reported by our main 70 farmer survey. This is presumably because of the low density of cattle and buffalo in these areas. Farmers in other parts of our study area reported using manure to maintain soil fertility on their own land and also that they made it freely available to other local farmers. In parts of the hill country of Sri Lanka (such as around Nuwara Eliya), where vegetable production is intense, cattle manure is trucked in from neighbouring intensive dairy farms (intensive dairy farming is more common than smallholder production in the hill country).

Other livestock

The total number of chickens in the country has gradually increased from an estimated 9.6 m to 11.0 m from 1998 to 2004 although egg production has shown a slight decline from 73.0 m to 72.9 m based on the 2002 Census of Agriculture (Department of Census and Statistics, 2005). A similar increase is reported in FAO data (Figure 5.17).

Figure 5.17: Chicken numbers in Sri Lanka



Source: FAOSTAT

Swine numbers have increased marginally since 1998 whilst the number of goats and sheep has declined by 20%, and the number of ducks has increased by around 25%.

Table 5-21: Swine, Goat/Sheep and Chicken Population 1998-2004

YEAR	Total Swines	Total Goat/Sheep	Total Chicken	Average Monthly egg Production ('000)	Ducks
2004	79,295	416,870	11,041,960	72,883	16,440
2003	67,740	423,880	9,773,500	73,751	15,970
2002	82,143	360,382	11,564,167	74,228	11,550
2001	68,300	504,300	10,654,870	78,841	12,400
2000	70,800	506,400	10,622,370	76,918	9,900
1999	73,600	526,500	9,922,672	74,832	10,300
1998	76,300	531,100	9,565,973	72,986	12,800

Revised Series of Estimates Based on Census of Agriculture 2002

Date of update: 03rd March 2005

5.4 Water Quality

5.4.1 Introduction

This section covers the water quality in the *yala* season (April to August) 2005, with the full data for being presented in Appendix C. This will be updated to include the *maha* season results. These results are presented to elucidate the relationship between water quality and agricultural practices by considering both spatial and temporal variation of the parameters. The locations discussed here are defined in section 3.2: locations 1 to 11 represent the *ara* from head to tail; location 12 is a tributary *ara* between locations 5 and 6. Seven additional locations (13 to 19) were sampled in April to ensure that we could isolate the impact of urban pollution, but these were not monitored for the remainder of the season.

Table 5.22: Areas draining to each sampling site (ha)

Sample Site	Paddy	Other field crops (OFC)			Total
		Banana (ha)	Vegetable (ha)	Permanent crop (ha)	
2	117	4	2	18	141
3	28	3	2	2	35
4	215	15	5	37	272
5	710	58	13	127	908
12	278	23	4	52	357
6	1,097	99	26	252	1,474
7	1,814	166	49	475	2,504
8	3,419	352	96	870	4,736
9	232	68	24	46	370
10	4,532	596	199	1,103	6,430
11	4,961	608	214	1,154	6,937
Total	**4,961**	**608**	**214**	**1,154**	**6,937**

Permanant crops include coconut, fruit trees etc.

We also undertook a preliminary sampling exercise, in March 2004 at the end of the *yala* cultivation season when the paddy already was harvested, water issues from Chandrika Wewa had been stopped, and water depths were low even in Metigathwala Wewa.

The pH was consistently alkaline (around 8 units) throughout the Kachchigala Ara system, with little difference among sites. Water temperatures were high (28 - 30^{0}C) throughout the sampling network. Electrical conductivity was similarly high along the stream (up to 900 µS cm^{-1}) but comparatively low in irrigation water (175 µS cm^{-1}) and Metigatwalawewa (300 µS cm^{-1}). The EC of Kalametiya Lagoon (15 260 µS cm^{-1}) was about 35 times higher than the *yala* 2004/2005 average – the difference presumably due to the devastation caused by the tsunami in December 2004. The low water availability is a likely reason for the high EC levels. Dissolved Oxygen levels (4.5 to 6.4 mg l^{-1}) were higher than those obtained during the main sampling period from April 2005.

Nutrient concentrations (predominantly nitrates) were lowest in the network of irrigation canals at the head of the system and in Methigathwala Wewa and range from 0 to 0.3 mg/l. Total phosphate levels were also very low (maximum 0.32 mg/l, which was found in the upper part of the ara); the lowest was recorded from the tank. Chemical oxygen demand was lowest in the irrigation canals and highest in the lagoon, where ammonia also was high. Turbity was high, except in the irrigation canals.

The main water quality sampling commenced at the onset of the *yala* cultivation season (the lesser/drier of the two cultivation seasons). The land preparation for the season started with the release of water from Chandrika Wewa (18th April 2005). Water quality results are presented in relation to the timing of the different stages of rice cultivation and associated applications of agrochemicals, as outlined in Table 5-23: .

Table 5-23: Growth stages of paddy and application of agrochemicals (*yala* season)

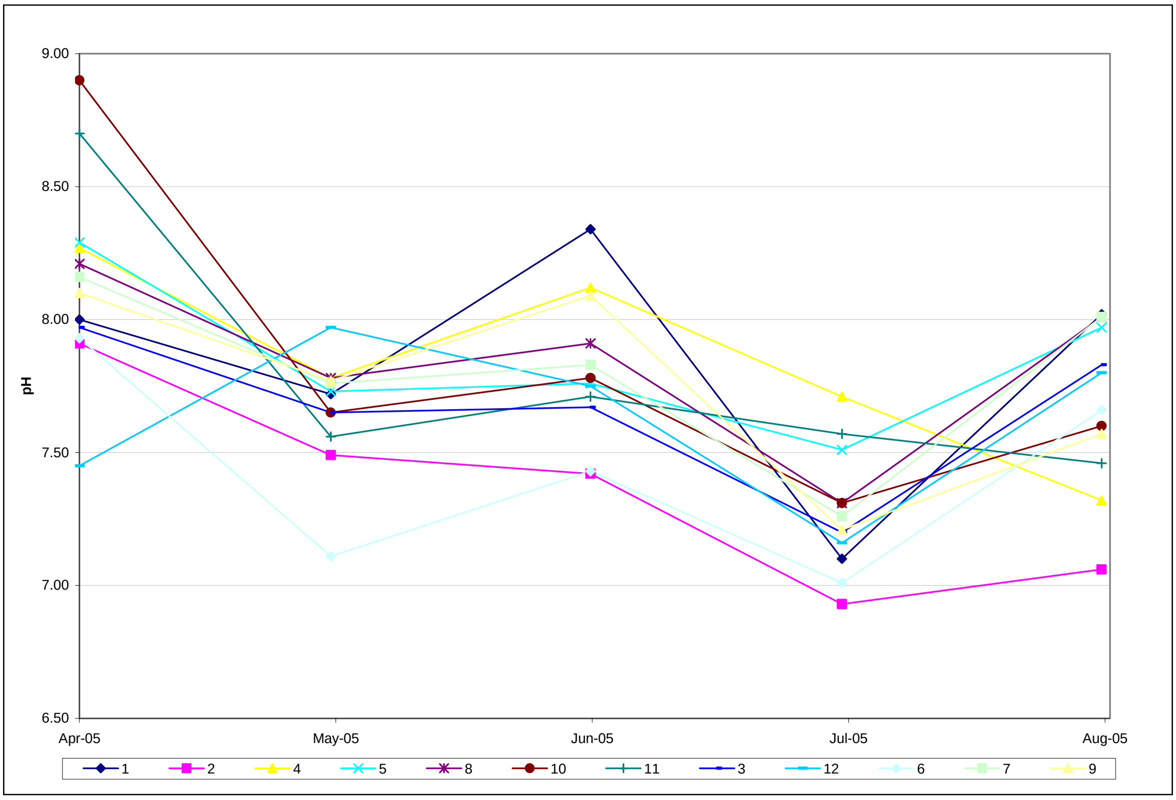
Month	Growth stage of paddy	Agrochemical application(s)
April	Land preparation in the upper parts of the catchment (monitoring points 1-7 and 12). Land preparation had not yet been started in lower part of the study area (8 and 9)	none
May	In the upper part of the catchment paddy is in the seedling and tillering stages (1–7 and 12). In the lower catchment, land was being prepared (8 and 9)	Vmix Weedicides
June	Later stages of the vegetative phase in the upper part of the catchment, while in the lower catchment the rice is in mid vegetative phase	Urea/TSP Insecticides Fungicides
July	Early reproductive phase in the upper catchment (1-7 and 12) and late vegetative phase in the lower catchment (8 and 9)	TDM (mixture of urea, TSP and murate of phosphate) Insecticides
August	Mature grains or harvesting in the upper parts of the catchment (1-7 and 12), while in the lower catchment (8 and 9) paddy is still in the late vegetative phase	none

5.4.2 Variation in water quality through the season

(i) Physical parameters – pH, temperature

Surface water temperature follows the air temperature, with January being the coolest month and July and August the warmest months. The pH does not reveal any large variation through the season in any location (Figure 5.18).

Figure 5.18: Seasonal variation in pH



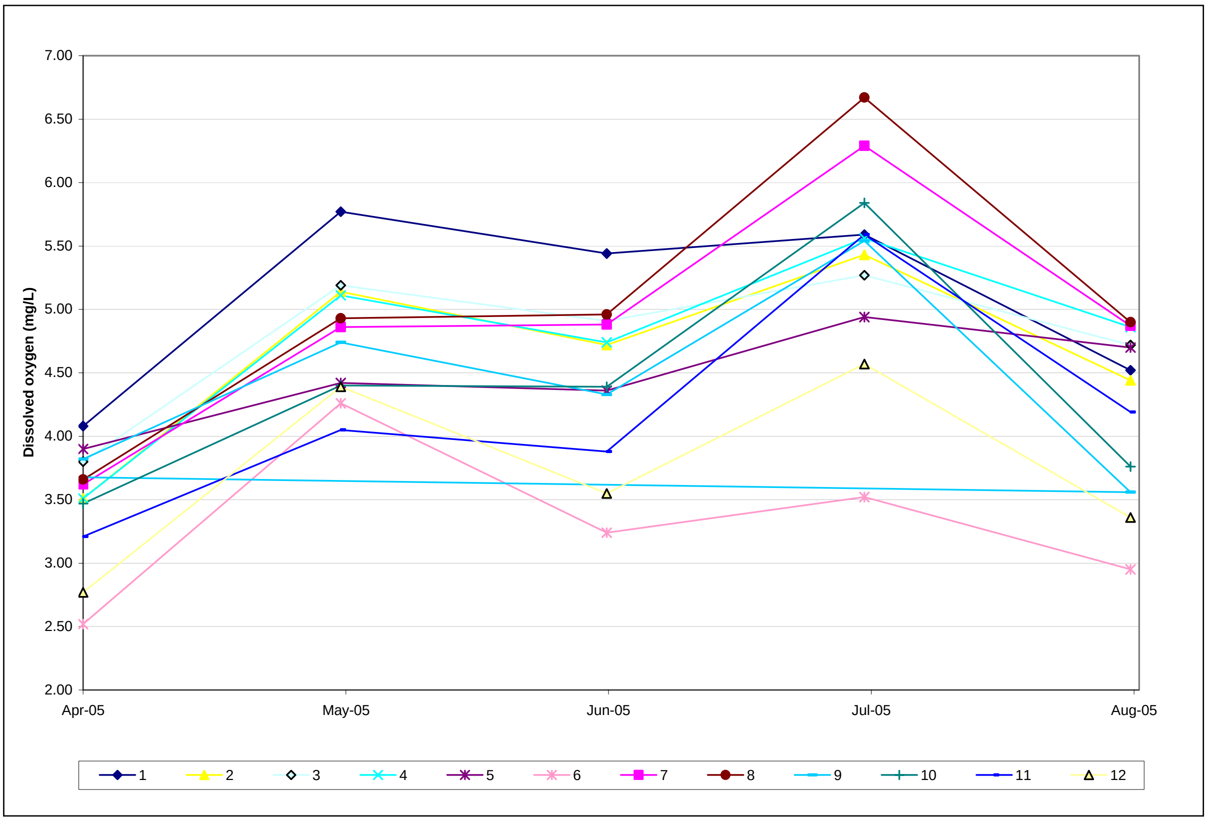
The water is always basic, with all pH values[51] in the *Yala* season higher than 7. This reflects the basicity of the soil (pH in Kachchigala area reported to be 8.1 by Watawala *et al*. (2004)). According to the FAO standards for agriculture, water with pH in the range of 6.5 to 8.4 can be used without any restriction. In the whole season this standard limit has been violated only in two sampling points at the extreme downstream end of the ara, which are surrounded with natural vegetation. The slightly higher values in April are at the beginning of cultivation season when high concentrations could be attributed to low water flow.

(ii) Dissolved oxygen and biological oxygen demand

Dissolved oxygen shows marked spatio-temporal variations as illustrated below.

[51] Apart from one marginal value at site 2 in July

Figure 5.19: Seasonal variation in dissolved oxygen



Dissolved oxygen (DO) is at its lowest in April which can be attributed to low flows in the system before the cultivation season. DO concentrations rise during the irrigation season reaching a peak in July (when both depth and turbulence of water are at a maximum, thus increasing DO), before decreasing again in August when irrigation is stopped (15th August). According to EU standards for fisheries and aquatic life DO level should be within 5.00 – 9.00 mg/L. The low DO levels could have a negative impact on the aquatic flora and fauna, but this cannot be directly attributed to irrigated agricultural practices[52].

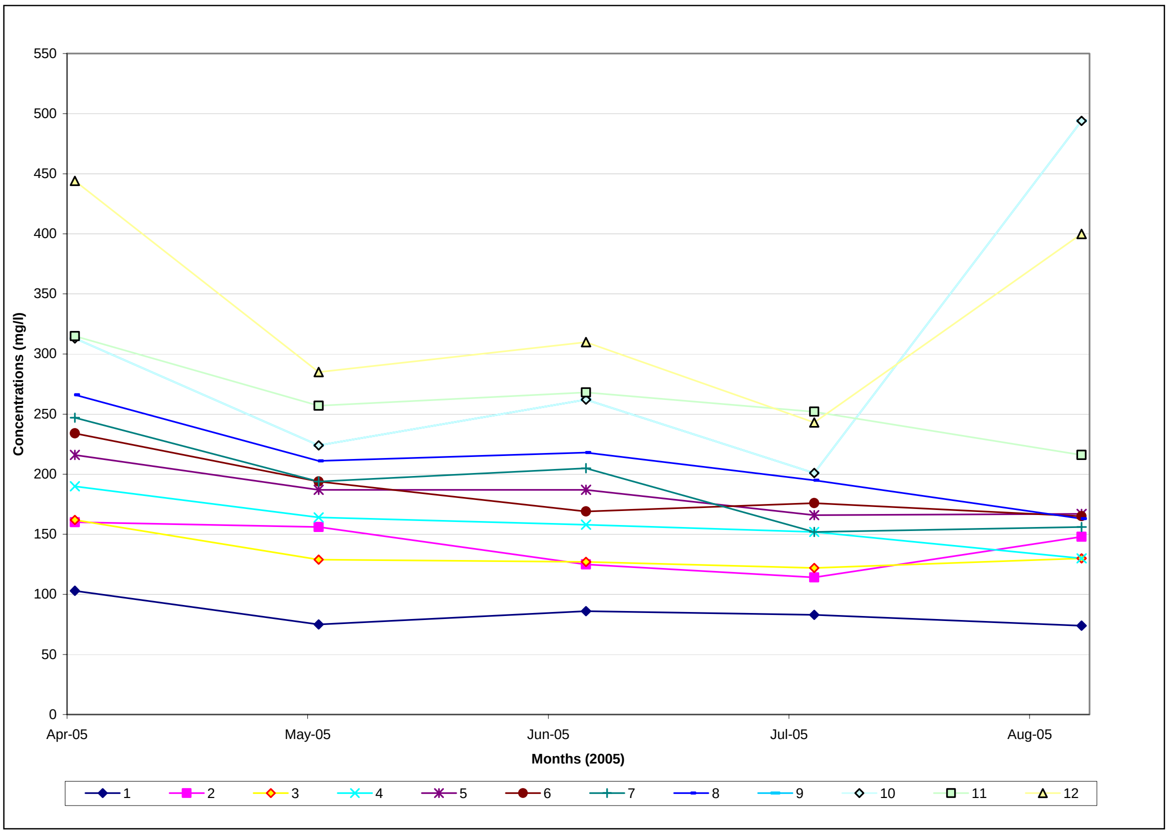
Biochemical oxygen demand (BOD) follows a similar pattern. The proposed ambient water quality standards for inland water in Sri Lanka indicates BOD for irrigation water should not exceed 5 mg/l, and this is only slight exceeded twice, i.e. at the sampling points 5 and 9 in the month of June. July values are quite interesting when compared to the amount of bacteria found – it is curious that BOD show concentrations are very low when some sites show incredible numbers of coliforms.

(iii) Salinity

Salinity as measure by total dissolved solids (TDS) and electrical conductivity (EC) is fairly uniform.

[52] the natural flow in the *ara* is strongly influenced by the old tank cascades which intercept and store natural runoff. There were thus very low or zero residual flows in the *ara* in the dry season. Water sampled in April represents the slow seepage of anoxic drainage water into an otherwise largely dry *ara*. Thus without the irrigation system there would be no water, with the irrigation system there is a small anaerobic flow. Flowing water with adequate DO could only be achieved by dismantling the ancient tank cascade as well as closing down the modern irrigation system

Figure 5.20: Seasonal variation in salinity



Values obtained by TDS measurements show uniform behaviour through out the season, and all values are low (typically 100-300 as compared to a standard of 1000 mg/l for irrigation water), although with some variations between sampling sites. In general, April shows slightly higher values than the other months, which may be because of the higher concentrations due to low flows at the beginning of the cultivation season. The high values in August for site 10 and 12 showing a different behaviour than all other sites may be attributed to the low flows exacerbated by the location at the tail of the system. No significant relations can be made with agricultural practices.

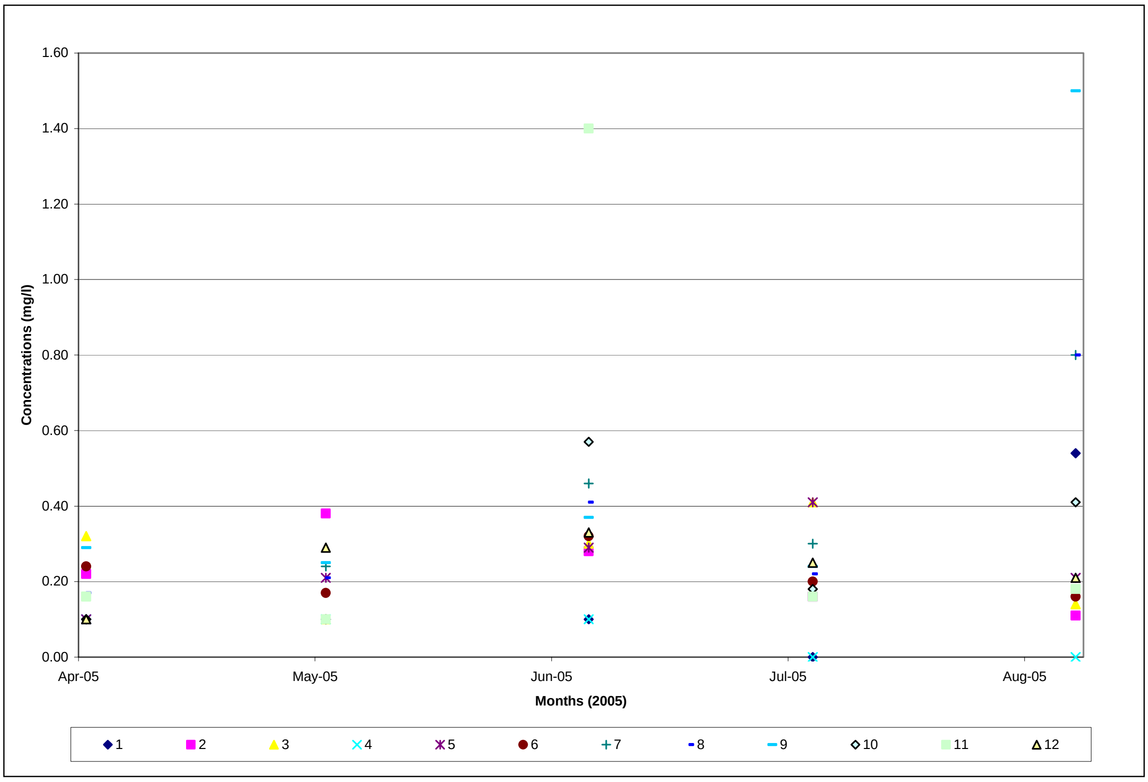
(iv) Nutrients

Nutrients (nitrogen and phosphorus compounds) have been monitored, with nitrogen in the form of nitrates, nitrites and ammonia, and phosphorus compounds as total phosphates and orthophosphates.

None of the nitrogen compounds show significant variations during the monitoring campaign. All values seem to be very low and uniform with no particular temporal variation, in every form studied. Nitrate levels are lower than the values given in WHO guidelines for drinking water, FAO guidelines for agriculture and the Sri Lankan proposed guidelines for bathing, fish, aquatic life and irrigation There are some slight spatial variations, particularly in nitrates which can be attributed to the type of fertilisers applied and of the nitrogen cycle in which ammonia and nitrite are transformed into nitrate by means of the nitrification processes.

In April, the highest concentrations were in the sites upstream of Metigathwala Wewa, the area where land preparation for paddy started first. In May and July nitrates were detected throughout the catchment at extremely low levels, a pattern that is likely to be a result of urea applications in both those months. By June, nitrate concentrations had reached their highest levels in waters within the lower catchment, represented by site 10 (most downstream site on the stream) and in the most downstream receiving waterbody, Kalametiya Lagoon (site 11).

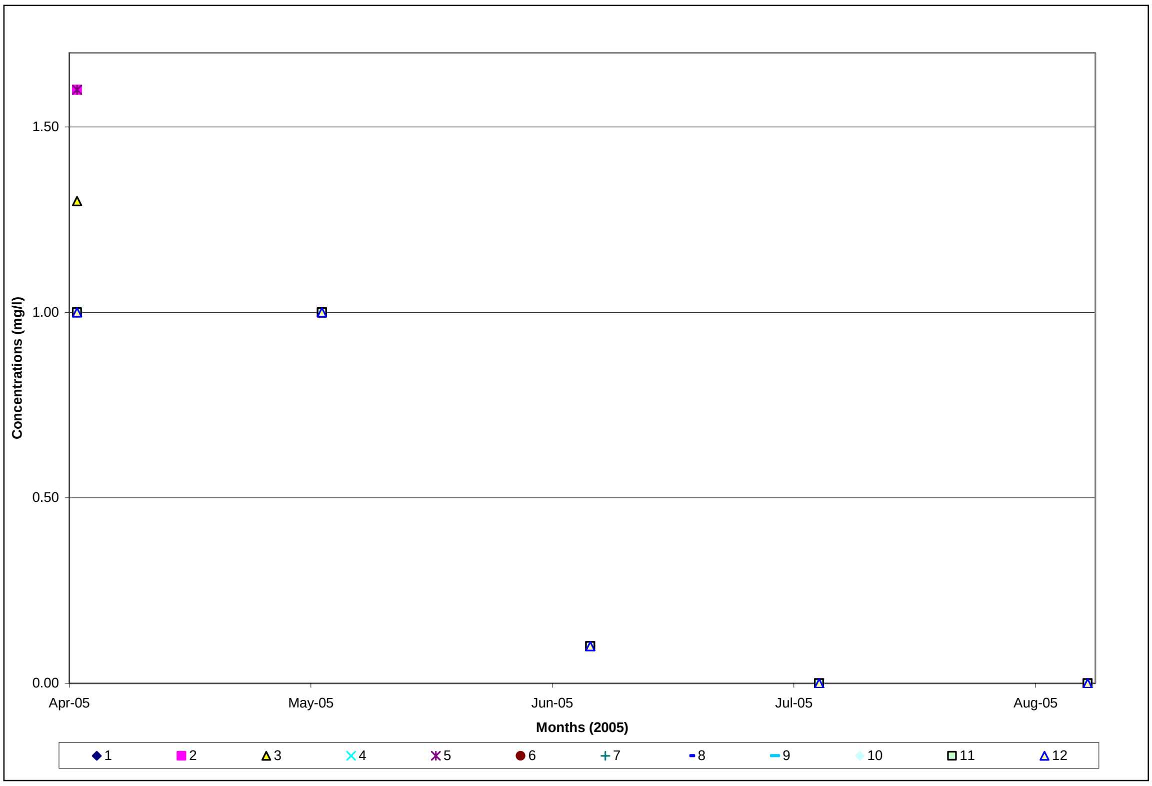
Figure 5.21: Seasonal variations in nitrates



Phosphate shows a totally different behaviour. All the values are high in April and gradually decrease until reaching very low values in July. Phosphate obviously shows a temporal variation affecting all the sites. It is however, not easy to relate this to agricultural practices since the concentrations are highest in April before the start of the agricultural season – this is probably due to domestic uses of scarce water resources, which are diluted later in the season.

The level of orthophosphate was always lower than the detection level. The total phosphate levels in April ranged up to 1.6 mg/l respectively, but Sri Lankan standards for potable water allow a maximum TP level of 2.0 mg/l.

Figure 5.22: Seasonal variations in phosphates



A reason for the low or undetectable levels of nutrients could be the high nutrient removal rate of macrophytes in the tanks and drainage canals.. Dissolved nutrients could be easily absorbed by the aquatic plants. These macrophytes may also be acting like buffer strips in catchments of the tanks which are very effective in reducing nutrients in agricultural drainage water that may reach the Kalmetya Laggon acting as the outlet of the system. Anecdotal evidence suggests that higher levels of nutrients were present in the lagoon prior to the tsunami which completely scoured out the lagoon.

(v) Pesticides

No pesticide residues were observed in water in the month of April. But in June, in the middle of the cultivation season Chloropyrifos, Dimethoate, Diazinon and in July Captan, Phenthoate, Profenophos were detected in water samples at levels below the limit of detection (Table 3.1). Captan and Profenofos are a fungicide and an insecticide respectively, which are used exclusively for vegetables, but the others are used as pesticides in paddy cultivation (although Diazinon is also used for vegetables).

Significantly, in July, Profenofos was detected at 6 µg l^{-1} at site 9, a drainage channel concentrating diffuse return flows from irrigated paddy in the lower catchment. According to the Sri Lankan standards, the WHO/ FAO levels apply, with the observed concentration exceeding/within acceptable limits.

There are several reasons why agrochemical residues were relatively low and in the most part unquantifiable in water. The new generation of pesticides reflected in the results below are deemed

highly degradable, and more than three months had passed between the first sampling event and the last pesticide application of the previous cultivation season. Photo-degradation and microbial activity can be considered high in tropical countries such as Sri Lanka, accelerating the breakdown of agrochemicals. Furthermore, the application of pesticides did not occur at the same time for all paddy and other crops in the study area.

Table 5.24: Pesticides detected in the water samples in Kachchigala *ara* catchment

Sampling point	Month	
	June	July
1	none	none
2	Dimethoate, Diazinon	Captan, Pherthoate
3	none	Phenthoate
4	Dimethoate, Diazinon	Diazinon
5	Chloropyrifos, Diazinon	none
6	Chloropyrifos, Dimethoate, Diazinon	none
7	none	Dimethoate, Diazinon
8	Dimethoate, Diazinon	Dimethoate, Diazinon, Captan
9	Diazinon	Profenofos
10	none	Dimethoate, Diazinon
11	none	Dimethoate, Diazinon

Organochlorine (OCs) residues were found in two out of nine fish tissue samples (in *Tilapia* which are imported species and a valued food source for local people) were positive for OCs in Methigathwala Wewa. No pesticides were found in other types of fish, molluscs and crustaceans. OCs were found in both sediment samples. The OCs recorded are no longer used in the area (and DDT was historically used for malaria control, not agriculture). The precise route by which OCs entered the food chain is not clear, particularly since the tank was rehabilitated (involving desilting the bed and clearing peripheral vegetation) in 2003 and is restocked annually with fingerlings. However, DDT is known to be very persistent and was presumably stored in the sediments – and may have been exposed by the rehabilitation. No pesticide residues were found in aquatic fauna for the downstream-most site on the Kachchigala Ara.

Table 5.25: Detected amounts of Organochlorines in fish tissues

Organo chlorine residue	Amount present (mg/kg)	
	Sample 1	Sample 2
Heptachlor	0.003	ND*
DDE	0.003	ND
DDT	0.010	0.002
DDD	0.001	ND

*ND – Not Detected

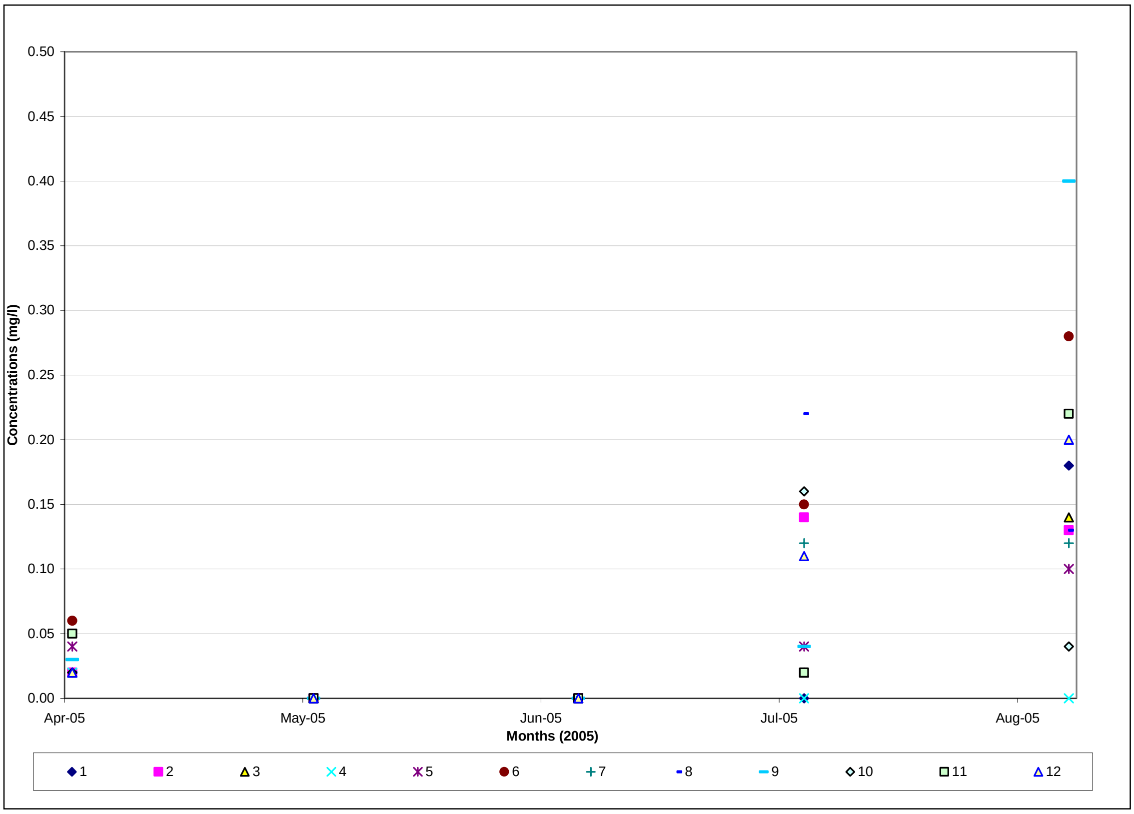
Table 5.26: Pesticide residues in sediments –

OC	Method	Site 4	Site 10	Limit of detection
		(mg/kg)		
p.p' DDT	GC (ECD / MS)	0.04	0.08	0.004

(vi) Metals

The majority of metals studied during the monitoring campaign in Sri Lanka are not detected through out the whole season. But, results observed for the manganese are very interesting.

Figure 5.23: Seasonal variations in manganese



Nevertheless, manganese concentrations through out the monitoring campaign show an increasing trend for all sites with some values over the drinking water limits[53]. Manganese show clear temporal variations on concentrations. We will consider spatial variations in section 5.4.2 in order to establish if there are any relations between agricultural practices and manganese concentrations. First, this metal is often assocated with iron in the natural environment where soil geochemistry facilitates the dissolution of both manganese and iron[54], and bacteria present in low flow waters can oxidize or reduce dissolved metals as sources of energy. Second, manganese may be present in fertilizers applied

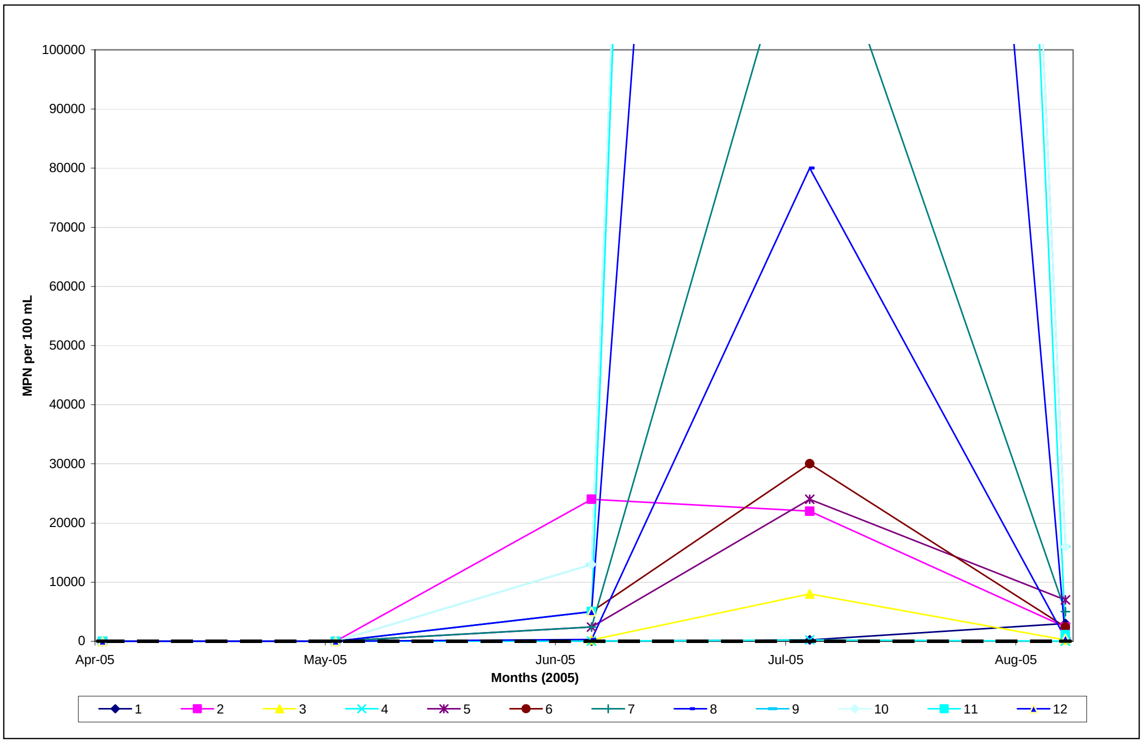
[53] manganese concentrations have not been analysed in May and June - nil values observed correspond to 'no data' and not absence in sampled water.
[54] In the absence of data on iron concentrations we cannot evaluate the importance of this factor

on cultivated fields.. Manganese does not represent a direct threat towards drinking water standards but further studies would be necessary to confirm the source of manganese.

(vii) Bacteriological

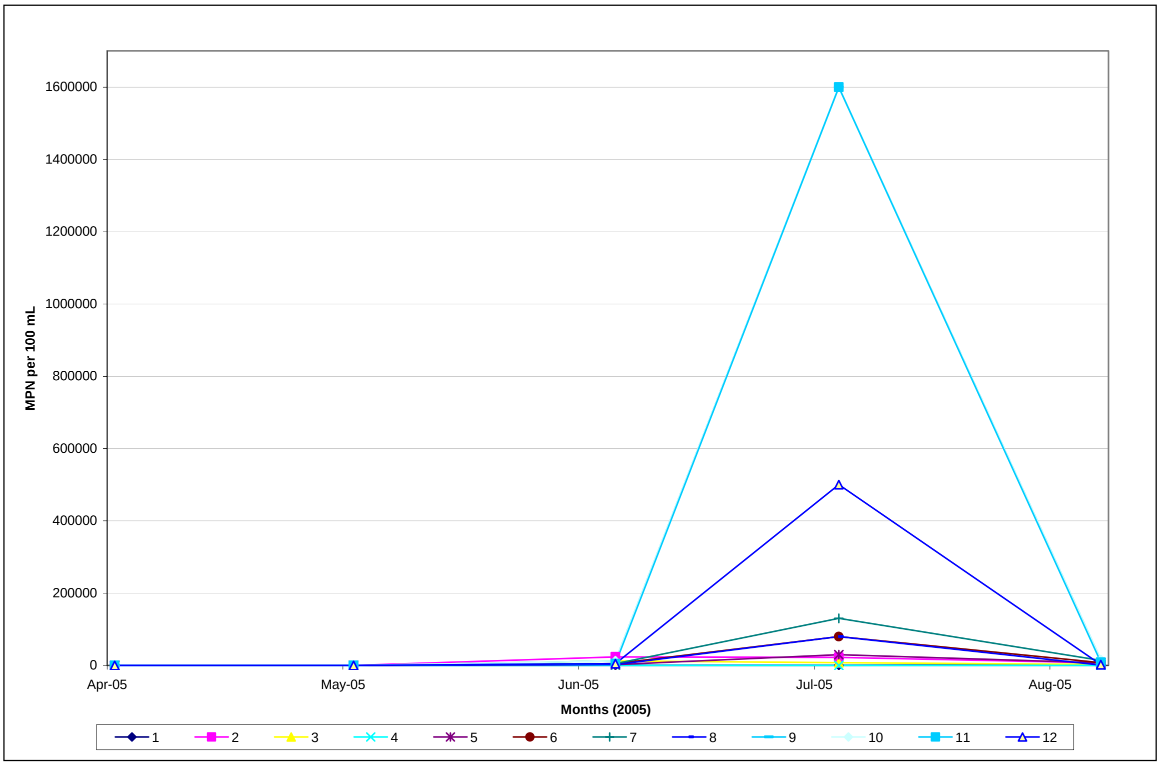
Bacteriological monitoring was again done through analysis of faecal and total coliforms in samples. There are some limitations in the data (only presence or absence was recorded in april, and in several samples the same numbers of faecal and total coliforms were recorded which mean that all coliforms are of faecal origins, whereas realistically total coliforms values would be higher than faecal values). Nevertheless the results are interesting results when data is obtained. The graph should be interpreted with care, since the April and May results appear as zero, whereas they should represent no data.

Figure 5.24: Seasonal variations in faecal coliforms



The very high values detected in July mask the high values in July on the graph due to the scale used, even though values detected were over 2000 counts per 100ml. The period between May and August corresponds to hottest and driest period of the year, when people are most dependent on the canal system for domestic purposes and bathing. However the values observed in July, particularly for Kalametiya Lagoon and Siyambalakala *Ara* are really extreme and may be considered as unusual for such environments.

Figure 5.25: Seasonal variations in total coliforms



The source of this pollution is largely of human origin. The number of livestock is relatively small and they are a relatively minor source of pollution. This is not related to agricultural practices, but it does confirm the total unsuitability of untreated surface water for drinking purposes.

5.4.3 Variation in water quality down the system

(i) Dissolved Oxygen and BOD.

Dissolved oxygen gradually decreases down the system from the entrance down to the Kalametiya Lagoon, but the change is small and concentrations are all low.

Figure 5.26: Spatial variations in dissolved oxygen

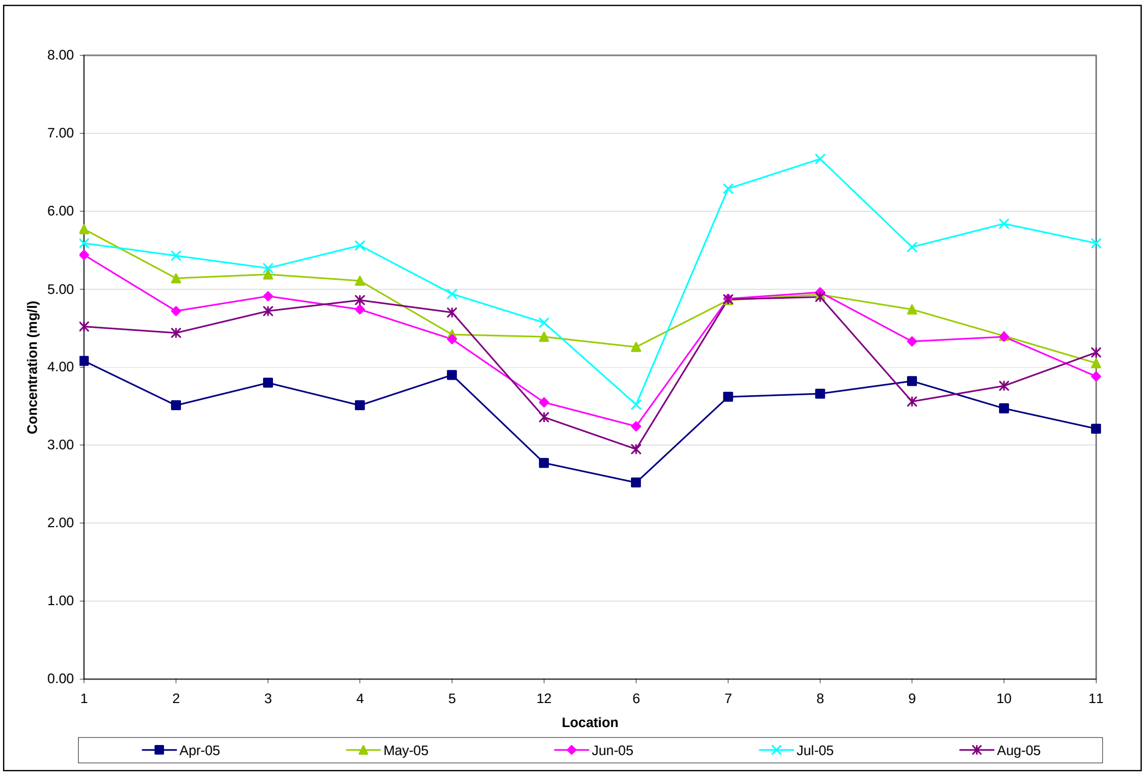
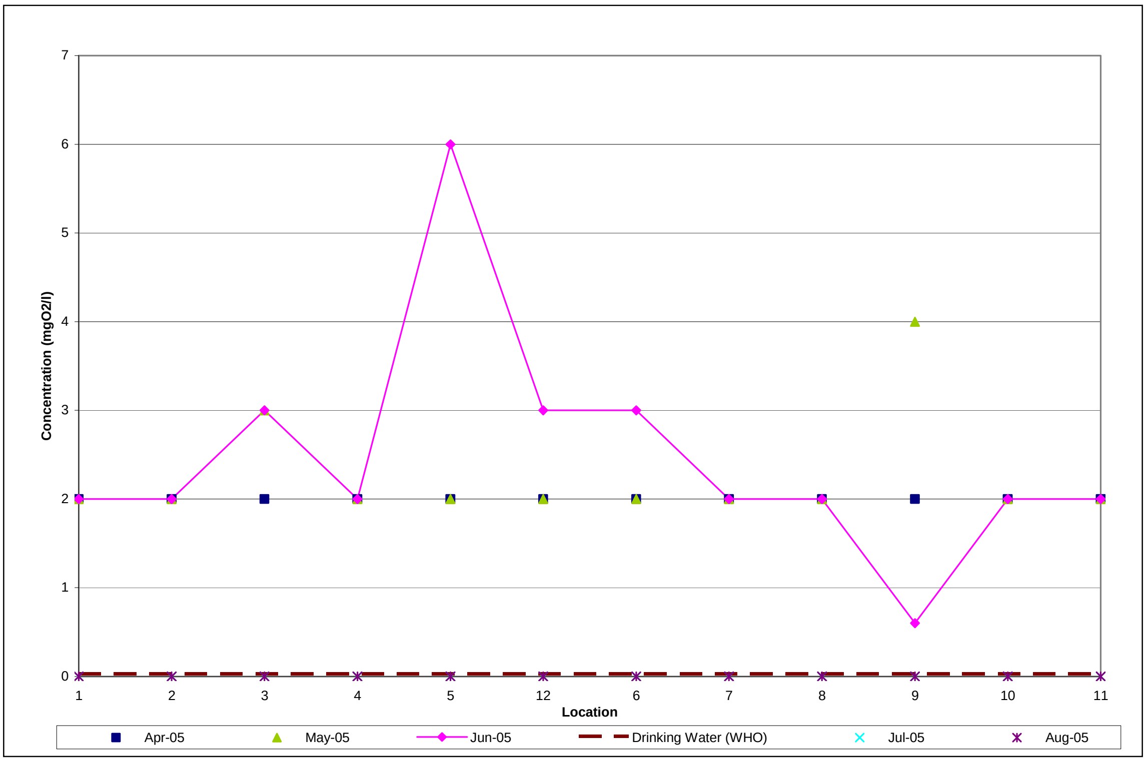


Figure 5.27: Spatial variations in biological oxygen demand

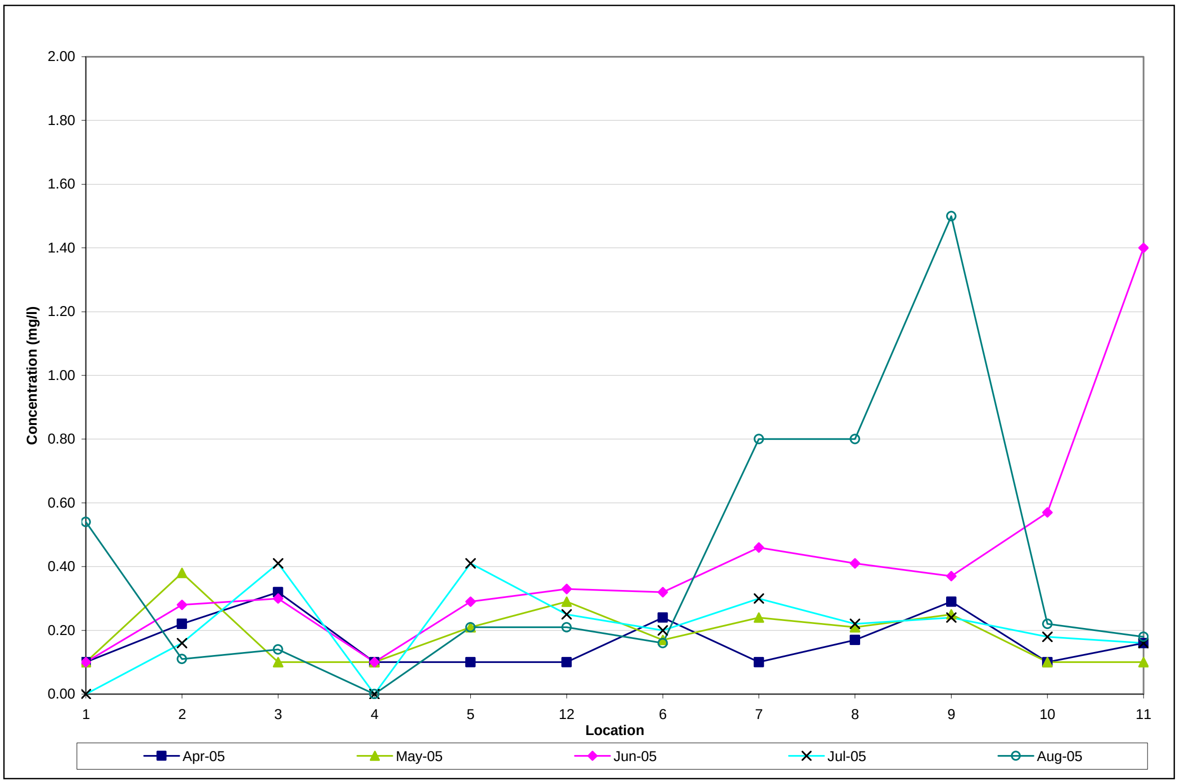


Such a decrease in DO shows that there is little reoxygenation in the system. In addition, values obtained show that dissolved oxygen is regularly consumed by living organisms in the sampling sites which is justified by uniform BOD values. The latter reveals that the majority of sampling sites may have low biological activity to the exception of some sites clearly affected in June. Such observations are more relevant to temporal variations probably involving rainfall and runoff contaminating the drains. When site 6 is considered on it's own, it shows the lower DO values whereas BOD ones are 1mgO_2/l higher than the other sites. This lack of oxygen could be attributed to the fact that this site is a tank with little oxygenation and low flow whereas it can be considered as favourable for biological activity. But site 12 located on the Siyambalukawa *Ara* show values nearly as low as site 6. These may be due to the lack of oxygenation processes due to the very low flow between the sampling site and the three upstream tanks which does not provide a good environments for re-oxygenation.

Otherwise, neither the Kachchigal *Ara* nor the other drains and canals show any extreme variations other than seasonal effects. As a consequence no direct relations can be made between these parameter and water coming out from drains. We may however remark that DO values in Kalametiya Lagoon are low compared to the rest of the system. Such values may be due to water input in the lagoon with low DO added to continuous oxygen consumption and little through flow: the lagoon is almost stagnant which does not constitute the best environment for water reoxygenation.

(ii) Nutrients

Figure 5.28: Spatial variation in nitrates



The majority of sampling sites show fairly constant nitrate values; most applications of nitrogen are in June, and this is reflected in an increasing trend in nitrates down the system, from site 6 (in the mid part of the Ara) to site 11 (in Kalmetiya lagoon). Even if nitrate concentrations remain low compared

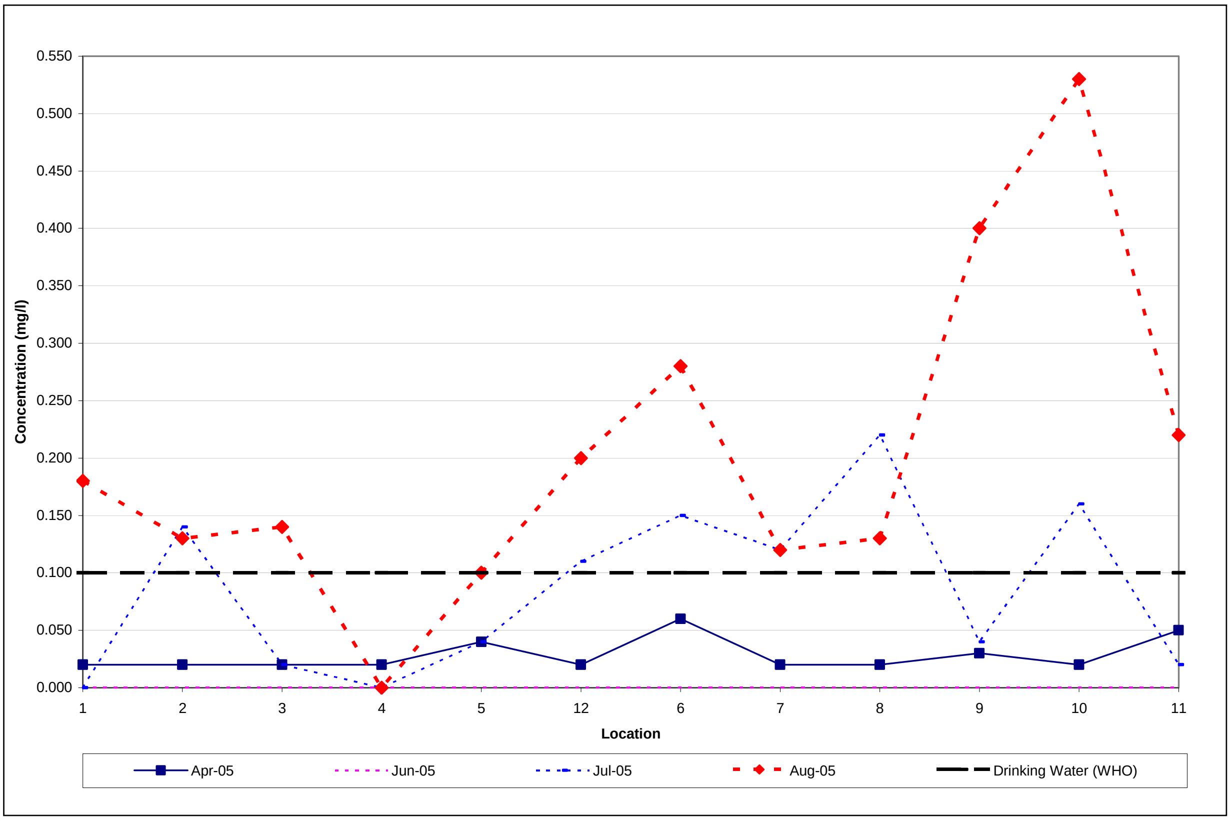
to the standards fixed by the FAO and the WHO, the slight increase of nitrate concentrations at these sites can be related to agricultural practices, and result in high concentrations in the almost stagnant lagoon.

The high values in August can be related to the end of the cultivation and irrigation season. Slightly elevated values of nitrates (and also of nitrites and ammonia) can be seen in some small drains (site 9) where there is presumably little dilution, but the concentrations at the end of the *ara* are again very low.

The concentrations and variations are very slight, but they can clearly be attributed to agricultural practices although they do not represent any particular danger to human health or livelihoods

(iii) Pesticide and Metals

Figure 5.29: Spatial variations in manganese

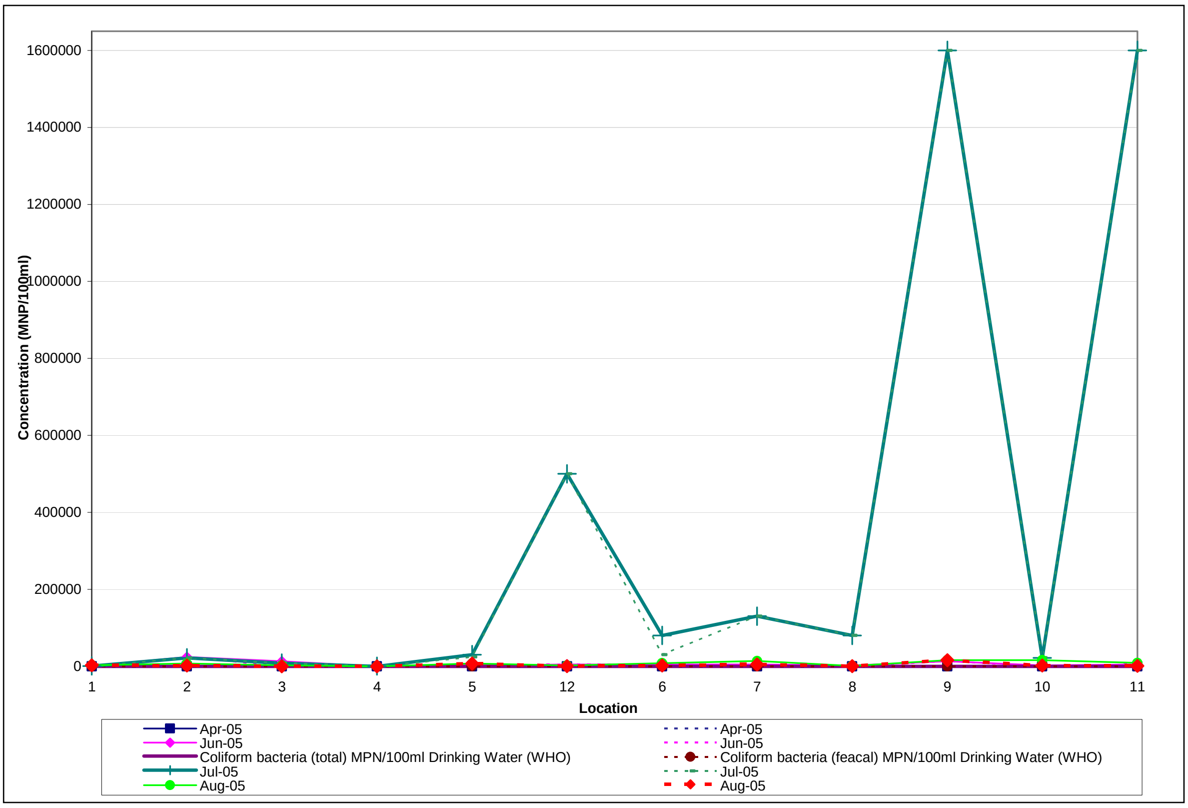


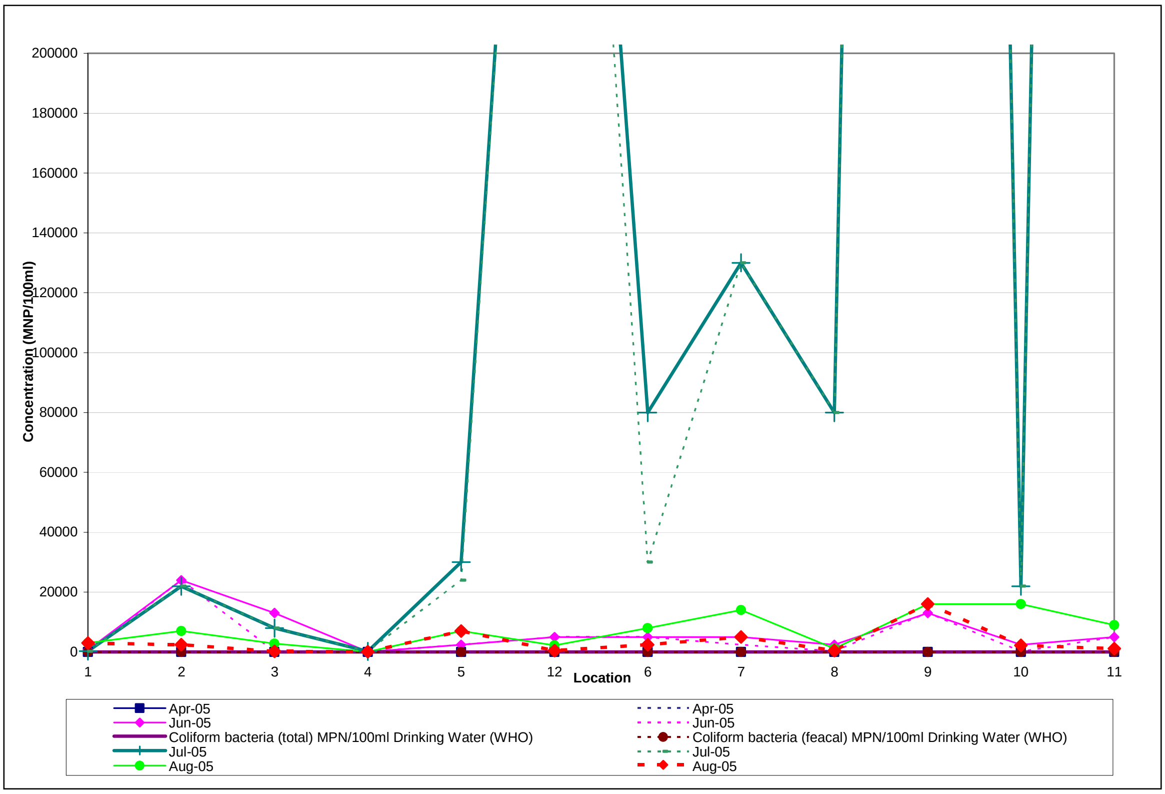
Manganese concentrations seem to be increasing during the cultivation season, and show an increase down the the system particularly in August. The concentrations observed are over the WHO limits in July and August for sites 6 to 10 and are not to be considered as immediate dangers as far as human health is concerned.

(iv) Bacteriological

The study of bacteriological parameter down the system has been studied by means of faecal and total coliforms. Results obtained show water with amounts of bacteria well above drinking water standards and not proper for direct consumption.

Figure 5.30: Spatial variations in coliforms





The above figures show the variation of total coliforms (continuous lines) and faecal coliforms (dotted lines) down the system. There is no particular trend apparent; the highest concentrations are to be found in sites with the lowest flow, and these can be related to degree of human contact – thus the small tributary channels have the highest concentrations, but these are diluted in the main ara. Extremely high values are found in July, which is a time of year when bathing in canals is likely to be very common, resulting in greatest pollution. Site 9 receives water from the extreme tail of Mamadala branch canal, and hence this water can be expected to be severely polluted by domestic uses upstream along the canal.

(v) Water quality at additional sites

For the few additional sites for which a one-off assessment was made during the main water quality monitoring programme, the water quality results are presented in Table 5-27. These were sampled in order to assess the impact of small towns, relations between surface and groundwater, and changes along major irrigation channels. On the basis of the results, it was considerd unnecessary to continue sampling as the sites on the streams exhibited similar water chemistry to the main stream sites sampled routinely throughout the *yala* cultivation season. Similarly, the additional sites on irrigation canals showed that it was not necessary to monitor other such sites on an ongoing basis. The canal water quality was of consistently higher quality than water within the drainage network, for instance in cation and anion (salt) concentrations, TDS and nitrate concentrations. Importantly, faecal coliforms and *E. coli* were present at all sites including wells used for domestic water. The two wells, which reflected shallow groundwater conditions, did not show particularly high nutrient, BOD or COD levels, but the waters contained higher levels of salts than the natural streams and irrigation canals.

Table 5-27: Water quality at additional baseline sites in the Kachchigala Catchment.

		Results						
Variable	**Units**	**Sample 101**	**Sample 102**	**Sample 103**	**Sample 104**	**Sample 105**	**Sample 106**	**Sample 107**
pH	%	8.70	7.45	8.46	8.75	8.46	8.01	7.91
Turbidity	NTU	0.8	8.1	22.0	0.6	3.2	1.4	1.3
TDS	mg l^{-1}	2560	292	215	547	105	102	493
TSS	mg l^{-1}	29	7	43	< 2	19	3	3
Cl^-	mg l^{-1}	1008.0	32.0	18.1	21.0	5.2	6.2	73.0
Ca^{2+}	mg l^{-1}	290.0	34.1	26.5	30.7	17.8	17.0	84.0
Na^+	mg l^{-1}	667.0	80.0	51.0	180.0	6.7	6.7	103.0
K^+	mg l^{-1}	7.5	10.6	9.4	4.8	15.0	14.0	12.7
Mg^{2+}	mg l^{-1}	191.0	13.5	11.5	15.0	5.6	5.9	17.7
SO_4^{2-}	mg l^{-1}	50	64	37	15	< 10	< 10	18
$CaCO_3$	mg l^{-1}	359	141	144	444	80	95	249
Mn	mg l^{-1}	41.00	0.10	0.03	0.02	< 0.02	< 0.02	0.12
Zn	mg l^{-1}	0.10	0.20	< 0.02	< 0.02	0.02	< 0.02	< 0.02
NH_3	mg l^{-1}	0.32	< 0.02	0.04	< 0.02	< 0.02	< 0.02	< 0.02
Nitrate (as N)	mg l^{-1}	0.29	0.15	0.24	0.13	< 0.10	< 0.10	0.16
Nitrite (as N)	mg l^{-1}	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Orthophosphate (as PO_4)	mg l^{-1}	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Total Phosphate (as PO_4)	mg l^{-1}	< 1.0	< 1.0	< 1.0	1.2	1.5	1.4	< 1.0
COD	mg O_2 l^{-1}	15	17	15	13	6	13	5
BOD_3 at 30 ^{0}C	mg O_2 l^{-1}	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Coliforms (per 100 ml) (MPN)		Present	Present	Present	Present	Present	Present	Present
E. coli (per 100 ml) (MPN)		Present	Present	Present	Present	Present	Present	Present

5.4.4 Relationship between water quality and agricultural practices

Pesticide residues are largely absent in sampled waters – with just traces detected at certain times and locations, so it is not possible to relate spatio-temporal variations with agricultural practices. However, the agricultural studies do show that pesticides are widely used in the study area and water samples were found to contain traces of some of the types of pesticides known to be applied (section 5.2 Tables 5.23, 5.24 and 5.25). Metals in water could also be closely related to pesticides applications as they are often constituents of the pesticides themselves, however this was also not detected in this study.

When nutrients are analysed in the study area, nitrogen compounds show some relationship to the time and locations of applications although concentrations observed remain low throughout the water quality monitoring campaign. The presence of nitrogen compounds in water can be attributed to agricultural practices, but their effects on water quality remain low and no immediate dangers are to be pointed. The nitrogen balance presented above indicates that theoretical nitrogen concentrations should be higher than those recorded: it is thus likely that a more frequent sampling programme would

detect occasional higher concentrations. The variation in nitrate content was compared with fertilizer applications during the *yala* cultivation season. According to the crop calendar (section 5.1.3), the timing of urea applications coincided entirely with the increases in nitrate concentrations in June-July. The high value of nitrite in the month of May (site 12) could be attributed to the application of urea and its conversion to nitrate.

Bacteriological parameters are obviously the major concern in terms of water quality, but the high numbers of coliforms present in water can not be attributed to agricultural practices but more to human activities and livelihoods. Waste water discharge in drains, bathing activities and livestock present in the immediate environment of the drains can be considered as the major sources of bacteriological contaminations which also is the main threat when human health is concerned.

Kalmetiya lagoon is located at the downstream end of the system and receives all drainage water. Given its location and its lack of regular throughflow, its status may be endangered on long term basis by nutrients and sediments from drains.

5.5 Livelihoods

5.5.1 Introduction

Focus group discussions were held in a total of eight villages, which fall into eight Grama Niladari (GN) Divisions, in three District Secretary (DS) Divisions and two Districts (Table 5.28). The total number of households in these villages is recorded by the GN offices to be around 3124[55] with a total population of 11,693 .

Table 5.28: Administrative area in which FGDs were conducted

District	DS Division	GN name and number	Village name	Number of families
Rathnapura	Embilipitiya	Rathmalvila	Rathmalvila	175
			Kachchigala	16
		Hingura	Thoragala	624
			Kachchigala	273
			Hingura	118
Hambantota	Angunakola-palassa	Uswewa	Uswewa	299
		Amarathungagama	Amarathungagama	153
			Athapathugama	92
			Vijesinhagama	73
		Matigathwala	Matigathwala	176
	Ambalantota	Hadunkatuwa	Hadunkatuwa	15
			Gamaralagama	108
			Walasgala	236
		Mahajadura	Wadumesthrigama	66
			Vidanagama	9
			Mahajadura	247

55 A slightly lower figure of 3036 is provided by the District Secretary's offices in Angunakolapalassa and Ambalantota.

District	DS Division	GN name and number	Village name	Number of families
		Ihalagama	Ihalagama	339
			Pattamaluwa	73
			Kiribath aragama	32
		Hungama	Hungama	175
			Medaeliya	60
			Tuduwa	180
Total				3,539

Source: Domestic member lists in the GN offices

(i) Income generating activities

The study area is predominantly agricultural land with the majority of the population being involved in some form of agriculture either as paddy farmers, *chena* farmers, livestock owners or agricultural labourers. In certain areas where there are large tanks or *kalapuwas* (lagoons) fishing is also an important livelihood activity. In many cases households will be engaged in more than one of these for example cultivating their own or leased land, undertaking daily agricultural labour and fishing for subsistence. In some household different income generating activities will be undertaken by different members of the family, for example men may cultivate their own land while women go for wage labour, whilst in other households individual family members may be engaged in multiple activities to ensure an adequate income.

According to statistics provided by the GN and corroborated in wealth ranking exercises, a large number of families in the villages studied depend on agriculture or agricultural labour for their main household income. Though farming is predominantly paddy farming, families are also engaged in *chena* and other farming activities (**Error! Reference source not found.**). The figures collected from the Grama Sevaka may even under estimate the number of families depending on agriculture and agricultural labour as 12 percent of the households "depend on their son and daughter", are "retired" or "depend on parents".

Table 5.29: Number of households involved in agriculture and labour

G/N Name	Selected villages	Total farmers: paddy, chena, other		Labourers		Total number of households[56]
		Number	Percent	Number	Percent	
Amarathungagama	Amarathunagagama	98	67	22	15	146
	Uswewa	32	86	1	3	37
Hadunkatuwa	Hadunkatuwa	7	54	2	15	13
	Walasgala	133	74	29	16	179
Ihalagama	Ilhalagama	11	20	19	35	54
	Kiribath aragama	6	30	2	10	20
	Pattamaluwa	22	30	21	29	73
	Peneriyagama	8	57	4	29	14

[56] This figure may not be identical to that provided by the GN or DS as it does not include households that are no longer in the village and only covers those households ranked by the community in the wealth ranking.

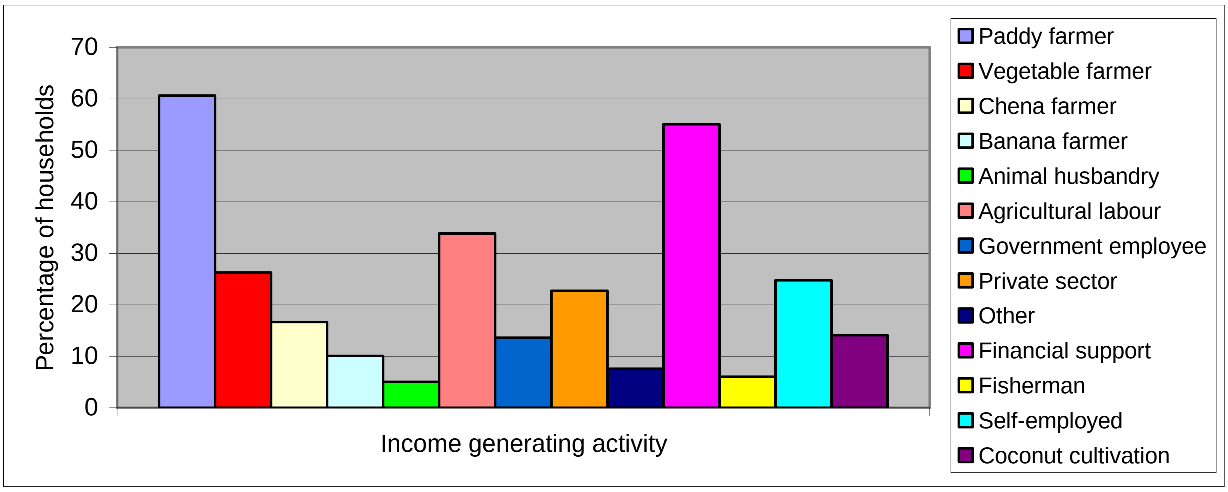
G/N Name	Selected villages	Total farmers: paddy, chena, other		Labourers		Total number of households[56]
		Number	Percent	Number	Percent	
Mahajadura	Mahajadura and Wadumeysthigama	108	76	13	9	143
Mulana	Mulana	53	28	23	12	188
Hungama	Thuduwa	8	7	39	33	123
	TOTAL	486	49	175	18	986

Data source: Grama Niladhari and wealth ranking exercise

A study of 40 households in the five villages in which detailed FGDs were conducted, showed that over 44 percent of farmers undertake paddy cultivation as their main IGA and that a further 10 percent undertaken some other form of cultivation. Furthermore over 60 percent of households derive some of their income from paddy cultivation, and 26 percent engage in vegetable, 17 percent in chena, 14 percent in coconut and 10 percent banana cultivation. Over 50 percent of the household receive some form of financial benefit either from family members or *samurdhi* (Figure 5.31).

In Thuduwa many of the families are engaged in fishing and fishing related activities but changes in the lagoon have resulted in many of them turning to agricultural labour to maintain their livelihoods. The household study found that only 6 percent of households engage in fishing as part of their livelihoods activities, with only 3 perecent considering it their main income generating activity. Of those who fished 77 percent were from Thuduwa (Figure 5.31).

Figure 5.31: Income source for households interviewed in the project area



Source: Household survey, 2005

(ii) Wealth Conditions

Wealth ranking was undertaken with the communities identified to be using Kachchigal *ara* water, which amounted to 63 percent of the 12 villages in which research was conducted. The wealth ranking revealed that an almost equal percentage of families were considered to be rich (36 percent)

and poor (37 percent) by their neighbours but that more families were considered very poor (18 percent) than very rich (9 percent)

Analysis of the data by main livelihood activity of the household head shows that of the households categorized as paddy farming households the majority (65 percent) are considered rich or very rich while only 5 percent are considered very poor. The household interviews corroborate this with 50 percent of rich households and 61 percent of poor households engaging in paddy farming as their main income-generating activity. By contrast labourers are amongst the poorest in the villages (98 percent of labourer's families are ranked as poor or very poor by members of their village). Field data in this study confirmed that labourers are among the poorest group of people, comprising 26 percent of the very poor households. 7% of the poor households undertake agricultural labour as their main IGA. Vegetable farming is the main activity of more poor than rich farmers, whilst the opposite was true for banana farmers, however the number of households engaging in these activities as a primary IGA is very low (9 percent).

The small number of fishermen are predominantly (88 percent) poor or very poor (

Table 5.31). The even smaller number of livestock owners are, however, considered rich.

Table 5.30: Wealth categories in each village

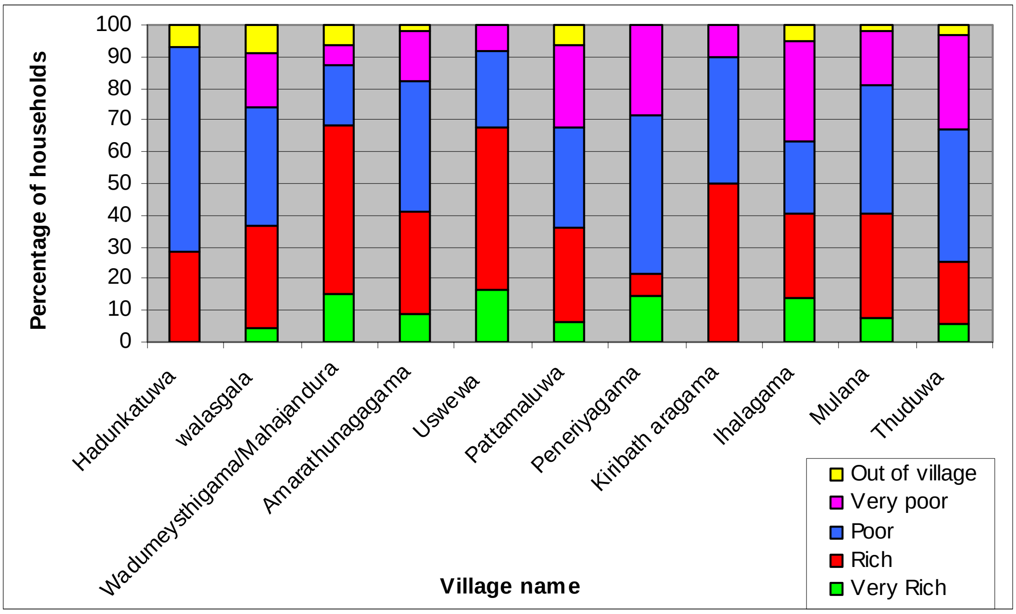


Table 5.31: Wealth rank by livelihoods activity

Main livelihood activity of household head[57]	Wealth ranking[58]				
	Very Rich	Rich	Poor	Very poor	Total
Paddy farmer	49	223	155	23	450
Chena farmer	0	1	6	1	8
Farmer	2	11	14	1	28
Retired	4	14	5	3	26
Government employee	19	38	14	2	73
Laborer	1	3	66	105	175
Private sector employee	1	12	22	2	37
Depend on children	0	3	35	22	60
Self-employed or own business	12	33	35	8	88
Depend on parents	0	0	3	2	5
Livestock owners	0	9	0	0	9
Fishing or fish trading	0	4	10	13	27
Total	**88**	**351**	**365**	**182**	**986**
	9%	36%	37%	18%	

5.5.2 Role of water in livelihoods

(i) Introduction

The diversity of livelihoods activities undertaken in the study area and the domestic water needs are supported by a number of water resources. These include the *ara*[59], canals, drains, shallow wells, deep tube wells, *wewes* and piped water supplies.

Canals are used for a variety of purposes including agriculture (cultivation and livestock), which is the dominant use, as well as bathing and other domestic purposes, but rarely drinking. In the irrigation season when the canals are filled they are the preferred source of water for bathing. They are however rarely used for fishing.

Tanks are also important for cultivation and as a source of bathing water, particularly when water is not being released in the irrigation scheme and thus the canals are dry or muddy. The tanks are often the source for drinking water supplies, sometimes from wells constructed in the tank bed and sometime from surface water (in which case it is filtered and chlorinated before delivery).

Drains are used much less than canals for domestic purposes, although the community in Thuduwa bathes in Kachchigal*ara* and also catches fish and prawns there. The main uses of drains are for agriculture (via tanks or *anicuts*), small-scale (individual) fisheries in tanks or the *ara*, and for livestock.

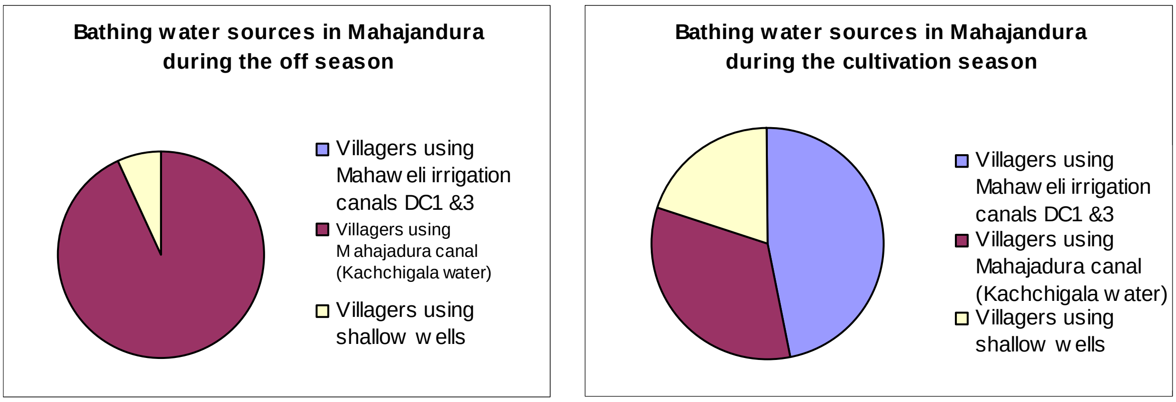
[57] Source: Grama Nilhadari office
[58] Source: Village level wealth ranking exercises
[59] this includes both the Kachchigal ara and subsidiary channels

(ii) Water for domestic needs and drinking

The irrigation canals, drainage canals and *wewes* (tanks) were constructed for irrigation purposes but are also utilized for a number of domestic purposes including bathing, washing clothes, and washing vehicles and other items such as pesticide spraying equipment. In a few cases these sources are even used for drinking but due to the government's commitment to providing safe drinking water sources this is rare. The main exception was Hingura where villagers may drink water from Chandrikawewa tank at times when water shortages are particularly severe and well water becomes saline.

The source that people use for such purposes is not static and may vary throughout the year depending on the quantity or quality of the water available. For example in Amaratungagama all FGD participants used Metighathwala tank in the off season, but no one used it in January and from April to July when there is irrigation water in the canals. Both sources are used at the start of the maha season (October-December). Irrigation canals are the preferred source of bathing water – and there are also preferences for particular canals. The seasonal differences are illustrated for Mahajandura in Figure 5.32. This village is located at the tail of distributary canals from the Mamadala branch canal and near to the Mahajandura canal which takes water from the Kachigala *ara* via an an abandoned tank.

Figure 5.32: Bathing water sources used in Mahajandura



Domestic water provision including water for drinking, cooking, cleaning and sanitation is usually from a single source. As with bathing this source may vary through the year due to water shortages and water quality but the changes are less marked.

In general the water source is also close to the homestead, being either a piped water supply, which is used by an average of 44 percent of households throughout the year and shallow wells used by an average of 39 percent (Figure 5.33). Shallow wells are usually on the homestead but some common wells also exist. Tube wells, which are used by an average of 15 percent of the families in the surveyed villages, tend to be shared by the village and many households only use them when they are not able to use their own wells or piped supply. Generally they are not the first choice because they may be some distance (100-500 m) away.

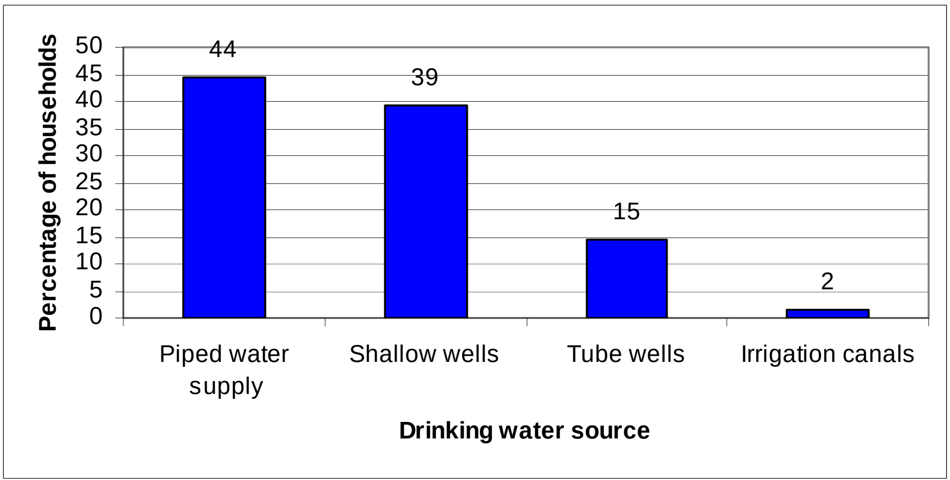
A very small number of people drink water occasionally from canals, mainly in Ihalagama, which can be expected to be of very poor quality. This is not their normal or their preferred supply, but it is the only guaranteed source: piped water is available in the village but not everyone can afford a

connection. There are no public taps and those who do not have a private connection have to take water from their neighbours, which is obviously a source of tension.

Inital FGD discussions with the community in Thuduwa suggested that around 60 households in the village drink water directly from Kachchigala Ara. However, further discussions with key informants clarified that in fact, most households have a piped water supply that was constructed some time in the late nineties (around 1999). Since then no additional households have obtained a supply as they are at the tail end, there is insufficient water, and it is too costly - instead they take drinking water from their neighbours, rotating who they collect water from so as not to raise their neighbours water bills too greatly and cause resentment. Almost all households continue to bathe in the *ara* as they do not want to waste piped water and they say that they are used to the quality of the *ara*, even if it is a little muddy.

As can be seen a number of water sources are used for various domestic purposes. The location of the village is one factor that affects which water resources are used, as is income generating activities and wealth rank. For example, unlike well water, piped water must be paid for and the initial investment to receive a piped supply can be prohibitively high for some members of the community, being around SLRS 5600 (approximately US$ 56) (Amaratungagama FGD).

Figure 5.33: Domestic water sources used in the area



(iii) Water for agriculture

Irrigation of paddy and other field crops is undoubtedly the largest water user in the area. Broadly it can be said that agricultural lands are irrigated with water

- directly from the Udawalawe Irrigation Scheme through the right bank main canal (RBMC);
- from *wewes* fed by drains from the Uda Walawe system; or
- through canals and *wewes* in a cascade system along the Kachigala *ara* and its tributary *aras*, but drainage from Uda Walawe is now the dominant source of water for these in the study area.

This system is described in full elsewhere in the report and is only discussed here in relation to the specific villages and *Grama Niladari* where focus group discussions (FGDs) took place.

Hingura *wewe* is located north west of the study area and drains into it. This tank is part of a traditional cascade system, and water is not available for most of the year. Farmers here predominantly practice *chena* cultivation, but also keep many livestock - 12 of the 17 participants own livestock. In general people here only have a few livestock which they keep on their home gardens, although a few people in the neighbouring villages of Debokkawa and Thalawe own up to 200 or more large livestock.

Farmers from Uswewa, Amaratungagama, Metigathwala and Kohobagaswewa GN Divisions all cultivate land under Metigathwalawewa tank (in the upper part of the study area), which irrigates 326 acres on which is grown paddy and banana. For the 35 households in Metigathwala village where the tank is located the main livelihood activity is paddy farming. Previously, when the tank only received water from Kachchigal *ara* they were only able to cultivate in *Maha* as there was too little water in *Yala*, however the tank now receives drainage water from the paddy fields under Mamadala canal and the right bank main canal which runs through Chandrika *wewa* and Kachchigala *wewa*. Metigathwala *wewa,* and the right bank main canal and its subsidiary canals are also used for drinking and bathing water for the cattle and buffalo owned by the people of Metigathwala.

Wadumaithreegama in Mahajadura GN division is located close to Mahajandura tank (in the middle of the study area), but most of the paddy lands cultivated by the families in this village are irrigated by two distributary canals from the tail of Mamadala Branch Canal. Although 95 percent of the households in the village have one hectare of land, water is scarce and most farmers have converted part of their paddy land and to gardens with perennial crops.

A few people in this village own land under Mahajadura tank which receives water from an *anicut* built across Kachchigala *ara.* Management responsibilities for this tank and anicut are confused and it appears that a small number of relatively rich people have exploited the situation to gain preferential access to both land and water. As water is diverted from the main stem of the Kachigala *ara*, there is an ample supply and the quality is good for agricultural purposes. The three villages are in a similar position:those that irrigate their lands with water from Mahajandura *wewa* have an ample supply but those solely dependent on Udawalawe irrigation system complain that the water supply is inadequate.

Mulana and Ihalagama GN Divisions get most of their irrigation water from Galbamma and Mulana anicuts across Kachchigal *ara – which is essentially drainage water from the Uda Walawe scheme* There are also two tanks, which receive water from paddy field drainage from Gajamangama canal and drain in Kachchigal ara. About 90 percent of the farmers also have land under the Uda Walawe scheme, but as this land is at the extreme tail of the system, they receive very little water directly from the canal system.

Thuduwa is situated at the tail end of Kachchigal *ara* adjacent to Kalametiya lagoon. Paddy farmers in this village take drainage water via an anicut across Kachchigal *ara*, as well as canal water from the tail of Gajamangama branch canal. As in the case of Mulana, canal flows are very limited, whereas drain flows are large and uncontrolled causing problems both of flooding and of water shortage. Although many people (the figure of 75 percent was quoted in the farmers FGD) in this village and surrounding area are involved in paddy and banana cultivation only around 8 percent own their own land, with the other 92 percent leasing in land. This land falls outside the area blocked out by MASL and thus has not been allocated by them to individuals (it is presumably privately owned and leased by

the landlords to the farmers). In addition farmers in this area have encroached onto lagoon land and now illegally cultivate paddy on land that is designated as a bird sanctuary: accelerated soil erosion since the Uda Walawe scheme was built has caused considerable sedimentation in the lagoon creating land that can be used for grazing livestock or for cultivation of paddy.

Although lagoon fishermen in Thuduwa bitterly resent the construction of the Uda Walawe scheme and feel that it has destroyed their livelihoods, and it would appear that it has increased the scope for paddy cultivation in the village. There has also been an increase in urban activity in the adjacent town of Hungama, creating other employment opportunities. Other major changes in the village include the closure of the lime factory in 1992 (due to restrictions on harvesting sea shells), which provided employment and a domestic water supply. Impacts of agricultural pollution thus need to be carefully disaggregated from these other changes in the same village which had around 50 houses at the time Uda Walawe was built and now contains 140 houses.

(iv) Water for livestock

It is difficult to determine the exact numbers of cattle and buffalo owned as people have cause to understate this number, particularly as it may affect their taxes and access to benefits such as *samurdi*. There are some villages such as Metigathwala where relatively large numbers are kept: discussions with individual livestock owners, the head of the farmers organization in Metigathwala and the veterinary officer in Angunakolapalassa suggest that about 50 percent of the households own 2-3 buffalo or cattle, whilst around 2-5 households per village own 200 or more large livestock. In the district as a whole, the veterinary office calculates that there are 1537 cattle and 3475 buffalo are owned by 377 farmers[60] in Angunakolapalassa (veterinary officer *pers comm.*, November 2005). Thus about 5% of households keep a few cattle and a very small number have large herds (50-100 head) that are kept locally[61]

However, in the household interviews with 22 percent of households, only 8 percent (3 households) said that they owned cattle or buffalo, with one owning between 10 and 50 and none owing more than 50. The community says that the number has declined since the construction of the irrigation scheme as there is no longer sufficient land and access to water sources, as cattle damage crops and this leads to conflict with other farmers. Consequently they say that larger herds of cattle and buffalo are kept in other districts including Hambegamuwa, Chandrikawewa and Sooriyawewa during cultivation seasons or permanently.. Livestock owners explained that they have also sold their cattle and bought buffalo as they are easier to control and do not do so much damage to field crops. Changes in agricultural practices also mean that buffalo are not needed for ploughing and are used less for transportation. Their main function in the livelihood of a household is therefore to provide milk for home consumption and sale, and to make curd earning an average of SLRS 35 per litre for buffalo milk and SLRS 15 litre for neat cow milk.

Whilst general discussions suggested that livestock ownership was highest in Amaratungagama, the households survey revealed that in the five villages studied 8 percent of the households interviewed

[60] This data is collected by the Agriculture Extension Research Assistants. The annual vaccination programme is also used to verify and amend figures. The veterinary surgeon estimates that around 80 percent of all cattle are vaccinated. He agreed that the data is difficult to collect but felt that it is 90 percent accurate.

[61] this is a traditional buffalo-farming area, but most animals now have to be kept outside the area in adjacent districts as, after construction of the irrigation system, there is no longer sufficient grazing land. Agriculture is now mechanised and so they do need to be kept for draught power

owned cattle or buffalo. The number of buffalo and cattle owners was highest in Handunkatuwa (13 percent) and lowest in Ilhalagama and Mulana (3 percent). In Hadunkatuwa buffalo can often be seen wallowing in Kachchigala Ara.

Households in Thuduwa are generally more dependent on fishing and have less money to purchase or keep livestock but the figures for Thuduwa are around the average (8 percent). Discussions also suggest that although livestock ownership is not high in the village, a number of people come from outside the area to graze their buffalo and wallow in the shallow areas of Kalametiya lagoon[62], most of these are owned by other villages. As with the other villages were FGDs were conducted there is some conflict between paddy farmers and livestock owners due to lack of land for grazing and damage to crops.

(v) Water for fishing

Fishing appears to be only a minor activity in the area with just 3 percent of households considering fishing to be their main IGA and the same number considering it their secondary IGA. Only 13 households (7 percent) said that they engaged in some form of fishing, although four only fished rarely. Fishing was undertaken in both the *ara* and the lagoon. Some fishing takes place in the tanks but it is also limited. What is noticeable is that 10 of the 13 fishing households are ranked as poor or very poor, and of the remaining three, two only engage rarely in fishing. This supports the comments in group discussions that people do not often admit to fishing as it is a low caste activity and only the poorest people fish.

According to the FGD participants from Metigathwala the tank in their village used to be famous for fish and a large number of fish traders came to this area to buy fish. At that time around 30 people fished there regularly and two fishermen could catch 60-70 kg per night. Now however there are only about 30-35 families and the average yield is about 5 kg per person, which can be sold for Rs. 50-60. There is a fisheries cooperative society with 70 members that was established in 1996, but it is not active.

Neither the reasons nor the timescale for this change are clear as the tank area or volume has not changed, it has recently been cleaned out and is restocked annually. The construction of the Walawe canals will have increased the inflow, reduced the annual variation in water levels, changed the turbidity of the water, and affected the marginal vegetation – all factors which could influence fish yield. The tank is also used for bathing, but it is unattractive for this purpose as it is muddy and awkward to access.

Thuduwa near Kalametiya lagoon is probably the village with greatest dependence on fisheries: figures provide by the GN suggest that 15 percent of households are dependent on lagoon fisheries and a further 5 percent are involved in fish trading (Clemett, Senaratna and Banda, 2004). Focus group discussions suggest that involvement in lagoon fishing is higher, with some people saying that 95 percent of households are involved in some way in fisheries, but in reality most people (around 70 percent) have moved away from lagoon fishing as a primary income generating activity and into paddy and banana farming or agricultural labour because the income from fishing is just too low. They explained that 15 to 20 years ago they had a good income from fish and prawn catches and could earn around Rs. 1500 per day but that the income now is Rs. 100-200 per person per day.

[62] the change in salinity has presumably made it more suitable for buffalo wallowing

Consequently families that depend on lagoon fishing are amongst the poorest people in the village (Clemett, Senaratna and Banda, 2004). Many people still practice subsistence fishing in the lagoon and kachchigalara.

Some fishing also takes place in other villages in the various tanks in the system and also in Kachchigal *ara* but it is limited and is usually not a primary income generating activity. None the less it is an important source of protein for many households.

Meeting with a fisherman in Metigathwala

I go fishing everyday in a canoe with my son and brother-in-law. There are about 8-10 other people from the village fishing in the tank, using 5 boats. We lay 3 deep nets of 4.5" and 3" at about 4pm and collect them in the morning. This morning we caught 10 tilapia a bit bigger than a hand. These 2 species are difficult to sell because they are only good for frying and not for curries. We get Rs 100 each for these so today my share of fish sold was only Rs 200. When there is not much water in the *wewe* we can catch a lot of fish and can make Rs 1000 but when there is a lot of water we catch fewer. There is not really a market here for indigenous fish as people prefer the introduced varieties like *catlow* and *row*. Generally we catch things like *pettiya*, *madara* and *kawaya*.

Eighteen months ago they reconstructed the bund, before that I did not fish here as the tank was very small. Some people also fish in *kachchigal ara* and the canal from Uswewa but there are no permanent fishermen in the ara, they just fish if they come to bathe there. Casual fishermen also come and fish in the tank in tires (inner tubes). The JVP fisheries ministry released 40000 fingerlings into the tank in July. They were *catlow* and *niloti*.

We bathe in the tank but when the water is very low but we don't like it as the mud at the bottom is very deep because so much sediment is flushed from the tank edges into the tank. At those times we try to use the water in the well on our land. If the mud and vegetation were removed from the tank the water would even be good enough for drinking.

5.5.3 Perceptions of quality of water sources

(i) Drinking and cooking water

Amaratungagama, Hadunkatuwa, Mahajandura and Metigathwala all use domestic wells for drinking water and all but Hadunkatuwa complain that they suffer from water shortages in the seasons when water is not available in the irrigation canals, because the ground water table goes down. These villages all complained that the water from these sources is also saline "*kivula*" as they describe it. This was also said to be the case for piped water supplies in Thuduwa, Hadunkatuwa and Mahajandura. The community complained that the salts in the water not only make it taste bad to drink but also make it difficult to cook with. When they boil water a layer of white sediment is left inside the pots or kettles, tea does not taste like it should, and lentils and rice can not be boiled properly.

The respondents in the FGDs also stated that their teeth were becoming yellow from drinking the well water (Amaratungagama, Mahajandura and Metigathwala) and the piped water (Hadunkatuwa, Thuduwa and Metigathwala). In Mahahandura they attributed this problem to fluoride in the water. In Amaratungagama, Hadunkatuwa and Thuduwa they also complained about urine and sometimes kidney problems arising from their drinking water. There is no evidence to support (or disprove) this belief but it should be noted that groundwater does have excessive concentrations of fluoride and other chemicals of geological origin, and is not generally suitable for drinking.

In Thuduwa were there complaints that the piped water supply was polluted with agrochemicals, sediment and cattle dung. They felt that this was the case because their piped water originates from

Kattakaduwa tank, which receives drainage from agricultural land, and is not adequately filtered or chlorinated.

(ii) Bathing water

Bathing water was the water use for which the greatest number of people found problems with the water sources that were available but they mostly cited problems during the dry season when water was not being released in the irrigation canals. Those people who bathe in Mahajandura canal for example, complained that they suffer from skin diseases and ulcers on their feet, which they attribute to the pollution in the now-abandoned tank which flows into the canal. All sorts of things are thrown into the tank including dead animals and empty pesticide containers; the tank also becomes full of decaying weeds. Those who bathe in the drainage canals originating from tail of the Mamadala canal. complained of water quality throughout the year as people in the upstream areas use these canals for bathing, and washing household items, tractors and pesticides equipment, as well as for watering cattle. that use the drainage canals pollute them. As a result they feel that they do not get good quality water for bathing and washing even during cultivation seasons.

In the off-season tank water levels drop and weeds start to decay giving the water a bad smell. As the Metigatwalawewa is the only perennial water source in that area a large number of people - from 500 to 800 people per day – bathe there in the dry season. The soap and detergent they use contributes to the pollution

The people of Mulana, Ihalagama and Thuduwa use the Kachchigal *Ara* to bathe in. These villages did not complain about water shortages and there is plenty of water even in the off-season, so problems relate to quality, not quantity, and are similar (but more severe) to those noted above for Mahajandura. In Mulana they mainly commented on the impact of buffalo, but did not feel that such pollution caused them any specific harm. Residents of Tuduwa, at the extreme end of the *ara*, are more concerned and they attribute the problems to agricultural pollution, as they feel that agro-chemical use has increased and that its impact has been compounded by an increase in run-off and sediment loss from irrigated land. They also cited other domestic or municipal causes, specifically bathing by pilgrims visiting Kataragama temple and people in Hungama washing their vehicles in the *ara*. Some people Ihalagama felt that water draining into Kachchigala *Ara* from tanks up-stream was significantly impacting on water quality (and hence their health) as they are full of weeds and aquatic plants which decay and pollute the water, and that dead animals are thrown in the tanks, as are other items of rubbish such as empty pesticide cans.

The bathing water quality problems are summarised in

Table 5.32

Table 5.32: Summary of bathing water problems cited in the FGDs

Amaratunga-gama	Hadunkatuwa village	Mulana and Ihalagama	Mahajandura paddy farmers	Mahajandura paddy farmers	Thuduwa	Metigathwal a
Canals+Metigat -wala tank Water shortage in off season. Far away	Mahajadura and Kachchigala Ara	Kachchigal ara	Mamadala branch canal Closed 1 day per week. Not available in off-season	Mahajandura canal (KAwater)	Kachchigal ara	Canals+Metigat -wala tank Dry in off-season
Decaying weeds Polluted by bathers	Tank polluted by weeds/waste; Canal by drainage water		Polluted by drainage water			Pollution from bathing
				Bad smell	Bad smell Colour change in off season	Bad smell due to decaying weeds
Itching, hair sticks	Itching Muddy skin Muddy clothes	Itching in cultivation season, wounds and leg ulcers		Itching and ulcers on feet Yellowing teeth Muddy clothes Hair sticks Muddy bodies	Itching, in off-season. Stomach problems if children swallow water Sticky/loss of hair .Muddy skin	Skin diseases and itching Sticky hair Muddy clothes

5.5.4 Impact of water quality on livelihood outcomes

(i) Health

The main water-related health problems in the villages studied and in neighbouring villages are communicable diseases spread through faecal contamination of water bodies and exacerbated by poor sanitation and hygiene practices. In the people of Hadunkatuwa village for example reported an e-coli outbreak in their water supply, which had been verified by the Public Health Inspector (PHI). These are unrelated to agricultural pollution, but they of much greater local significance that pollution-related disease. Insect-borne diseases such as malaria and Japanese encephalitis also occur in the area, but changes in their incidence are also essentially unrelated to agricultural pollution.

There were some reports of difficulty in passing urine, a burning sensation when urinating and kidney problems. Research in other areas of Sri Lanka is on going into the possible connection between pesticide use and renal failure however the link has not yet been proven and is much more likely to be as a result of exposure of farmers during pesticide application than through contact with polluted water (Amarasinghe, *pers comm.)*.

Discussions at the hospital and veterinary office in Angunukolapellassa suggested that some zoonoses may be of relevance in the area including leptospirosis and cryptosporidia, of which the latter can be transmitted through contact with cattle urine/faeces. However, the risk arising from bathing in drains is likely to be very small in comparison to direct contact.

There was no evidence from the study that people were suffering significant health problems as a result of drinking or bathing in water contaminated with agricultural pollutants. The only health

problem regularly discussed by the community which is likely to be caused by water quality is that of skin irrigation. However, it is difficult to say with the current data whether this relates to the presence of specific chemicals or simply high sediment loads. A more important impact following on from this, however, is that standards of hygiene might decline due to inadequate water, which could lead to an increase in diarrhoeal diseases.

(ii) Fisheries

People report a reduction in the number of species and sizes of fish, but this should be kept in context: new species have been introduced and the increased volume of water has increased the potential yield. To offset this beneficial change, some people reported that the turbidity of the water does discourage some fish species, that indigenous varieties are killed off by chemical pollutants and that the appearance and taste of fish has deteriorated. These changes are attributed to pollution of water in the tanks and changes in the tank ecosystem.

According to people interviewed in Thuduwa in the past there was extensive fishing in Kachchigal ara and there were plenty of traditional fish species such as, *Lula, Korali, Pethiya Madar*a, and *Weligoveva*, however they believe that these traditional fish varieties have declined in number because of the contamination of the water with agro-chemicals. Community members in Metigathwala belive that the changes have taken place because of the Mahaweli development and the introduction of new species such as *nailodi* and *kapi*. Fishermen in Hadunkatuwa explained that 6-7 years ago the fisheries department stocked the inland tanks with nailodi but that these were also washed into the canal system during the rains. These fish are very large and eat the eggs of other species, including indigenous species. However the fishermen are not unhappy about this as they are large fish and people are happy to buy them.

The FGD held in the residence of a fisherman in Metigathwala revealed that the community perceive that fish tasted nicer and looked a better colour in the past. Now they feel that fish look muddy, do not taste good and are small in size. They attribute all these changes to pollution of water in the tank and changes in the tank ecosystem. There is however little or no evidence from the research to suggest that agro-chemicals are having a negative impact on fish quantity or quality. The belief that the area of tanks is declining due to sedimentation and plant growth may be impacting on fisheries but Metigathwala tank, to which these comments were applied, has recently been rehabilitated and sedimentation should therefore be less of an issue. The use of illegal fishing gear and over explointation of resources, which was also cited as a problem may be impacting the numbers and size of fish caught.

A discussion held with casual fishermen in Hadunkatuwa who have been fishing in Kachchigal *ara* for eight and 12 years respectively, revealed that in their opinion the species composition in Kachchigal *ara* had not changed much but that the number of all species had declined, though they now rarely find prawn, *hiriknaya* or *welligowa*. They estimated that whilst in the past they could catch around 2-3 kg of fish in one and a half hours it would now take them a day to catch the same quantity. This they would generally consume themselves but if they caught enough fish they could make around SLRs 150-200 for 3-4 kg of fish.

6 Comparative analysis of case study sites

6.1 Water management and livelihoods

We take as a starting point that irrigation systems are designed and (largely) managed for the single objective of irrigated crop production, but recognise that they in fact serve many diverse uses both for the intended direct beneficiaries and also for others in the same area. They may also have negative impacts, either on people or on the natural environment.

(i) Uses of irrigation and drainage system

The main uses in the two case study sites, as in many other places are

- Irrigation from the canal system,
- Irrigation from return flows
- Domestic uses (bathing, washing, recreation)
- Livestock
- Fisheries (canals, drains, tanks/lakes, coastal lagoons)

Drinking water is rarely taken untreated from the canal system (and never in the case study sites), and thus is considered separately.

Methods of irrigation differ in the two areas, with basin irrigation of paddy often with flowing from field to field being the usual arrangement in KA, whereas furrow irrigation of a wide range of crops is practiced in WR. WR has a controlled drainage system, with pipe laterals and collectors discharging into open secondary drains, whereas Kachchigala *ara* relies on surface drainage and overland flow to natural drainage channels. In both cases water management is by WUAs, and is generally allocated to be proportionate to land area. Wadi Rayan is noted for its highly structured water management system which should ensure an equitable distribution of water, but it is a very arid region and there are severe shortages in some areas – partly due to excess cultivation of rice in upstream areas. Some canals are consistently short of water, such as the Faragala canal in the study area, and these people struggle with inadequate supplies, making use of on-farm storage to compensate for erratic supplies, cultivation of crops with low water requirements, or re-use of drainage water. Water management in KA is more informal but is also intended to be time-based proportionate to area. However, the soils are not well-suited to rice cultivation leading to high losses (which are higher than designed for[63]). This leads to increasing shortages down the system which are reflected in lower crop yields in the tail, but this is sometimes mitigated by reuse of drainage water.

In both cases water quality in the canal system is good, despite mixing with drainage water (by pumping from the wadi drain into the canals in Wadi Rayan, or simply by cross drainage inflows to the main canal at Kachchigala ara). Access to water by individual farmers is determined by location, performance of the WUA, and relations with the WUA.

[63] See Molle et al 2005 for a discussion of this

Irrigation by return flows is important in both sites for some (mainly tail-end) users. In Kachchigala ara. reuse is possible via tanks in some tributary drains or for land adjacent to drains where anicuts have been constructed to divert water. A relatively small area of land is irrigated in this way, and there is no concern expressed over water quality. There is much less irrigation from return flows at Wadi Rayan, largely because of its salinity which makes it generally unsuitable for irrigation. There is some pumping to irrigate land adjacent to small drains, but this is not possible from the main drains: this can be seen on the Sha'lan drain which drains the study area and then flows into the main wadi drain. Water is pumped from the drain for agriculture in the first 2 km, but not in the remaining reach to the wadi drain.

Domestic uses are important in both places: household water supplies are limited and thus many people use canals for washing clothes and utensils, and for bathing and recreational swimming. Drains are also used – particularly in Kachchigala ara, but they are much muddier and less attractive sites than canals for such purposes. Domestic use of canals is officially discouraged in Wadi Rayan because of the risk of contracting bilharzia, but is still practiced by some people. The drains tend to be too saline and too steeply incised for this to be an option.

Most households in Egypt have a few cattle which they water in the canals (and more rarely in the drains, for the same reasons of difficulty of access). They are an important part of most households livelihood strategy – they are used as draught animals and for milk – and a significant part of their cropping is to grow fodder for them. Cattle are much less important for most people in Kachchigala ara, where perhaps 5% of households own any large livestock – lack of grazing land being the main reason. A small number of people keep relatively large numbers, with herds of up to 500, but these are usually kept out of the irrigated area except in the periods between cultivation seasons. They wallow in tanks and drains, and are kept for their milk (for curd production). The dung is used as manure, but agriculture is largely mechanised (apart from some tasks which are done by hand).

Fisheries are not very important in either area, but fishing is an activity which poor farmers can do to supplement livelihoods. Some are members of fisheries societies, but these are confined to specific villages (Wadi Rayan lake fishermen all come from the village of Kahk, and in Kachchigala *ara* there are only licensed fisheries in Methigatwala wewa and Halekada wewa). In addition, many people fish on a casual basis in canals or drains. The productivity is low: in Egypt measures to control the snails responsible for bilharzia transmission have reduced fish numbers, but in Sri Lanka fish numbers are relatively high and an increasing number of generally poor people catch them occasionally. Fish species have changed recently – attributed to reduced salinity at the tail of the system, and to cleaning / restocking of tanks. There is a small community which is dependent on the lagoon fisheries which have changed fundamentally since construction of the irrigation system 40 years ago which turned the brackish lagoon fresh.

(ii) Drinking water in irrigated areas

Untreated surface water is unsuitable for human consumption but this is mainly because of its bacteriological quality rather than agricultural pollution. In both Egypt and Sri Lanka, the governments have a policy of supplying safe drinking water to the entire population. People do occasionally drink from canals as well as other surface sources, but no one in the study areas now depend on this as a main or regular source of water (even in the dry season).

Surface water – including agricultural drainage – is, however, used as source for drinking water supply schemes (for example at Eraminyaya in Sri Lanka), and canal seepage can also recharge aquifers which are tapped for drinking. Natural filtration makes such water relatively safe, but some wells are extremely shallow and in direct hydraulic connection with paddy fields in Sri Lanka and can be expected to be of poor quality. Other wells have poor quality for reasons of geochemical origin (salinity, fluoride). We should not expect such sources of water to meet drinking water criteria. If they are used, they should meet appropriate standards as a raw water source for drinking water and then be treated in an appropriate way.

Surface water sources are inevitably used for domestic and recreational purposes in hot climates – even in those places, such as the Fayoum, where these should be strongly discouraged to control bilharzia. Improvements to domestic supplies will gradually reduce the need for washing and bathing in canals and drains, but in the short term this is an important use of canals and drains in Sri Lanka (especially for the poor). Access to ample water is important for hygiene and can be expected to have a positive impact in reducing faecal-oral diseases. Such water should meet standards for bathing water, which are less stringent by a factor of ten than drinking water standards[64]. The difficulties or measuring pesticide concentrations at this level will make it difficult to monitor compliance. Even though bacteriological water quality is far more important in the short term, measures should be taken to ensure that pesticides in bathing waters are minimised.

(iii) Livestock

Livestock are both potential causes of water quality problems and sufferers from poor quality, although in both study sites they are not important in either context. Small numbers are kept by almost all households in Egypt, and are an important and integrated part of the agricultural system being used for draught power as well as a source of manure[65]. They are not kept in close contact with watercourses and are unlikely to have a significant impact on water quality since the manure is carefully stored for use on fields. Agrochemicals in the water they consume are not significant for livestock health, and earlier reports of pesticides detected in milk are believed to be caused by the method of application (particularly aerial spraying in the past). Tests of milk in this study did not reveal any pesticides in milk.

Livestock are less important for livelihoods in Sri Lanka, where perhaps 5% of the population keep cattle or buffalo. Those who do keep animals may have 50-100 head[66] and these will wallow in the drains. This will have an adverse impact on water quality and appearance, which may discourage some people from bathing in drains or put them at a slightly increased risk of certain zoonoses (eg. cryptosporidiosis, leptospirosis). The total number kept is, however, small and in the context of the volume of drainage water is not perceived to be a problem – except perhaps very locally around buffalo-wallowing points. People pointed out that cattle urine is drunk for medicinal purposes and dung is used for plastering houses – given that deliberate and direct contact, they consider indirect consumption via polluted water to be insignificant.

[64] WHO recommendations

[65] There are a very small number of larger commercial livestock enterprises in the Fayoum, but those inspected were kept far from canals and drains. Management of effluent from such places is important and should be monitored

[66] some local residents have herds of several hundred cattle, but these are kept permanently outside the study area

Cattle also cause a certain amount of damage to crops and infrastructure and there appear to be slightly strained relations between livestock farmers and others – particularly in those villages (such as Amaratungagama) where relatively large numbers are kept.

(iv) Fisheries

Fishing is minor livelihood activity in both study sites, but it is important for a small number of people. It is mainly a subsistence-level activity by very poor people who have insufficient agricultural land although there are small-scale commercial fisheries in the downstream lakes and lagoons. There is very little scope for fishing in canals and drains in the Fayoum, largely because of the accidental introduction of a species of crayfish (locally known as *stachosa*) which has reduced fish population. This crayfish is however important for controlling the snail intermediate hosts of bilharzia. There are a small number of people who are dependent on fishing in the wadi rayan lakes. They do not consider water quality to be an issue yet, and are more concerned with water level which influences both the number of fish and ease of catching them. The lakes are stocked artificially, and no problems with fish quality have been reported (or detected in this study). The situation in the Wadi Qarun lakes is slightly different, but this deterioration is attributed to municipal and industrial pollution.

Fishing is a more diversified activity in Sri Lanka. There are a small number of members of licensed fishery societies who fish in managed tanks (which are periodically restocked), and a much large number of people who fish casually in tanks and drains. Fishing is a low-status activity, and many people are not prepared to admit to doing it. However, many people fish occasionally. There have been a lot of changes due to changes in water volume, sediment load and salinity since construction of the canal system. Restocking tanks has had a significant impact in the last decade: draining, rehabilitating and restocking tanks can affect downstream fisheries for more than a year.

Water quality in the *ara* is not perceived to be a problem, but the finding in this study that organochlorine pesticides have been detected in some fish and sediments suggest that the situation is not quite so good. The pesticides in question were used for malaria control and their use was discontinued some 20 years ago, however they have been detected even in newly-restored tanks as well as in fish.

Unlike in the wadi rayan where downstream lake fisheries were created by irrigation, irrigation in Kachchigala *ara* has severely damaged the coastal lagoon fisheries – with changes in water volume, level, salinity and sediment load having a profound impact. Higher nutrient loads are also believed to cause problems of excess weed growth. Unfortunately we were unable to assess the impact on the lagoon systematically because the tsunami in 2004 scoured out the lagoon and removed much of the water hyacinth and other signs of eutrophication. The number of households involved in lagoon fisheries – perhaps 50 in 1980 - was small and many have successfully diversified their activities, but they strongly believe that upstream irrigation development has had a profound negative impact on their livelihoods.

6.2 Agricultural practices

The two study areas are very different in agricultural terms, but both are dominated by smallholder farming with largely independent choice over crops and agricultural practices. Egypt used to have more centralised control, but this has been reformed in recent decades. Cropping in Egypt is fairly diverse with a mix of subsistence, cash and fodder crops. In Sri Lanka, rice is the main crop in both

seasons but bananas are widely grown. Few vegetables or any other crops which require a high intensity of agro-chemicals are grown.

The Fayoum has been an agricultural area for several millennia and has always been irrigated from the Nile. In recent decades there has been a small area of land reclamation, which mainly relies on reuse of drainage water – some water is pumped out of the Wadi Rayan lakes for irrigation, but these villages rely on water supplied by tanker for drinking and domestic use. Agriculture in the Kachchigala *ara* is much more recent, and only became possible on a large scale in the 1970s after construction of a storage reservoir and feeder canal. This was combined with a large resettlement programme. Most of the land in the study area is owned by the government, but rights to use it has been allocated to individual farmers. Land irrigated by the smaller tanks is privately owned, although a large part of this is owned by the Mulkirigala temple who rent the land to farmers.

The governments provide agronomically-based advice on input requirements, but farmers are free to make their own decisions on input use. In both cases there are specific recommendations on fertiliser application times and rates, but there are no longer any recommendations for pesticide use. In the past, farmers tended to apply insecticide in accordance with standard recommendations rather than to suit crop needs. There used to be aerial spraying of pesticides on cotton in Egypt, but this was discontinued more than a decade ago.

Livestock are closely linked to agricultural practices: they are used for draught power and as a source of manure (as well as for meat, milk etc) – particularly in Egypt, where a significant part of agricultural land is devoted to growing fodder crops. In Sri Lanka, however, agriculture is largely mechanised and there is little grazing so only a very small proportion of the population keep cattle.

(i) Crop choice

In both countries, farmers are now free to grow the crops of their own choice[67], with some restrictions on rice in Egypt. There is a policy to encourage farmers to grow other field crops (in order to reduce water demand) in Sri Lanka but rice is still the crop of choice in the study area. Crop choice is thus governed by markets, soil type, water availability and personal preference. It is difficult for individual farmers to diversify within an area such as Kachchigala *ara* which is predominantly flood irrigated rice, but there is much greater diversity in Egypt. In the Walawe scheme as a whole, bananas are now quite widely grown and there are very few vegetables grown which reduces input use considerably. The study area, however, is not so close to the main market in Embilipitiya and is still dominated by paddy despite government efforts to encourage farmers to diversify. This situation may change in the future as the Walawe irrigation system is being extended on the left bank of the Walawe river: the existing 12,000 ha is being doubled – even though there is little or no surplus water available. This may lead to greater crop diversification in the Kachchigala ara.

Yields in Kachchigala *ara* have been fairly stable for the past decade. Fertiliser use is still below recommended levels. There is no further scope for land reclamation within the study area, although there may be minor encroachment in some tail-end areas. Yields have been increasing in Fayoum and there is unlimited land available for reclamation: water is the limiting factor. Choice of crops is changing faster in Fayoum, as new markets make diversification profitable. Tomatoes are particularly attractive in some years but the price does vary substantially making them a slightly risky crop.

[67] until the 1980s crops were planned centrally in Egypt

Crop choice is not influenced by environmental considerations, and new crops are likely to have a greater environmental impact which will not, in the short term, be offset by moves towards organic agriculture.

(ii) Fertilisers

Trends in total fertiliser use and fertiliser use per unit area are both increasing, leading to greater environmental pressure which is likely to be reflected in water quality. This is caused by a combination of increases in cultivated areas, changes in crop types, and better practices on existing crops. Whilst there are international pressures towards reduced fertiliser subsidies, which were abolished in Egypt in the early 1990s, some fertiliser is still heavily subsidised in Sri Lanka. This encourages excess use of urea by farmers, either because it is cheaper for them, or because retailers incorrectly mix fertiliser compounds and use more N than P or K. Farmers are aware that fertiliser quality is poor, but they are unable to do anything about it: the feel bound for social or other reasons to purchase from particular retailers and have to accept whatever quality is provided. A better balance of fertilisers would increase yields and reduce nitrogen losses to the watercourses.

Application rates and times are influenced by individual farmer's knowledge, his cash flow and the local availability of fertiliser. There is a tendency in both countries to increasing fertiliser use, as farmers become more aware of the marginal benefits of correct applications. Environmental issues are not considered, and the nitrogen content of water is ignored. Applications are timed to coincide with irrigation to ensure uptake by the crop rather than loss through volatilisation. Although farmers endeavour to avoid wastage during irrigation, some losses are inevitable – particularly in Sri Lanka where flow rates and irrigation losses are high.

There is accelerated soil erosion in irrigated areas: the turbidity and sediment load of drainage water in Sri Lanka provides evidence of this, and the sedimentation of those coastal lagoons which receive drainage water is very visible. Such erosion takes with it a proportion of the applied nitrogen which is bound to soil particles and means that more fertiliser needs to be applied. This is much less evident in Egypt where drainage rates are much lower (1 l/sec/ha cf 6 l/s/ha in Sri Lanka) and has a lower concentration of sediment.

(iii) Pesticides

There have been a lot of changes in pesticide applications. Unrestricted use of persistent organochlorine pesticides has gradually given way to a more scientific use of less persistent and lower dose carbamates and organophosphates. This has been driven by increasing restrictions on pesticide use, better knowledge of agricultural practices and changing approaches to agricultural extension. Indiscriminate aerial spraying has been discontinued (in Egypt) and provision of generic advice to spray at specific times has been stopped regardless of infestation (in Sri Lanka). In both countries, there are strong controls on what is permitted to be used, and extension advice is given to help farmers make best use of the permitted chemicals – they are taught about pests and diseases and the specific measures needed to control these. This does not necessarily lead to a reduction in total applications, although this has been the case in Egypt.

Integrated pest management programmes have been introduced in both study areas, but with variable degrees of success. As the name suggests, pest management is achieved by a combination of methods covering all aspects of agricultural practices – tillage, irrigation, and fertilisation as well as chemical

usage. Insecticide applications are targeted at specific known problems and not indiscriminately according to the calendar or observations of unidentified insects. It is thus a more comprehensive form of agricultural extension than simply pest management, and it is undertaken in a carefully structured way through season-long farmers' field schools. However, as reported elsewhere (FAO) the uptake has not been as good as expected – and this is believed to be largely for socio-economic reasons. In Sri Lanka, we found that some farmers in our study areas regarded some techniques as too laborious and not worthy of the effort, and some farmers believe that IPM techniques do not take sufficient account of traditional practices. Few farmers in our study area in Egypt had had any IPM training, and even if they had been trained this only covered a limited range of crops. There is thus considerable scope for improving knowledge of pest management and pesticide use.

Secondly application techniques are poor, so that agricultural workers are directly exposed to chemicals – they wear inadequate protective clothing and commonly report symptoms of poisoning immediately after spraying insecticides. The direct impact on themselves is the most significant, but these fairly crude techniques can lead to unnecessary wastage and spray drift onto watercourses which will lead to greater environmental pollution that is necessary. The network of surface channels is relatively sparse in Egypt as there is sub-surface drainage. Spray drift onto field irrigation channels is likely to be dissipated in field applications rather than cause specific problems. Pollution of watercourses in Sri Lanka is diluted by the high rainfall and irrigation losses – but thus may be of concern at times of peak demand in the dry (yala) season when there is little runoff.

Soil types have a significant impact on the extent to which pesticides are leached to groundwater or run off to surface channels. The high organic content in Kachchigala *ara* results in lower water pollution, and a large proportion retained in the soil matrix which will be released slowly. Whilst the active ingredient of the pesticides will decay, the breakdown products may also have an environmental impact.

Herbicides are widely used – in Sri Lanka they are an essential part of paddy cultivation, since rice is broadcast and there is insufficient labour for manual weeding. Effective weed control is essential for ensuring a healthy crop growth in the early stages.

(iv) Irrigation and drainage

Irrigation and drainage practices influence the concentration of applications in drainage water. In arid zones, such as Egypt, additional water has to be applied for salinity control – this is typically 10%, but needs to be increased to 15-20% in cases where the irrigation water is more saline. Some loss of nutrients is thus inevitable. Watering rates are much higher in Sri Lanka – there has historically been a generous supply, soils are highly porous and management controls have been fairly weak. Losses by both seepage and surface runoff are thus high.

In both cases water is supplied on a rotational basis, typically once per week, but the duration of supplies depends on the local availability. Irrigation is far more regular in Fayoum, where the system is highly formalised, than in KA where farmers are able to take water more freely. Each plot takes water directly from a field channel, and they do not here rely on field to field irrigation.

7 Impacts and Options for mitigating impacts

7.1 Introduction

The data collected in this study suggests water quality is still good and meets the standards for the uses the water is put to. There is also no reason to suggest it will deteriorate rapidly. This is perhaps a surprising conclusion and needs to be taken in context.

Excess nutrients can cause eutrophication, with consequences for weed growth, fisheries and health of the ecosystem. However, phosphates rather than nitrates are generally the limiting factor for freshwater and these are mainly supplied from municipal and industrial sources. Nitrates are the limiting nutrient for brackish water, and this may account for the reported eutrophication in coastal lagoons. Fertiliser applications in both sites are generally lower than the recommendations, and high temperatures encourage losses by volatilisation. In Sri Lanka high drainage rates cause considerable dilution. It is thus not surprising that nitrate levels are low, and for the most part do not have a significant impact. However, eutrophication in the coastal lagoons is of concern.

Modern pesticides decay fairly quickly and are applied in low doses. Water sampling will only detect pesticides dissolved in water, whereas pesticides may also be adsorbed onto soil or volatilised. Monthly sampling – even if related to pesticide application times – may be insufficient to detect specific problems, and we cannot exclude the possibility that there are short term peaks in contaminants which we did not detect or pollution in minor channels which were not sampled.

Further, many farmers do not use pesticides: insecticides are used by barely 50% of paddy farmers in Sri Lanka (dimethoate and chlorpyrifos are the most commonly used) and traces of insecticides were found in some water samples. The concentrations were very low, but given the sparse sampling, the high dilution and low persistence of these compounds, it can be expected that much higher concentrations would be found in small drains for short periods and will have an environmental impact. The main chemicals used on paddy are herbicides, and are used by all farmers in our sample: the kinds used have low persistence and were not be detected due to the sparse sampling regime and difficulties of testing for some of these chemicals. However, there many routes by which pesticides might be ingested: poor application techniques are of much greater significance than consumption of contaminated water.

We have detected contamination of fish and sediment by organochlorine pesticides in Sri Lanka. This contamination is of concern, and the contamination of sediment suggests that the problem is likely to persist – even though the pesticides detected are no longer in use. The precise route by which introduced species have become contaminated in newly-rehabilitated tanks, with a pesticide which was used for household spraying for malaria control but discontinued more than a decade remains unclear. However, it underlines the ubiquitous nature of persistent pesticides in the environment.

Communities are concerned about some aspects of water quality. In Sri Lanka, they are most concerned about the appearance and odour of water in the *ara*, which makes it unattractive for bathing. They are also concerned about the geochemical characteristics of groundwater (notably fluoride and hardness) which is used for drinking water. The *ara* is naturally not regarded as a potential source for drinking water: its poor bacteriological quality is thus not regarded as a matter of particular concern. In Egypt, it is the bacteriological quality of drinking water supply that is of greatest concern – this is

taken from the canal system but people that the treatment is inadequate even for bacteriological parameters. Some farmers are also worried that pesticides in the water supply system may survive the treatment process which is perceived to be inadequate.

In general agro-chemicals are seen to be of less importance than other pollutants or aspects of water management (salinity and volume of water being their main concerns). Those at the extreme tail of irrigation systems who could be expected to suffer most from agro-chemical pollution are also the most likely to suffer from water excesses and shortages, and changes in water salinity. These larger changes often have profound impacts on livelihoods in these communities.

7.2 Impact of water pollution on livelihoods

The impact of pollution on livelihoods can be divided into three categories:

- Actual and perceived - these were not identified in the fieldwork of this study but informal observations and literature suggest that they do occur in some places and times such as changes in fisheries as a result of eutrophication, increased maintenance costs of infrastructure. These might occur in cases where polluted drainage flows discharging into a river depleted by irrigation abstractions
- Uncertain – such as changes in fish productivity or quality, which may be occurring in some locations but we were unable to confirm them during this study because they were masked by the impact of other larger changes in water management
- Potential – such as to human health. This is less significant (for most people) than other routes for consumption or contact with pollutants, but there may be hidden or uncertain risks for some people – such those who don't apply (downstream users) – esp marginal downstream communities eg Thuduwa (Sri Lanka) who don't apply chemicals but use polluted water. Breakdown products of pesticides may also have an impact on these people.

Problems related to agrochemical pollution of water courses are as yet relatively minor and are not yet reflected in the perceptions of local communities – indeed we should not expect them to be, as the consequences of low level contamination will subtle and chronic. The immediate impact will be on health of the ecosystem, rather than directly on livelihoods.

The focus of the livelihoods studies was to elucidate the ways drainage water is used so that the impacts of this reuse could be assessed, but fortunately neither the literature review nor fieldwork revealed any significant potential impact on livelihoods that can be attributed specifically to diffuse pollution of surface water by agro-chemicals:

Canals are used for many purposes: agriculture is the dominant use, although domestic uses[68] are common in the larger canals during the season (but they are closed at times). No one deliberately drinks canal water (except accidentally when swimming or as an expedient when working in fields near by), nor do they use them for fishing. They provide raw water source for rural supplies which are chlorinated and/or filtered to varying degrees of efficacy.

Drains are used less than canals for domestic purposes – problems of access and probably visual cleanliness of water constrain this in most locations: Hungama/Tuduwa in Sri Lanka is the main exception. However some drainage water feeds raw water source for drinking water supplies (eg

[68] bathing and clothes washing, rather than drinking or cooking

Kattakaduwa tank in Sri Lanka, and drainage water is pumped into canals in Egypt). These are not treated to remove agrochemicals, but as noted above other aspects of water quality (ie faecal contamination) are of far greater concern in the short term

Drains in a few areas provide the best sources for bathing, but canals are always preferred – especially in Egypt. Drains are muddy and unattractive (and saline in Egypt) to wash in. In Sri Lanka, this is a marked deterioration since before the main irrigation system was built. Some people report problems of dermatitis or other skin complaints. Whether this is due to a specific contaminant needs to be confirmed. It may be more serious in discouraging hygiene which has a health impact, than for its direct consequences. Shallow wells are hydraulically connected to paddy fields or to channels which have poor bacteriological quality in some places. These are unsuited for human consumption, and although they might become polluted by agrochemicals this is less significant than other contaminants

The main uses of drainage water are agriculture, fisheries and watering livestock. In Sri Lanka, reuse agriculture is via tanks or anicuts on the *aras*. In Egypt, it is done on a small-scale by individuals pumping from drains, but the main mechanism via large scale reuse pump stations which mix saline drainage water with fresh irrigation water. Pollution by agro-chemicals is not perceived to be a problem: pesticide use is believed to have declined[69], and excess nutrients are seen as a bonus which would increase production.

There are a relatively small number of people who rely on fishing as their main source of livelihoods. More people fish occasionally in various tanks and channels. There is thus a potential long term health risk if fish are affected by pesticides, but there is no perception that fish quality or taste has deteriorated. Changes in fish numbers or species are attributed to changes in water level and salinity and to restocking programmes (or accidental introductions). Introduced species are generally preferred as they are more valuable and easier to sell than indigenous species, but there are some valuable indigenous species (such as freshwater shrimps in Thuduwa) which have declined – possibly due to overfishing, although some people attribute this to pollution.

Some tanks and the Kalametiya lagoon are heavily overgrown, as a result of the greater sediment load following irrigation development[70]. The effect of this can be seen by comparing the status of Kalametiya with the adjacent Lunama lagoon. Lunama has no major inflows from drainage, has remained relatively free of sediment and with a high salinity. It is not possible to isolate the additional impact of nutrient loads from the much larger changes caused by increases in water flow volume and sediment load and reduction of salinity, but it is clearly a contributory factor. Sedimentation has enable some encroachment of tank or lagoon land, but this must be on a fairly small scale as encroached land remains liable to waterlogging or flooding – it is perhaps more valuable as grazing land, and particularly in Egypt it would be very saline:

Livestock numbers are constrained by availability of grazing land: in Egypt most people keep a small number and need to cultivate fodder crops. Cultivation of fodder is rarer in Sri Lanka and only a few people (perhaps 5%) keep any large livestock – crop cultivation is mechanised, so people are not dependent on cattle for ploughing. Manure is valuable and is generally stored and used away from watercourses, although some leaching or runoff into drains is inevitable. Buffaloes are watered in the

[69] as a result of IPM programmes, restrictions on registration of pesticides, and modifications to agricultural extension advice – pesticide applications are no longer listed in standard advice on crop production

[70] these changes occurred long ago - the lagoon fisheries declined drastically over 30 years ago and a very small number of people are now dependent on the lagoon

drains in Sri Lanka, which does affect bathing water quality although not to the extent of impacting on health or livelihoods of other users

These issues do *not* mean that agro-chemical pollution is not a concern or should not be controlled, but they do mean that it is unlikely to be perceived as a major problem, and the drivers for change will be related to the larger issues. There is little no local pressure to change agricultural practices in either of our study sites to reduce agro-chemical pollution, although there is strong pressure to improve other aspects of water management.

Measures to improve these aspects of pest management these will have an additional impact on water quality, and we believe that people are using less chemicals now (for a range of other reasons) than in the recent past. However, there is still scope for further reductions in chemical use whilst increasing net returns to agriculture (eg by changes to on-farm water management, improving fertiliser quality control, and stimulating a greater understanding of insects by farmers)

7.3 Impacts on health

7.3.1 Introduction

Agrochemical pollution in the study areas does not have an immediate impact on human health. Any impacts are subtle and long term: they have been assessed in this study by considering the risk associated with different aspects of people's livelihood strategies – ie they way they use or are exposed to polluted water.

7.3.2 Pesticides

The very low concentrations of pesticides in water make it a minor health risk compared to those due to misuse of pesticides or poor application techniques. However, it should not be neglected: there is a growing concern worldwide over the health impacts of chronic exposure including renal failure and neurological problems, and there are great difficulties in proving links between exposure and disease. These may affect downstream water users even if they are not exposed directly to pesticides.

Epidemiological studies on directly exposed groups, such as sprayers in malaria control programmes and farmers have raised suspicion that there may be a causal relationship between high-level acute exposure to organo-phosphates, and possibly organochlorines and carbamates and depression (to the extent of causing suicide). Fortunately, the studies do not show evidence of a causal relationship between depression and chronic exposure, although no threshold limits have been established to indicate levels of exposure which would induce depression[71].

The immediate problems that people complain about – itching, skin problems etc – are due to bathing in muddy water, perhaps with decaying vegetation, and do not reflect serious problems. Dermatitis can be caused by direct exposure to pesticides but not in the extremely dilute concentrations found in the Kachigal *Ara*.

[71] http://www.pmac.net/exposure.html

Pesticides do have a significant impact on human health and on the environment through other routes: direct exposure to pesticides through poor application techniques or inadequate understanding of optimum pest management methods have a much greater impact that water pollution. Chlorpyrifos for example can be toxic via the skin or eyes (PAN). Pesticides such as diazinon are sometimes used as a fish poison which may then become a hazard for those who eat the fish (PAN)[72].

7.3.3 Other risks

Bathing in contaminated water carries a health risk if water is ingested, and in some cases it can be transmitted simply by contact with water. The main risk, globally, is bilharzia which is found in Egypt but not in Sri Lanka. Faecal oral diseases are transmitted through polluted water (although this is not the main transmission mechanism). Such diseases can be regarded as a consequence of diffuse agricultural pollution to the extent that the contamination is partially caused by agricultural workers, however we are really concerned with diseases that are caused by agrochemicals or livestock pollution.

Buffalos wallow in the same watercourses that people bathe in, and some diseases are transmissible through this route. Cryptosporidiosis is the most likely to occur; is long-lived and has a very low infective dose (and being resistant to chlorine it may also be found in piped supplies using contaminated raw water sources). However, the dilution in the *ara* is such that only those in very close contact with buffaloes would be at risk: excluding buffalos from close to drinking water sources. Bathing sites are in any case normally separate from buffalo wallows. Poor quality drainage water does discourage people from washing – which could cause health problems - but there are alternative nearby sites which are less polluted. Those who find the *ara* water particularly unattractive or suffer skin problems and are far from canals rely on piped water supplies (notably in Tuduwa).

There is also a risk of leptospirosis which is reported in this area, but it is mainly transmitted by rats and requires a greater exposure than is likely to be found in drains. Toxocara is another remote possibility, although it is unclear whether *T. vitulorum* which is carried by buffaloes causes disease or whether the disease is due to concurrent *T.canis* infection.

Heavy metals in other agrochemicals can be taken up by plants (eg arsenic in brassicas), but none were detected in this study, nor are they reported to be applied by farmers so we do not consider this a significant risk.

Changes in water management can be expected to affect the habitats of vectors and intermediate hosts of water-related diseases such as schistosomiasis, malaria and Japanese encephalitis. The most likely significant changes are due to sedimentation, excess water at the tail of systems, and changes in the salinity of coastal lagoons. These are not related to agro-chemicals, but increased weed growth as a result of excess nutrients in drains could lead to an increase in mosquito-breeding. This, however, does not appear to be applicable to the main vector species in the study areas.

We conclude, therefore, that there is no immediate health risk due to agrochemicals in the study areas, but recommend caution as there are potential long term impacts. These can be minimized by taking the

[72] indirect impacts of pesticide misuse can occasionally also be beneficial: the benefits of a herbal treatment for thrush extracted from grapefruit pips were found to be caused by the chemical contaminants rather than the grapefruit itself (http://www.jr2.ox.ac.uk/bandolier/)

same precautions which are recommended to avoid direct exposure to pesticides (careful licensing and monitoring of pesticides, encouragement of integrated pest management, etc)

7.4 Need for Pollution Mitigation

Given the low concentrations of pesticides detected in the water system, we may question the need for pollution mitigation measures (particularly any that might result in short term production losses). However, we still recommend caution:

- The sampling regime was sparse, and will not have detected short term local peaks or products that decay rapidly – these may affect the natural ecosystem and may also have indirect impacts on livelihoods
- Pollution was not identified as large-scale problem – but local problems do occur (both due to pesticides and nutrients), and there is some uncertainty in the nature of the impacts; and
- There is a also degree of uncertainty in data – due to the unreliability of measurements, or inadequate techniques for detecting some compounds.

Agrochemical pollution should however be viewed in the broader context of water quality (including municipal, human, and industrial pollution). There is a need for safe water supplies to all people – this is a key millennium development goal and a key component of all national water policies. This does not (necessarily) mean that all existing unsafe sources should be made safe by excluding pollutants but that all people should be given access to safe drinking water (ie the solution for people who currently rely on unsafe canal water is not to improve canal water quality to drinking water standards, but to provide a separate and adequate safe supply). There is however a need to minimise contamination of raw water sources.

There is also need to improve better agricultural techniques – to reduce, for example, the risk to people who use pesticides (often unskilled and poor labourers), to increase production, and to reduce access to chemicals used for suicide, etc). The fact that concentrations of pesticides are higher in canals than drains suggests that leaching and runoff is a less significant route of contamination than spray drift and washing containers etc – highlighting the importance of improve techniques for applying pesticides

These other influences are likely to be greater than the direct impact of agricultural pollution, and will therefore drive change.

7.5 Drivers for Change

Despite the small impacts observed, we believe that it would be prudent to minimize agrochemical use – particularly since this can be done in ways which do not have a negative impact on livelihoods.

Each potential impact from agro-chemical water pollution is masked by other larger and more widely-perceived problems. Measures to reduce the impacts due to poor water quality will be stimulated mainly by the need to mitigate these bigger issues. There are some possible exceptions to this general statement, such as the pressures to reduce livestock numbers or to restore lagoon fisheries in Sri Lanka, but we believe that other issues will be given greater prominence even in these cases.

Legislation on agricultural aspects of water quality barely exists, and in the short-term most efforts will continue to be on management of industrial and urban areas. The cost and complexity of monitoring and identifying causality will make it unlikely to receive much attention.

Thus mitigation measures are most likely to be driven by other factors:

- Fertiliser prices
- Pesticide restrictions (because of application methods, poisoning), knowledge and advertising
- Crop choice – markets, policies, water availability.

Fertiliser use is generally lower than formal recommendations, so it may increase even if recommendations are refined to take better account of nutrient losses. In the long run, we can expect subsidies to be reduced[73] but the marginal returns to fertiliser use are still likely to justify their use at present or higher levels. However, nutrient levels in surface waters are generally so low that this is of little environmental concern. There are possible exceptions to this: for example the coastal lagoons in Sri Lanka. The tsunami removed any signs of eutrophication, which therefore could not be confirmed, but these may occur in future. As however, fertiliser applications and nutrient levels in the kachigala *ara* are so low, it is hard to see how further controls on fertiliser applications could either be introduced or be effective in the lagoon.

Pesticide restrictions will remain in place and indeed become more stringent, but effective programmes have been introduced to reduce insecticide use without affecting agricultural returns significantly. IPM is well-known to be effective, but there are problems with uptake – some farmers consider it to be too laborious and FAO report that few adopt the recommendations after they have been trained.

Both government policy and constraints of water availability will encourage a change in cropping from paddy to OFCs in Sri Lanka: this would be expected to increase chemical use considerably. Fortuitously, the OFC most widely grown in Walawe is bananas which use little fertiliser and no pesticides (apart from carbofuran before planting). Thus the change from paddy to OFCs has actually reduced usage of chemicals. This was however a fortuitous change, and we cannot assume that it will be sustained: an increase in vegetable crops is still possible. Trends in the Fayoum are, however, towards crops towards more input-intensive crops[74]. There is an increasing amount of organic farming, but it is still on an extremely small scale.

Rice is a far less attractive crop, financially, than it used to be and in comparison with OFCs – these low prices are expected to continue for some time although long term trends – global population growth, rice production elsewhere, climate change – may change this. Rice remains, however, a popular crop for cultural reasons, because it is difficult for individuals to diversify within a large paddy growing area (seepage from adjacent fields damages other crops), and because the irrigation infrastructure is insufficiently flexible to meet the water demands of vegetables.

[73] government policy is to continues with and even increase support fertiliser subsidies, but the global trend and pressures are towards a reduction of subsidies

[74] this may not be reflected in Egypt as a whole, where a large increase in wheat has been reported

7.6 Options for Mitigation

7.6.1 Introduction

An earlier study of agro-chemical pollution management (Pearce 1998) proposed an enabling framework, comprising the following five elements

- Technical training
- Best management practices
- Legislation
- Monitoring
- Compliance

We will use this framework for evaluating alternatives.

(i) Technical Training

Agrochemicals are sophisticated modern synthetic products made readily available to farmers who have no technical background or training in their use. It is hardly surprising if they are not used in accordance with best practice. This points to the need for improved training and extension advice to farmers covering use and safety of agrochemicals and to local departments to enable them to manage agro-chemical strategies in their area.

Integrated Pest Management (IPM) programmes are effective both as a general method of extension[75] – they are supported through a highly participatory programme of farmers' field schools – and as a specific means of improving methods and efficiency of pest control strategies (including minimising use of pesticides). Both Sri Lanka and Egypt promote IPM (for example Egypt started a programme of IPM for cotton in 1980 according to El-Hage Scialabba and Hatton, 2002), and have phased inefficient methods such as aerial spraying and blanket recommendations (regardless of pest incidence).

These programmes should be continued and indeed strengthened, as the uptake of recommendations is still far below what is required – this is considered further below. Curricula for these FFS should cover the specific issues related to water pollution, although these are already partly covered by training in normal pesticide practices in the existing curriculum.

The benefits of IPM can be seen from the findings of the Fayoum IPM Project which undertook (for example) a number of trials on Nili and early season tomatoes during the 2001/2002 season. The results of these trials indicate that considerable benefit in terms of yield and gross margin are possible by the adoption of more controlled fertilizer application, more targeted use of pesticides and the selection of disease tolerant varieties.

During the course of the trial a number of key issues regarding common husbandry practices came to light, including:

[75] for this reason they lead to changes in many aspects of agricultural practices, and may even lead to an increase in pesticide use, in places where it was previously sub-optimal. However, the recommendations are for the most appropriate and safest applications

- Generally farmers do not fertilize their fields adequately.
- Too much nitrogen and not enough phosphate or potassium is applied.
- Farmers frequently use highly toxic insecticides e.g. Icon and Lanate, whereas products like Admire and Admiral are available on the market. These are less toxic, more efficient and less hazardous to the environment.
- Weekly spraying of insecticides was the norm, whereas less frequent application proved adequate to control insect pests e.g. whitefly.
- Fungicides are used by farmers according to the national recommendations, rather than when fungal diseases occur.

Analysis of the results achieved by in these trials indicates that on average a 62% increase in yield was achieved with a corresponding 69% increase in gross margin. Admittedly the trials were undertaken on a small scale with a consequent ability to control husbandry practices much more easily than in field scale operations. However, the results are striking and do serve to indicate that through extension and subsequent changes in crop husbandry practices significant yield, financial and potentially environmental and health benefits are realistically possible.

The organic approach also appears to be an option, currently for a relatively small proportion of farmers in El Fayoum. The Fayoum Agro Organic Development Association is exploring this approach and it is evident that a number of their members are proving to be very successful. The organic approach does enable access to lucrative export markets and high value outlets in the big cities, however, the conditions of entry to these markets are very stringent and for the time being this is really only an option for a select few.

Specific areas where greater knowledge is needed include

- Safety aspects of agrochemical use (handling, application and disposal of containers etc)
- Awareness of the risks of water pollution, and the mechanisms by which such pollution might occur
- Techniques to avoid water pollution (spraying at watercourse margins, impact of wind and weather conditions, timing related to irrigation activities)

Such training if implemented effectively will increase the understanding of the true causes and impacts of water pollution, and will enable environmental requirements to be taken account of whilst still maximising production.

It should also be noted that Farmers Field Schools are a two-way process and will enable the facilitators (and hence local and national authorities) to build up a detailed picture of local problems and solutions (see section 7.7).

(ii) Best Management Practices (BMPs)

BMPs should promote sustainable and safe practices.

- **Land management** – use of buffer strips/zones around canals and drains (and also tanks) could reduce the risk of pesticide spray drift into water courses, as well as act as sediment

traps as well as nutrient sinks. Encroachment of canal reservations is a common problem and causes problems for sustainability of the infrastructure. It would thus be feasible to encourage farmers not to spray within 10m of canals and drains, although in some cases this may require careful adjustment to crop plans in some fields (see below). Improved irrigation practises, particularly in sloping terrain may make it possible to reduce soil loss and hence loss of nutrients adsorbed to the soil;

- **Crop selection** – there is a widespread awareness of the different input requirements of different crops. Whilst we would not expect farmers to change crops to reduce water pollution in general, it is often the case that high inputs crops also require frequent water applications. Thus they are grown in land adjacent to canals, or possibly make use of drinking water wells. The location where farmers grow particular crops thus does need to be careful consideration;
- **Fertiliser quantities and timing** (related to crop requirements and irrigation schedules) - there is likely to be scope for a modest reduction (e.g. 10-20%) in *total N* in the fertiliser recommendations without risk of serious yield penalties[76] since calculations suggest that concentrations of nitrates leaving the field may occasionally exceed 50 mg/l. It should be noted, of course, that such 'lost' nitrates are recognised and appreciated as a free source of fertiliser by downstream farmers who rely on the drainage water (who are generally poorer). If upstream management is improved, then they will no longer receive this very small benefit[77], but relying on such losses is a very inefficient and ineffective way of helping poor farmers. Provision of a soil sampling service to test for nutrient status would make it possible to improve the timing of when the fertiliser is applied to coincide with the greatest need for nutrients from the crop. Subsidies distort use, but they are political but are widely promoted in some countries (Sri Lanka, but not Egypt) – however they have not yet increased use even as high as recommended levels]
- **Pesticide management** – the need for improved knowledge of pesticides is described above. There will need to be a gradual improvement in guidelines as new pesticides are developed, increased knowledge of the impacts of pesticides is gained, and new problems emerge – such as resistance to herbicides and insecticides.
- **Livestock management** - livestock populations are not high in the study areas and there considerable cultural difficulties in restricting their access to water even where there is a risk of pollution. Such pollution does not yet cause a problem in the study areas, although this may not be true of other areas where livestock intensities are high and where there may need to be a system of zoning to restrict livestock from areas where humans bathe. Large livestock units need to be managed systematically stressing the need for keeping the production process clean; promoting manure management with recycling back to the soil to improve fertility; limiting the housing intensity of livestock.

(iii) Legislation

There is clearly a need for effective and enforceable legislation to control agro-chemical pollution. The challenge is enforceability, which requires an effective monitoring network. Legislation in Egypt, where water quality is a relatively high priority, do provide the framework for water quality management – Law 48 / 1992 on the Protection of the Nile and Law 4 / 1994 on the Protection of the

[76] this should be combined with field trials before implementation

[77] Our figures suggest that the nitrate level in drainage water in Sri Lanka is so low, on average, that the benefit to downstream users is insignificant. In Egypt, salinity prevents the use of drainage water except in very small drains where the nitrate content is either very low, or just high for such brief periods that downstream farmers cannot make use of it effectively.

Environment. As far as we can tell agro-chemical pollution does not cause water quality to exceed the limits laid down by this legislation.

Restrictions on pesticides have been introduced in both Sri Lanka and Egypt. Environmentally persistent pesticides such as organochlorines have been banned and a pesticide registration process has been introduced. This system needs to be continued and continually updated in the light of new knowledge

(iv) Monitoring and Compliance

A major challenge is to design and implement monitoring programmes that are capable of detecting agro-chemicals to a sufficient degree of accuracy and reliability. There is now a routine monitoring programme in Egypt, although this does not cover pesticides.

Sophisticated methods exist for analysing what quantities of pesticides are found in food or soil, but it is much more difficult to analyse for pesticides in water (Pesticide Action Network, 2000) for some of the following reasons:

- there are many compounds of different chemical types in use, which means that scanning samples is expensive;
- it is difficult to isolate specific pesticides from the multitude of other chemicals in water;
- some pesticides are highly toxic at low concentrations close to detection limits, and large volumes of water are needed for sample analysis;
- further work is needed to establish characteristics of pesticide degradation for many soils;
- soil and hydrogeological mapping is needed in order to predict vulnerable catchment areas;
- pesticides can be adsorbed to soil or other particulate matter or suspended solids found in sediments;
- seasonal variation in sampling and changes in weather conditions such as rain can affect levels of pesticides in water;
- high levels of organic matter in water can mask low concentrations of pesticides making them difficult to detect.

Ultimately it is difficult to discover what pesticides are in water if methods of analysis and testing are inadequate. A review across the EU of the impact of pesticides in water found that ‘acceptable analytical methods are only available for approximately a quarter of all active substances’ and also noted that techniques for insecticides and fungicides especially were required – most analysis tends to focus on herbicides (Pesticides Action Network, 2000).

For these reasons a routine pesticide monitoring programme cannot be established in most countries. Rapid bio-assessment of invertebrates, however, should provide a useful proxy of water quality.

7.7 Methods for Selection and Introduction of Selected Measures

Control of agro-chemical pollution requires design of appropriate measures at a central level, but the real challenge is to implement them effectively at field level – particularly given the low perceptions of any problems and the difficulties in ensuring compliance with regulations.

Pollution mitigation will only be effective if local stakeholders are aware of the problem and agree in the measures proposed. Legislation and centralised measures for enforcement are necessary but not sufficient. A community based approach to controlling diffuse pollution similar to the approach used by Mtetwa and Schutte (2003) (described earlier) might be suitable. This entails establishment of stakeholder groups, followed by recording of baseline conditions, risk awareness creation, empowerment, design of a protocol to reduce the risk of diffuse pollution, implementation of the agreed mitigation programme, and finally monitoring progress and reviewing the strategy.

Training is clearly important and needs to take account of the low levels of literacy found in many rural households (EWPS found that only 34 percent of 800 surveyed household heads claimed to be literate (Croppenstedt, 2005).

The farmers' field school concept, which is central to IPM programmes, should be an important part of wider measures to improve input use and control pollution. The IPM programme is widely acknowledged to be very effective, but FAO report that uptake is still low (largely because of socio-economic factors). Farmers Field Schools could be modified to make specific mention of water pollution issues as described earlier, and used to refine the understanding of local problems and hence design appropriate solutions. We have had considerable success in modifying FFS for improving water management in the irrigation section (Mott MacDonald, 2005) and this approach could easily be adapted to incorporate water quality considerations.

7.8 Conclusions

This is a preliminary report as field investigations are still in progress. However we have not found any evidence of serious problems of water pollution arising from diffuse agricultural pollution. Pollution of water from sewage and from industrial sources is still the main problem in or adjacent to the study areas.

Irrigation leads to large changes in water flows in many channels (which may be positive or negative). These large hydrological changes have a major impact which makes it difficult to see the specific incremental impact of water quality changes. The potential risks of pesticide pollution are, however, serious both for the natural ecosystem and for human health. This makes it important to improve routine monitoring water quality and to reduce environmental exposure through all risks.

Livelihoods are not yet affected by agricultural aspects of water pollution in the case study sites. Agro-pollution would be a concern if water were used untreated for drinking, but bacteriological parameters would be more serious in short term. Improved water supply systems would be a priority in such situations, and the low concentrations of pesticides encountered would not present a problem for low cost treatment). Fisheries are the aspect of livelihoods which are the most likely to be affected.

Despite these generally positive findings, we still recommend caution and recognition of environmental issues when developing agricultural policy. It is possible to design measures to improve agricultural productivity which can be taken without adverse impacts on the environment. Better communication and understanding between the respective agencies is important for this.

7.9 Recommendations

Our recommendations are grouped in four categories

- Technical training
- Best management practices
- Legislation
- Monitoring and compliance

Farmers have a growing knowledge and understanding of agrochemicals, but new products are continually being introduced and farmers have a patchy access to information – as a result their techniques are sub-optimal and sometimes dangerous. Traditional extension methods have not been very effective at reaching all farmers, but participatory methods such as farmers' field schools for integrated pest management are potentially very effective. However, uptake of these methods is still fairly weak and there is little dissemination of the knowledge to those who do not attend. Further work is needed to address the factors limiting this uptake, which are reported by Gutierrez and Waibel (nd)[78] to be due to an excessive focus on technical issues and a lack of attention to social and policy aspects. It is also important that women and children who directly involved in chemical applications are included in these programmes.

There are many aspects of agricultural management which could be improved to reduce water pollution without harming productivity – these include land management (restricting encroachment of drain and tank margins, irrigation practices to reduce soil loss); fertiliser application quantities and timing (particularly related to water management practices); pesticide application techniques (especially along drain margins, and for cleaning and disposal of equipment); and livestock husbandry and manure management. There will need to be further agricultural research before definitive recommendations can be made on issues such as modified fertiliser recommendations

Legislation is necessary before any water quality improvements can be enforced; this is generally in place in the study countries, although agricultural pollution is not specifically identified. Pesticide registration procedures need to be continually refined as new products are introduced, or new risks are identified.

Enforcement of water quality improvements is not possible until monitoring systems are improved. The costs and complexity of monitoring means that this needs to be a carefully targeted programme – focussing on key parameters and locations. In addition to water this programme should cover sediments, fish and invertebrates.

[78] http://www.spipm.cgiar.org/PDFs/SPIPM.%20First%20EPMR%20report,%202001.pdf

Appendix A: References

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Appendix B: Logical Framework

	Narrative summary	Measurable indicators	Means of verification (MoVs)	Important assumptions
Goal	Combate degradation of water resource and enhance livelihoods in areas affected by diffuse agricultural pollution.	Recommendation to implement study findings by Govt Departments.	Personal communication.	
Purpose	Improved understanding of the impact that diffuse agricultural pollution from large scale irrigation has on the river environment and on downstream livelihoods, and the identification of solutions to reduce/mitigate the environmental and livelihoods impacts of such pollution.	Stakeholder realisation that agricultural practises can be a significant source of pollution with social, environmental and economic impacts by 24 months.	Stakeholder workshop feedback notes.	Local Institutions able and willing to implement mitigation options.
Outputs	1. Increased knowledge of the extent of agricultural pollution in each case study site. 2. Improved understanding of downstream household livelihood strategies (with attention to diversity factors such as gender and type of land tenure) and the role that water plays as a productive asset. 3. Improved local capacity to monitor water quality and agricultural pollution. 4. Improved understanding of the socio-economic impact of agricultural pollution on downstream water users and on the environment. 5. Improved awareness of impacts of agricultural pollution amongst all stakeholders. 6. Recommended pollution reduction/mitigation options for each case study.	Report of results of water sampling programme within 18 months. Appropriate equipment and training of local organisations provided within 12 months. Results of participatory livelihood analysis and basic environmental assessment produced within 20 months. Meetings held to present study findings to different stakeholder groups within 23 months. Report for each case study within 22 months	Progress report Capacity Building progress chart. Progress report Minutes of meetings Final report	Sites are chosen where there is a discernible impact on water quality, which can be traced to agricultural sources.

Appendix C: Water Quality and Agricultural Pollution

C.1 Relevant Parameters

A list of necessary parameters to be analysed in a monitoring programme in relation to agriculture activities is proposed (Chapman[79], 1996) below. This list is based on the likelihood that the concentration of a specific variable will be affected by agricultural activities.

This list includes:

- Pesticides[80]
- Nutrients – Ammonia, Nitrate, Nitrite, Phosphorus Compounds
- Suspended Solids (TSS)
- Dissolved Oxygen (DO)
- Biological Oxygen Demand (BOD)
- Chloride
- Mercury[81]
- Arsenic[3]

Also to be considered according to local specificity:

- Conductivity (EC)
- Sodium[82]
- Copper[3]
- Zinc[3]
- Microbiological indicators – Faecal Coliforms, other Pathogens

C.2 Water Quality Standards

Water quality standards are established as guidelines for pollution control of water resources and aquatic ecosystems. In order to evaluate water quality results, numerous standards, both national and international, have been used in this study as a guidance index. The determination of acceptable water quality has been based on a case-by-case basis, using relevant standards depending upon usage, as follow:

- Drinking Water:
  - WHO – 1993: Guidelines for drinking-water quality, 2nd ed. Vol. 1. Recommendations. Geneva, World Health Organization.

[79] Published on behalf of UNESCO, WHO and UNEP.
[80] Specific compounds should be measured according to their level of use in the region.
[81] Need only be measured when used locally or occur naturally at high concentrations
[82] Expressed as Sodium Adsorption Ratio (SAR). SAR determines the amount of sodium ions present in relation to calcium and magnesium

- Egypt – 1995: Ministry of Health and Population, 1995
- Sri Lanka –

- Ambient Drainage Water:
  - Egypt – Ministerial Decree 8 on Law 48 (1982), Article 60: Ambient Drainage Water for Nile and Canals.
  - Egypt – Ministerial Decree 8 on Law 48 (1982), Article 68: Ambient Drainage Water for Drains, Ponds and Lakes.
  - Egypt – Ministerial Decree 8 (1986) on Law 48 (1982), Article 65: Standards for Mixing Drainage Water with Canal Water.
  - Sri Lanka –
- Irrigation Water:
  - FAO – 1985: Water quality for agriculture. Irrigation and Drainage Paper No. 29 (Rev. 1). Rome.
- Livestock Drinking Water:
  - FAO – 1985: Water quality for agriculture. Irrigation and Drainage Paper No. 29 (Rev. 1). Rome.
  - WHO – 1989: Guidelines for Livestock Drinking Water
- Fish and other Aquatic Life Water:
  - Egypt –Ministerial Decree 8 on Law 48 (1982): Ambient Drainage Water for Nile and Canals.
  - Canada – 1987: Canadian water quality guidelines for fisheries and aquatic life
  - EU – Standards for salmonides (79/923/EEG)
  - EU – Standards for cyprionides (79/923/EEG)

Abstracts of relevant national and international standards for specific elements are given below.

C.3 Human Drinking Water Quality Standards

This section gives an overview of National and International Drinking and Recreation Water Quality Standards relevant to the analysis undertaken in this study.

Table C.1: Drinking Water Standards

Parameter	Abbreviation	Unit	WHO[1] 1993, 1998	Egypt[2] 1995	Sri Lanka[3]
Alachlor		ug/l	20	-	
Aldrin/Dieldrin		ug/l	0.03[a]	0.03	
Ammonia	NH_4-N	mg/l	1.15*[b]	200	
Arsenic	As	mg/l	0.01	0.05	
Biological Oxygen Demand	BOD	mg/l	0.03		
Cadmium	Cd	mg/l	0.003	0.003	
Chloride	Cl	mg/l	250*	500	

Chemical Oxygen Demand	COD	mg/l	-	
Coliform bacteria (Total)		MPN/100ml	nd	
Coliform bacteria (Faecal)		MPN/100ml	nd	
Copper	Cu	mg/l	2	2
DDT+metabolites		ug/l	2	2
Dieldrin		ug/l	0.03	0.03
Electrical Conductivity	E.C.		-	
Heptachlor		ug/l	0.03	0.03
Heptachlor Epoxide		ug/l	0.03	0.03
Iron	Fe	mg/l	0.3*	0.3
Lead	Pb	mg/l	0.01	0.05
Lindane		ug/l	2	2
Magnesium	Mg	mg/l	-	150
Manganese	Mn	mg/l	0.1	0.1
Mercury (total)	Hg	mg/l	0.001	0.001
Methoxychlor		ug/l	20	-
Nitrate	NO_3-N	mg/l	11[c]	10
Nitrite	NO_2-N	mg/l	0.9[c] / 0.06[d]	0.005
Permethrin		ug/l	20	20
Pesticides (total)		ug/l	0.5[g]	
Propanil		ug/l	20	-
Sodium	Na	mg/l	200*	200
Sulphate	SO_4	mg/l	250*	400
Total Dissolved Solids	TDS	mg/l	1000*	1000
Zinc	Zn	mg/l	3*	3

[1]: WHO (1993) Guidelines for drinking-water quality, 2nd ed. Vol. 1. Recommendations. Geneva, World Health Organization. WHO (1998) Guidelines for drinking-water quality, 2nd ed. Addendum to Volume 1. Recommendations.Geneva, World Health Organization.
[2]: Ministry of Health and Population, 1995
[a]: For combined aldrin plus dieldrin
[b]: Staining of laundry and sanitary ware may occur below guideline value. Value corresponding to 1.5 mg/l NH_4
[c]: Short-term (acute) exposure. Corresponding respectively to 50 mg/l NO_3 and 3 mg/l NO_2.
[d]: Long term (chronic) exposure. Corresponding to 0.2 mg/l NO_2.
[e]: Imperative Standard: 10,000
[f]: Imperative Standard: 2,000
[g]: Parametric value given by the EU's drinking water standards. Council Directive 98/83/EC on the quality of water intended for human consumption. Adopted by the Council, on 3 November 1998.
*: Recommended values

C.i Ambient Drainage Water Quality Standards

Table C.2: Drainage Water Quality Standards

Parameter	Abbr.	Unit	Egypt Law 48 (60)[1] 1982	Egypt Law 48 (68)[2] 1982	Egypt Law 48 (65)[3] 1982
Ammonia, ionized	NH_4^+-N	mg/l	0.5		0.5
Arsenic	As	mg/l	0.05		0.05
Biological Oxygen Demand	BOD	mg/l	6		10

Parameter	Abbr.	Unit	Egypt Law 48 (60)[1] 1982	Egypt Law 48 (68)[2] 1982	Egypt Law 48 (65)[3] 1982
Cadmium	Cd	mg/l	0.01		0.01
Chemical Oxygen demand	COD	mg/l	10		15/6.5[a]
Coliform Bacteria (Total)	Coli	MNP/100ml		≤5000	≤5000
Copper	Cu	mg/l	1		
Iron	Fe	mg/l	0.1		
Lead	Pb	mg/l	0.05		
Manganese	Mn	mg/l	0.5		
Mercury	Hg	mg/l	0.001		
Nitrate	NO_3-N	mg/l	10		
Oxygen (dissolved)	D.O	mg/l	5 (minimum)	4 (minimum)	5 (minimum)
pH		mg/l	7-8.5	7-8.5	7-8.5
Phosphate	PO_4	mg/l			1
Sulphate	SO_4	mg/l	200		
Temperature	T	°C	≤ normal +5	≤ normal +5	≤ normal +5
Total Dissolved Solids	TDS	mg/l	500	≤650	500
Turbidity		NTU		≤50	
Zinc	Zn	mg/l	1		1

[1]: Ministerial Decree 8 on Law 48 (1982), Article 60: Ambient Drainage Water for Nile and Canals.
[2]: Ministerial Decree 8 on Law 48 (1982), Article 68: Ambient Drainage Water for Drains, Ponds and Lakes.
[3]: Ministerial Decree 8 (1986) on Law 48 (1982), Article 65: Standards for Mixing Drainage Water with Canal Water.
[a]: Dichromate/ Permanganate

C.4 Irrigation Water Quality Standards

Table C.3: Irrigation Water Quality Standards (FAO[1]1985)

Parameter	Abbreviation	Unit	No Restriction on use	Slight to moderate restriction on use	Severe restriction on use
Arsenic	As	mg/l	≤0.1		≥0.2
Cadmium	Cd	mg/l	≤0.001		≥0.05
Chloride	Cl	mg/l	≤142	142-355	≥355
Copper	Cu	mg/l	≤0.2		≥5
Electrical Conductivity	E.C.	dS/m			
SAR= 0-3			>0.7	0.7-0.2	<0.2
SAR= 3-6			>1.2	1.2-0.3	<0.3
SAR= 6-12			>1.9	1.9-0.5	<0.5
SAR= 12-20			>2.9	2.9-1.3	<1.3
SAR= 20-40			>5.0	5.0-2.9	<2.9
Iron	Fe	mg/l	≤5		≥20
Lead	Pb	mg/l	≤5		≥10
Manganese	Mn	mg/l	≤0.2		≥10
Nitrate	NO_3-N	mg/l	≤5	5-30	≥30

Parameter	Abbreviation	Unit	No Restriction on use	Slight to moderate restriction on use	Severe restriction on use
pH			Normal range: 6.5 – 8.4		
Sodium [a]	Na	meq/l	≤3	3-9	≥9
Sulphate	SO_4	mg/l	≤192-480	192-480	576-960
Total Dissolved Solids	TDS	g/l	≤450	450-2000	≥2000
Zinc	Zn	mg/l	≤2		≥10

[1]: FAO. 1985. Water quality for agriculture, by R.S. Ayers & D.W. Westcot. Irrigation and Drainage Paper No. 29 (Rev. 1). Rome. The maximum concentration is based on a water rate which is consistent with good irrigation practices (10,000m^3 per hectare per year).

[a]: Sodium (Na) as SAR

C.5 Livestock Drinking Water Quality Standards

Table C.4: Livestock Water Quality Standards

Parameter	Abbreviation	Unit	FAO[1] 1985	WHO[2] 1985
Arsenic	As	mg/l	0.2	0.2
Cadmium	Cd	mg/l	0.05	0.05
Copper	Cu	mg/l	0.5-5[a]	0.5
Lead	Pb	mg/l	0.1	0.1
Mercury	Hg	mg/l	0.01	0.01
Nitrate + Nitrite	NO3-N + NO2-N	mg/l	100	10
Nitrite	NO2-N	mg/l	10	10
Total Dissolved Solids	TDS	mg/l	<1000 (<1.5 dS/m): excellent 1000-3000 (1.5-5 dS/m): very satisfactory 3000-5000 (5-8 dS/m): satisfactory for livestock/ unfit for poultry 5000-7000 (8-11 dS/m): limited use for livestock/ unfit for poultry 7000-10000 (11-16 dS/m): very limited use >10000 (>16 dS/m): not recommended	1000-10000
Zinc	Zn	mg/l	24	25

[1]: FAO. 1985. Water quality for agriculture, by R.S. Ayers & D.W. Westcot. Irrigation and Drainage Paper No. 29 (Rev. 1). Rome.

[2]: Guidelines for Livestock Drinking Quality (WHO; 1989)

[a]: 0.5mg/l for sheep, 1 mg/l for cattle and 5 mg/l for swine and poultry

C.6 Fish and other Aquatic Life Water Quality Standards

Table C.5: Aquatic life water quality standards

Parameter	Abbreviation	Unit	Egypt Law 48[1]	Canada[2] 1987	EU[3] 19XX		EU[4] 19XX	
					Guide	*Imperative*	*guide*	*Imperative*
Aluminium	Al	ug/l		5-100				
Ammonia, free	NH_3-N	mg/l		1.37-2.2[b]	≤0.005	≤0.025	≤0.005	≤0.025
Ammonia, ionized	NH_4^+-N	mg/l		1.37-2.2[b]	≤0.04	≤1	≤0.2	≤1
Arsenic	As	ug/l		50				
Biological Oxygen Demand	BOD	mg/l O_2			≤3		≤6	
Cadmium	Cd	ug/l		0.2-1.8[c]				
Chromium	Cr	ug/l		2-20[c]				
Coliform Bacteria (Total)		MNP/100ml				≤5000		≤5000
Copper (Soluble)	Cu	mg/l		2-4	≤0.06		≤0.04	
Cyanide	CN	mg/l		0.005				
DDT		ug/l		0.001				
Dieldrin		ug/l		0.004				
Dissolved Oxygen	DO	mg/l O_2		5-9.5	50% ≤9 100% ≤7	10 50% ≥8	50% ≥8 100%≥5	10 50% ≥7
Iron	Fe	ug/l		300[c]				
Lead	Pb	ug/l		1-7				
Mercury	Hg	ug/l		0.1[c]				
Nickel	Ni	ug/l		25-150				
Nitrite	NO_2	mg/l		0.06	≤0.01		≤0.03	
pH		Unit		6.5-9	6-9	6-9	6-9	6-9
Temperature		ºC				≤1.5 above natural		≤3 above natural
Total Suspended Solids	TSS	mg/l		10[a]	≤25		≤25	
Zinc (Total)	Zn	mg/l		30		≤0.3		≤1.0

[1]: Ministerial Decree 8 on Law 48 (1982): Ambient Drainage Water for Nile and Canals.
[2]: Canadian water quality guidelines for fisheries and aquatic life (1987)
[3]: Standards for freshwater fish as established by the EU (79/923/EEG) for salmonides
[4]: Standards for freshwater fish as established by the EU (79/923/EEG) for cyprionides
[a]: Increase of 10 mg/l above background
[b]: Total ammonia
[c]: Depending on hardness

C.7 Impacts of Water Quality Parameter

The extent and magnitude of water quality degradation that may occur is difficult to assess because of the non-point nature of diffuse agriculture pollution. However a non exhaustive discussion

Some of the possible impacts that significant water quality parameters (as identified above) might have on water quality are proposed and discussed below.

C.i Pesticides

This group of agrochemicals comprises insectices, herbicides and fungicides, and are usually referred to as pesticides. According to Ongley (1996) the abuse and misuse of pesticides remains a major problem in many countries, particularly in Latin America, Asia and Eastern Europe. In Africa too, inappropriate and excessive use of pesticides has been widely documented.

Ongley (1996) also found that the resulting pollution problem is exacerbated in many developing countries by the fact that older pesticides (eg. DDT (dichlorodiphenyltrichloroethane)), which may have been banned due to their high environmental risk, are cheap and effective. The monitoring of pesticide concentrations is both costly and complex, and regulations are often not enforced. Thus, many banned pesticides may be openly sold and used in agricultural practise (particularly in developing countries), resulting in a dichotomy between actual pesticide use and official policy in many countries.

In tropical and sub-tropical environments, irrigation of agriculture can provide a habitat conducive to breeding of insects responsible for vector-borne diseases. This can lead, not only to higher application rates for pesticides, but also to usage of extremely toxic and persistent pesticides, such as DDT. Generally, developing countries suffer impacts from pesticides both as a result of overuse and also by inappropriate use, e.g. the use of cotton specific pesticides on foodstuffs.

Ongley (1996) summarise the main problems associated with pesticide management in developing countries:

- Inadequate legislation and enforcement
- Gifts of pesticides from donors (which can encourage inefficient use and abandonment of older stocks)
- Stockpiling of pesticides
- Storage and handling
- High costs of pesticide destruction
- Lack of training of users
- Inappropriate use
- Recycling of old pesticide drums.

The central purpose of pesticides is to kill pests associated, in many cases, with agriculture. They are, thus, toxic in nature and of a potential threat to wildlife. The toxicity of different pesticides in water is, however, highly variable. Four factors principally determine toxicity in water. Firstly, and most obviously, is the toxicity of the pesticides themselves. Secondly, this has to be balanced out with the

persistence of the chemical. Modern pesticides are short-lived and tend to reflect the growing cycle of the pest involved, whereas certain pesticides (many of which are now banned over all or much of the world) can endure for decades. Thirdly the chemical degradation path of pesticides is an important factor and can lead to the formation of compounds which are themselves toxic, for example, DDT can degrade to DDD (dichlorodiphenyldichloroethane) and DDE (dichlorodiphenyldichloroethylene). Fourthly, the potential impact of pesticides is partially dependant upon the compounds speciation, i.e. whether the pesticide is more associated with the solid, liquid or gaseous component, or whether the pesticide has an affinity with biota (Ongley, 1996).

Once a pesticide enters the soil, its fate is largely dependant on sorption and persistence. Sorption is mainly related to the organic carbon content of soils while persistence is evaluated in terms of half-life (the time taken for 50 percent of the chemical to be degraded or transformed). Pesticides with a low sorption coefficient and high water solubility are likely to be leached while pesticides with pesticides with a long half-life could be persistent.

Pesticides can enter the food chain and become an ecological problem principally by either bioconcentration or biomagnefication. Bioconcentration occurs when the pesticide has an affinity with biota (or more likely, the fatty tissue). In cases when this occurs (i.e. when the pesticide is lipophilic), the compound is absorbed from the surrounding environment into the fatty tissue. Biomagnefication occurs as organisms are consumed by a predator resulting in a concentration of the compound within the tissues of the predator.

Some of the effects of pesticides on the aquatic ecosystem can be obvious, e.g. fish kills or clear illness. Other effects, however, can be far less apparent, such as reproduction inhibition, DNA damage, immuno-suppression or some other physiological effect. These less-apparent chronic effects may only be observable long after pesticide enters the ecosystem, possibly even generations later.

C.ii Nutrients

According to the FAO Technical Paper on controlling water pollution from agriculture (Ongley (1996)), there has been a trend of huge increases in fertiliser usage worldwide in the past 40 years and it can be expected that agriculture will be responsible for an ever-increasing contribution of nutrients to surface water pollution.

The crop requirements for nutrients cannot always be met by the underlying soil, either because the soil is infertile or nutrients have been removed by the previous crop (Pearce, 1998). Through the application of fertilisers, increased nutrients can lead to greater productivity. However, this can also put water bodies at risk from pollution. Nutrients can enter water bodies through drainage water, run-off, soil erosion or from surface waters (National Rivers Authority, 1992). There are two main sources of nutrients which are derived from agrochemicals: nitrate fertilisers and phosphate fertilisers. These are discussed in more detail at the end of this section.

The main impact of excess nutrients in surface waters is eutrophication. Eutrophication can be defined as the enrichment of surface waters with plant nutrients, and it results in an increase in biomass. Although there are many sources of nutrients in surface waters, agrochemicals are considered to be a major contributing factor. A particular characteristic of eutrophication is the production of “algal blooms”. In reality, this often leads to the complete dominance of the ecosystem by a small number of organisms, often algae. By blanketing the area, the chemistry of the ecosystem will be disrupted. Due

to the increased biomass, anoxia (or partial anoxia) will often ensue, thus resulting in further loss of biodiversity, both in the water body and to the surrounding ecosystem. Algal blooms can also be potentially toxic. Obviously, depending on the usage, this can have a profound effect upon human activity. Plate 3.1 shows an example of a eutrophic watercourse in southern Sri Lanka.

Ongley (1996) summarises the main symptoms and impacts of eutrophication, which are valid for both inland and coastal waters, as:

- Increase in production and biomass of phytoplankton, attached algae and macrophytes
- Shift in habitat characteristics due to change of aquatic plants
- Replacement of desirable fish by less desirable fish
- Production of toxins by certain algae
- Deoxygenation of water which often results in fish kills, especially after collapse of algal blooms
- Infilling and clogging of irrigation canals with aquatic weeds.
- Loss of recreational use of water due to slime, weed infestation and noxious odour from decaying algae
- Impediments to navigation
- Adverse impacts on fishing industry.

Blooms of cyanobacteria can also cause toxicity problems (Hester & Harrison, 1996).

Nevertheless, Ongley (1996) concludes that by careful application of fertilisers to minimize waste, farmers can have a profound impact upon the reduction of nutrient concentrations and thus, on the surrounding environment.

Nitrogen fertilisers

In agricultural areas suffering from low nitrate concentrations, nitrogen can be supplemented through the application of: -

- Fast release fertilisers – containing chemical nitrates
- Moderately fast fertilisers – containing ammonium nitrate which contains nitrates (immediate) and NH_4^+ which is fairly rapidly oxidised in the soil to nitrate
- Slow release fertilizers – containing organic compounds either as naturally occurring organic biochemicals, or as urea fertilisers. These all eventually break down to form nitrate in the soil.

(Pearce, 1998)

Ultimately all of these fertilisers have the same effect of releasing nitrates into the soil but differ in the speed of that release. The nitrate ion is extremely soluble in water and by coming into contact with drainage water or rain water; nitrate can be easily leached from the soil into groundwater or surrounding surface water bodies. By reducing the concentration of nitrates (or substances such as ammonia which can reduce to nitrate) within the soil profile, the potential for impact to the water environment is reduced. The most obvious way of achieving this is by applying nitrogen at such a quantity that the crop can absorb with no excess.

Phosphate Fertilisers

Despite phosphate fertilisers being used excessively by farmers, phosphates are generally well-retained in soils, and therefore are generally seen as less of a pollution threat compared to nitrates. Only soluble reactive ortho-phosphate (SRP) is generally associated with the soluble phase, but concentrations in drainage water are not generally high enough to contribute significantly to eutrophication. The main route for phosphorus to drainage water is through runoff as sediment-bound inorganic and organic phosphate.

C.iii Sediments

Agriculture activities, such as disturbing the soil through tillage and cultivation and leaving it without vegetative cover may increase the rate of soil erosion. While there are no global figures, it is probable that agriculture, in the broadest context, is responsible for much of the global sediment supply to rivers, lakes, estuaries and finally into the world's oceans (Ongley,1996).

Pollution by sediment has two major dimensions(Ongley,1996)

(a) One is the PHYSICAL DIMENSION - top soil loss and land degradation by gullying and sheet erosion and which leads both to excessive levels of turbidity in receiving waters, and to off-site ecological and physical impacts from deposition in river and lake beds.

(b) The other is a CHEMICAL DIMENSION - the silt and clay fraction (<63μ m fraction), is a primary carrier of adsorbed chemicals, especially phosphorus, chlorinated pesticides and most metals, which are transported by sediment into the aquatic system

Sediment may cause both, physical and chemical damages to water resources and to water users. The most obvious impact of suspended sediment is to reduce light penetration through the water column and therefore reduce the level of photosynthetic activity, alters oxygen levels and reduces the food supply for certain aquatic organisms, which may destroy or degrade aquatic wildlife habitat. Sedimentation may also causes algae blooms from the increased nutrient levels in the water. Sedimentation slowly fills in lakes and reservoirs, reducing their water holding capacity and may increase the probability and severity of floods. Sedimentation may also increase the cost of water treatment.

Sediment particles (clay, silt, and sand), but also algae, plankton, microbes, and other substances that will not pass through a filter with pores of around 2 microns (0.002 cm) in size are expressed by the Total Suspended Solids (TSS). TSS is measured in the lab, following standard procedures.

C.iv Metals

Metals in the drainage water from agricultural areas can originate from a number of varied sources. Organic fertilisers and pesticides can be a source of metal enrichment, as can machinery required for the function of many modern farms. Soils themselves can also be a source of metals. Metals tend to be immobile under highly reducing environments. Aeration of the soil by tillage or acidification by ammonia volatilization can alter the soil chemistry to increase the mobility of metals (Calder, 2000).

Non-essential heavy metals of particular concern to surface water systems, which are related to agricultural activities, include mercury and arsenic (Chapman, 1996). Additional metals (Cu, Zn, etc.) can be analysed depending on specific local use or natural occurrence at significant concentrations.

Excess metal levels in surface water may pose a health risk to humans and to the environment (Chapman, 1996). However, chronic metal poisoning usually present minor symptoms similar to those of many common ailments, making actual metal poisoning difficult to diagnose.

C.v Pathogens

A number of bacteria occur naturally in freshwater streams, however, when a stream is polluted by faecal material, pathogenic (disease-causing) bacteria, viruses, and parasites may be introduced, posing a health hazard to those who come in contact with the water.

Rather than test water directly for pathogens, which can be difficult, expensive and even hazardous, an indicator organism is usually used to assess the possibility of faecal contamination. Faecal coliform bacteria are often used as indicators as they (Chapman, 1996):

- Are present when **pathogens** are present, absent when **pathogens** are absent.
- Are present in sufficient numbers to provide an estimate of pathogen density.
- Are easily and economically quantifiable and do not provide false tests.
- Respond similarly to the **pathogens** of interest

The most commonly tested faecal bacteria indicators are: Total Coliforms (TC), Faecal Coliforms (FC), Eschericia coli (E.coli), Faecal Stroptococci (FS) and Enterococci.

Most faecal bacteria are not pathogenic. However, because they are eliminated with faeces, they are sometimes associated with pathogenic bacteria, viruses and protozoans such as *Vibrio cholera* bacteria or a form of Hepatitus virus that is found in the digestive tract.

Total coliforms are a group of bacteria that are widespread; found in human, animal faeces as well as outside any living organism, which makes them less precise indicators as they can live and reproduce in soil and water. However, they are the standard test for drinking water because their presence indicates contamination of a water supply by an outside source (Chapman, 1996).

Feacal coliforms, a subset of Total coliform bacteria, are often used as the indicator bacteria. Although of a more faecal-specific origin, this group contains a genus (Klebsiella) with species that are not necessarily fecal in origin. Therefore relatively recent recommendations are proposed to use E.coli and Enterococci as better indicators of health risk from water contact (U.S. EPA. 1997).

Escherichia coli and Faecal streptococci are typical members of the bacterial flora of the gastrointestinal tract of humans and other warm-blooded animals. No indicator has been identified that is exclusive to humans or animal. The ratio of streptococci to fecal coliform was once thought to determine human versus animal fecal contamination. But, this is no longer though to be reliable because streptococci numbers vary in response to a wide variety of environmental and physiological parameters, making it difficult to assess true concentrations (U.S. EPA. 1997).

Enterococcal bacteria are a subgroup within the faecal streptococcus group and are typically more human-specific than the larger faecal streptococcus group (U.S. EPA. 1997). However, testing for these organisms involves a lengthy and complicated procedure.

C.vi Dissolved Oxygen and Biological Oxygen Demand

Aquatic ecosystems both produce and consume oxygen: oxygen is gained from the atmosphere and from plants as a result of photosynthesis, while respiration by aquatic animals, decomposition, and various chemical reactions consume oxygen.

Oxygen is a necessary element to all forms of life and an adequate dissolved oxygen is necessary for good water quality.

Oxygen is measured in its dissolved form as dissolved oxygen (DO). If more oxygen is consumed than is produced, dissolved oxygen levels decline and some sensitive animals may move away, weaken, or die. DO levels fluctuate seasonally and over a 24-hour period. They vary with water temperature, salinity and pressure.

Wastewater from agricultural land often contains organic materials that are decomposed by microorganisms, which use oxygen in the process. The amount of oxygen consumed by these organisms in breaking down the waste is known as the biochemical oxygen demand (BOD). BOD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die. Although BOD is not a specific compound, it is defined as a test to establish potential pollution by organic materials. This is of particular concern, as organic particles in the water may harbour harmful bacteria and pathogens. Infections by the microorganisms may occur if the water is used for primary contact or as a raw drinking water source.

C.vii Specific Ions

Irrigation, especially in arid areas can lead to salinisation of surface and groundwaters and therefore, inclusion of chloride, conductivity and sodium might be important for water quality assessment. Dominance of certain ions might cause an imbalance affecting living organisms, crops, and the aquatic environment in general.

Chloride is an anion that works closely with sodium and water to help the distribution of body fluids (mineral electrolyte) and is therefore required for normal cell functions in plant and animal life. Deficiency and toxicity are not of much concern, although chloride can be found paired as a salt with other organic and inorganic elements, which might in turn constitute a threat to human health and the environment. Large amounts of chloride intake (more than 15 grams per day), usually in salt, may cause some problems with blood pressure, fluid retention and altered acid-base balance (although the main problem lies with the sodium). High chloride levels can also affect plant growth and fish and aquatic communities cannot survive in high levels of chlorides. Chlorides can corrode metals and affect the taste of food products.

Conductivity (EC) is a measure of the ability of water to pass an electrical current. It is affected by the presence of inorganic dissolved solids such as chloride, sodium, calcium, sulphate, nitrate, magnesium, phosphate, iron and aluminium. Because it is affected by temperature: the warmer the water, the higher the conductivity, conductivity is reported as conductivity at 25 degrees Celsius (25 C) and expressed in micromhos per centimetre (µmhos/cm) or microsiemens per centimetre (µs/cm). Discharges to streams can change the conductivity depending on their make-up; agricultural run-off

would raise the conductivity because of the presence of chloride, phosphate, and nitrate, while an oil spill would lower the conductivity. Conductivity outside this range could indicate a stress to the environment and to human health, as the water is not suitable for certain organisms and especially certain species of fish or macroinvertebrates.

Where irrigation water is dependent on water reuse, not only the total salt concentration should be taken into account, but also the sodium to calcium and magnesium ratio, commonly expressed as the sodium adsorption ratio (SAR). The SAR is used to predict the sodium hazard of crops, where sodium replaces calcium and magnesium at the expenses of the plants. This replacement affects plants in three ways (Chapman, 1996):

- By destroying soil structure causing clay particles to disperse rather than cling together as small peds (coarse blocky texture, crust formation after rain or irrigation) and reducing water movement (permeability) and aeration in the soil.
- By poisoning sodium sensitive plants when absorbed by either their roots or leaves.
- Calcium and/or potassium deficiencies may occur if the soil or irrigation water is high in sodium.

Therefore, FAO has set specific values to guide the quality of irrigation water.

Appendix D: Methods: Water Quality

D.1 General

D.1.1 Introduction

As the study of livelihoods and agricultural practices, water quality of both study cases has been monitored in this project in order to assess the impacts of diffuse agricultural pollution through the analysis of several parameters in each case study.

The timing of sampling was linked to the crop calendar and samples were approximately taken on a monthly basis during the crop season, although this was slightly adjusted to correspond to planed applications of agrochemicals. In each country, twelve sampling locations were respectively defined under several criteria thus enabling the monitoring of all significant locations. Samples were collected by the grab sample method and analysed in central laboratories in Cairo and Colombo in accordance with standard procedures (generally APHA). A systematic Quality Assurance system (QA) was set up including testing of blanks and duplicates in both central laboratories and in the United Kingdom.

The monitoring campaign was realised in each country by local organisms: The Drainage Research Institute (DRI) in Egypt and The International Water Management Institute (IWMI) in Sri Lanka. A guidance schedule was established with these local organisms defining the parameters to be analysed each month. Two types of analyses have been undertaken through out the whole campaign such as:

- In situ : where some physico-chemical parameters have been directly analysed on each sampling sites,
- Ex situ analyses where samples were taken to laboratories to undertake analyses of precised parameters.

Although precautions were taken during the 2005 Water Quality Monitoring campaign, the methodology applied is subjected to limitations (particularly concerning pesticides) as discussed in this report (see Section 3.2.2).

D.1.2 Parameters analysed through out the campaign

D.i List of parameters studied within in situ conditions

Field analyses for physico-chemical and microbiological variables were carried out using field apparatus. The significant advantage of field analysis is that tests are carried out on fresh samples which characteristics have not been contaminated or altered from container used. Some resultx coming out of laboratory analysis could be checked by comparing the obtained values to those obtained within in situ conditions. Further, samples taken within in situ condition are clearly relevant of the realistic conditions found in each study case where evolution of samples before any laboratory analysis could bias the results, hence their interpretation which has to remain critical.

Figure D.1: Descriptive list of parameters studied within in situ conditions

Parameter	Unit	Remarks
Temperature	Degree Celsius (ºC)	
pH	pH Unit	Also analysed in laboratory conditions
Electric conductivity (EC)	mS/cm (or equivalent to dS/m)	
Total Dissolved Solids (TDS)	mg/l	
Turbidity	NTU	
Salinity	g/l	
Dissolved Oxygen (DO)	mg/L (and % O_2 saturation)	
Visual	-	Done by sampler on field highlighting any particular remark in sampling conditions

D.ii List of Parameters studied in laboratories

For each sample (including blank and duplicates), parameters have been studied in laboratories covering several aspects of the water quality monitoring relative to this project. However general, the following list of parameters is subjected to local laboratory procedures which will be dealt with later for each case study. The parameters examined in this project may be grouped in seven categories as follow:

- Physical parameters (some of which are also analysed within in situ conditions)
- Oxygen budget (some of which are also analysed within in situ conditions)
- Salts (some of which are also analysed within in situ conditions)
- Nutrients
- Bacteriological
- Metals
- Pesticides

In addition, the list of pesticides analysed in both case studies has been established in accordance with the agricultural studies and general knowledge from the respective study areas. Although considered as complete, this list is to be considered as the broadest range of chemical that could be potentially found in the studied areas rather than biocides detected during the monitoring campaign. We will additionally remark that several limitations are recognised after the campaign and discussed in the main report.

Table D.6: Descriptive list of water quality parameters studied within laboratory conditions

Group	Parameter	Symbol	Unit	Indicative LoD (UK Laboratory)
Physical Parameters	Acidity	pH	-	NA
	Turbidity	Tur	NTU	NA
	Total Suspended Solids	TSS	mg/l	NA

Group	Parameter	Symbol	Unit	Indicative LoD (UK Laboratory)
Oxygen Budget	Dissolved Oxygen	DO	mg/l O_2	NA
	Oxygen saturation	DO %	% saturation O_2	NA
	Biological Oxygen Demand	BOD	mg/l O_2	NA
	Chemical Oxygen Demand	COD	mg/l O_2	NA
Salts	Electric Conductivity	EC	mS/cm (or dS/m)	NA
	Total Dissolved Salts	TDS	mg/l	NA
	Sodium Adsorption Ratio	SAR	-	NA
	Calcium	Ca	mg/l (or meq/l) Ca^{2+}	< 5µg/l
	Magnesium	Mg	mg/l (or meq/l) Mg^{2+}	< 5µg/l
	Sodium	NA	mg/l (or meq/l) Na^{+}	< 0.2 mg/l
	Potassium	K	mg/l (or meq/l) K^{+}	< 0.2mg/l
	Carbonate	CO_3	mg/l (or meq/l) CO_3^{2-}	NA
	Bicarbonate	HCO_3	mg/l (or meq/l) HCO_3^{-}	< 2mg/l
	Sulphate	SO_4	mg/l (or meq/l) SO_4^{2-}	< 3mg/l
	Chloride	Cl	mg/l (or meq/l) Cl^{-}	< 1mg/l

Table D.7: Descriptive list of water quality parameters studied within laboratory conditions (CONTINUED)

Group	Parameter	Symbol	Unit	Indicative LoD (UK Laboratory)
Nutrients	Nitrates	NO_3-N	mg/l NO_3-N	< 0.3mg/l
	Nitrites	NO_2-N	mg/l NO_2-N	-
	Ammonia	NH_4-N	mg/l NH_4-N	< 0.2mg/l
	Total Phosphate	PO_4	mg/l PO_4	< 0.08mg/l
Bacteriological	Total Coliforms	T-Coli	MPN / 100 ml	NA
	Faecal Coliforms	F-Coli	MPN / 100 ml	
Metals	Iron	Fe	mg/l (or µg/l)	< 5µg/l
	Manganese	Mn		< 1µg/l
	Zinc	Zn		< 3µg/l
	Copper	Cu		-
	Cadmium	Cd	µg/l	< 0.4µg/l
	Lead	Pb		-
	Arsenic	As		-
	Mercury	Hg		-
Pesticides	See separate table relative to each case study			

D.1.3 Field Procedures

D.i Samples related procedures

1. Sample preservation

The preservative treatment was applied immediately upon sampling and summarized in Table D.8

Table D.8: Preservative treatments applied to samples

Element	Container (type)	Volume (indicative)	type of conditioning
Anions	polyethylene	-	Cool 4°C
Cations	polyethylene		
Nitrate	polyethylene	250ml	Cool 4°C
Nitrite	polyethylene		
Ammonia	polyethylene		H_2SO_4 Cool4°C
Phosphorus	Glass	50ml	Cool 4°C
Iron	polyethylene	1000ml	HNO_3 under normal temperature
Manganese	polyethylene		
Zinc	polyethylene		
Copper	polyethylene		
Cadmium	polyethylene		
Lead	polyethylene		

Element	Container (type)	Volume (indicative)	type of conditioning
Arsenic	polyethylene		
Mercury	Glass	100ml	$H_2SO_4+2Cr_2O_7$ Cool 4°C
BOD	polyethylene	1000ml	Cool 4°C
COD	polyethylene		

2. .Transportation and storage of samples

After collection of samples the following actions need to be undertaken by the collectors (for both primary and duplicate samples):

- Provide an identification label on every sample on which the following information as legibly written:
  - Name of the study
  - Sample number
  - Station number
  - Sampling depth
  - Date and time of sampling
  - name of the collector
  - Details of weather and unusual conditions at the time of sampling.
- Place sample bottles in a suitable transport box containing cold water (4°C) together with ice packs.
- After conditioning, the samples should be sent on the same day to laboratories so as to limit any evolution of the parameters from in situ conditions.

3. Field procedures for pesticide monitoring samples

Pesticide monitoring is particularly difficult as the products are applied in very small quantities and decay quite rapidly under the influence of several factors (hydrolysis, photodegradation, etc). Moreover the quality of samples taken is highly dependant on the time and place of sampling affecting the amounts of residues found in Waters. As a result, specific sampling and preservation conditions need to be applied during collection of samples.

Table D.9: Indicative Preservative Treatment applied to Pesticide Collection.

Type of pesticide	Sample container	Preservation treatment
Carbamate Herbicides	Glass	$H_2SO_4+Na_2SO_4$ Extract immediately -
Organo-phosphorus		HCl No holding extraction in site

The sample container is preferably a brown glass bottle which volume is one litre. Samples are collected for each site at a depth of 50 cm from the surface and filled to the top without any air bubble trapped in the bottle. After collection, the samples should follow the same conditioning steps as described above. In addition, the sample delivery to laboratories should be done within the same day whereas the maximum time elapsed from collection is of three days.

D.ii Field testing method: In-situ measurements

The procedures for measuring each parameter are mentioned below as should be done by collectors in the field. However general, these methods may be used during in situ analyses as guidelines and differences may occur due to the type of apparatus used. Moreover, one or two additional measurements should systematically be done so as to check the values obtained. To avoid any contamination of samples, the apparatus must be rinsed between each site and measurements should not be made directly in samples' containers to be sent to laboratories.

1. Temperature

Temperature may be measured in situ with several apparatus basically consisting of two different methods: In both cases, repeated measurements should be made to check the previous values obtained.

- With a glass thermometer (i.e. mercury-filled). The thermometer must be immersed in the water until the liquid column stops moving. Reading should be recorded to the nearest 0.1^oC (however depending on the graduation of the thermometer).

- With electrometric thermometers where the probe should be immersed in water until displayed values on the screen become stable.

2. Acidity (pH)

pH is usually measured by electrometric pH meter being relatively accurate thus needing regular calibration before starting the sampling campaign. During in situ measurements some steps need to be undertaken by the collectors such as:

- Rinsing the electrodes and the beaker with a portion of the sample.

- Fill the beaker with the sample and immerse the electrodes into the sample beaker concerned with the tip immersed to an approximate depth of 3cm.

- The temperature and the pH are usually measured at the same time. Some apparatus need temperature compensation while measuring the pH (which is usually done automatically, but this aptitude has to be checked systematically for each apparatus).

- A quick check may be realised with colour band pH measurements.

3. Electric conductivity (EC)

The measurement of the electric conductivity should be made systematically during sample collection as this parameter evolves rapidly even within the best storage conditions. EC is usually measured with electrometric apparatus and is highly dependent on temperature, thus needing temperature adjustment for some apparatus. The following steps should be realised when sampling:

- Rinse the conductivity cell with a portion of the sample.

- Immerse the conductivity cell into the sample container until reaching approximately the middle of the latter

- Both temperature and EC values should be recorded when a relative stability is obtained on the display screen.

4. Dissolved oxygen (DO)

The dissolved oxygen concentration depends on the physical, chemical and biochemical activities in the water body, and its measurement provides a good indication of water quality. Field measurements with electrometric method may be considered as a reference when establishing oxygen budget of the samples. However, this parameter is highly dependant on temperature which needs to be measured systematically when taking the following steps:

- Calibrate the electrometer.

- Rinse the electrode with a portion of the water to be sampled.

- Immerse the electrode in the sample.

- Record the temperature and the meter reading when relative stability is obtained.

5. Visual assessment

When collecting the samples and proceeding to analyses within in situ conditions any specific remark concerning the sampling conditions should be recorded by the collector. These include the weather conditions, colour and relative turbidity as visible in the streams, abnormal low/high flow velocity, etc. Such information may become of use when interpreting the data obtained and proceeding to comparison with ex situ analyses results.

D.2 Description of each case study and laboratory procedures

D.2.1 Egypt Case Study

D.i Description of sampling sites and conditions

The study areas are quite large, and thus it was necessary to design a monitoring programme which gave an overview of problems throughout the catchment and a detailed understanding within a smaller area. The general study focused on the main canals and drains, whereas the detailed studies looked at conditions within small drains. Sampling was not done within fields.

The general study covered seven locations from the main supply from the Nile to the last lake.

- **Site 10**: Located on Bahr Yussef, which transports water from the Nile and is the only source of water for the Wadi El-Rayan catchment.
- **Site 9:** The start of Wadi El-Rayan Drain downstream of Al-Mukhtalatah village just after branching off from Wadi Qarun Drain. This is the main drain of the study area
- **Site 8**: Sampling location selected on Bahr El-Nazla, a main canal before any drainage water from the Wadi El-Rayan Drain is added.

- **Site 6**: At the end of the Wadi El-Rayan drain, before discharging into the first lake in Wadi El-Rayan. This location is also included in the NAWQAM Project.
- **Site 7**: Just before the waterfall between the first and the second Wadi El-Rayan Lake, where water levels are also automatically recorded. This location is also included in the NAWQAM Project.
- **Site 12:** The centre of the second Wadi El-Rayan Lake drains into a second lake, where a sampling location has been selected.
- **Site 11:** Drinking water sampled in Wadi El-Rayan village..

The Detailed Study area focused on five locations around Sha'lan village

- **Site 1:** Bahr El-Banat canal, immediately upstream of the detailed study area.
- **Site 2:** At Hanna Habib on the secondary canal flowing from Bahr El-Banat.
- **Site 3:** A collector drain taking water from a maize-beans area.
- **Site 5:** A collector draining a cotton-berseem area..
- **Site 4:** The secondary drain taking all drainage waters from the detailed study area.

A short summary of the sampling sites involved in the Egypt case study is summarized in the table D.13. The sample collection was undertaken on an approximate monthly basis in accordance to the local cultivation season. Samples collected from January to November 2005 were sent to a central laboratory in Cairo were ex situ analyses have bee undertaken.

Table D.10: Sampling Sites List

Site	Name	Coordinates	Location	Type	Study Site	Remarks
1	Bahr El-Banat	29 17 52 N 30 34 88 E	Iz. Wadi El-Rayan	Main Canal	Detailed study	Before mixing with drain water
2	Hanna Habib	29 19 22 N 30 34 22 E	Downstream of village	Main Canal	Detailed study	Canal water used for irrigation
3	Collector 1	29 19 17 N 30 3512 E	Detailed study area	Tertiary Drain	Detailed study	Maize field.
4	Secondary drain	29 18 30 N 30 35 20 E	Detailed study area	Secondary Drain	Detailed study	Combined drainage
5	Collector 2	29 18 44 N 30 35 18 E	Detailed study area	Tertiary Drain	Detailed study	Cotton field.
6	End of tunnel	29 17 38 N 30 35 10 E	End of Wadi tunnel	Primary Drain	General study	Entrance Wadi El-Rayan 1st lake
7	Upstream Waterfall	29 17 50 N 30 25 22 E	Waterfall	Lake	General study	Outlet Wadi El-Rayan 1st lake
8	Bahr el-Nazla	29 17 77 N 30 35 79 E	Iz. El-Sadawi	Main canal	General study	before mixing with drain water
9	Wadi El-Rayan	29 17 42N 30 36 16.4E	Downstream of Al-Mukhtalatah	Primary Drain	General study	Mixed urban-rural drainage
10	Bahr Yussef	29 14 59.4 N 30 54 38.7E	Upstream of Al-Fayyum	Primary Canal (Nile)	General study	Sole inflow to study site
11	Drinking Water	-	Iz. Wadi El-Rayan	Drinking water	General study	Treatment station
12	Second Lake	-	Wadi El-Rayan 2nd lake	Lake	General study	-

D.ii Water quality monitoring schedule

Table D.11: Descriptive Schedule of Water Quality Monitoring in Egypt

Month (2005)	Date	Type of analysis	Replicates
March	5-6/03/2005	WQ (General)	6 samples at location 9
	29/03/2005	Pesticides	-
April	13/04/2005	WQ (General)	-
May	17/05/2005	Pesticides	-
	22/05/2005	WQ (General)	3 locations with 2 samples each
June	10/06/2005	WQ (General)/Pesticides	2 locations with 2 samples each
July	16/07/2005	WQ (General)/Pesticides	1 sample
August	7/08/2005	WQ (General)/Pesticides	1 sample
September	1/09/2005	WQ (General)/Pesticides	1 sample
October	23/10/2005	WQ (General)/Pesticides	1 sample
November	27/11/2005	WQ (General)/Pesticides	1 sample

D.iii Laboratory Procedure: General methodology

On their arrival to the laboratory, samples handed over are placed in refrigerators at 4ºC. Analyses of bacteriological and oxygen budget parameters are done within the first two hours whereas the other parameters are dealt with in the first 24 hours. The procedures recommended for laboratory analyses should be as follow:

- All the necessary details are recorded from the labels of sample bottles,
- The storage temperature of samples is checked,
- The maximal permissible storage time of samples is checked.
- Visual assessment of both containers and samples is made,
- Proceed to the analyses in accordance to list of parameters defined through out this study where priority should be given to fleeting ones
- Observe notes on specific conditions of the sample during the analysis and record the results.
- A special attention should be made, when recording the results where any remarks from the laboratory should be reported to the local organisms.

D.iv Specific Procedures applied to Pesticides

The list of pesticide analysed in the Egypt case study is summarised as follow:

Abamectin	Dichlorvos	Gamma-BHC (Lindane)	p,p'-DDT
Aldrin	Dieldrin	Gamma-chlordane	P,P-Dicofol
Alpha-BHC	Dimethoate	Heptachlor	p,p'-Methoxychlor
Azinphos methyl	Endosulphan I	Heptachlor Epoxide	p,p'-TDE(DDD)
Beta-BHC	Endosulphan II	Malathion	Parathion
Carbaryl	Endosulphan sulphate	Meothrin	Permethrin
Chlorpyriphos	Endrin	Methamidophos	Phenthoate
Chlorpyriphosmethyl	Esfenvalerate	Methomyl	Pirimiphosmethyl
Cyahalothrin	Ethion	Methoxychlor	Profenophos
Cypermethrin	Ethoprophos	Methyl Parathion	Prothiophos
Delta-BHC	Fenamiphos	Mevinphos	Sumithrin
Deltamethrin	Fenitrothion	o,p'-DDT	Tetramethrin
Diazinon	Fenvelerate	p,p'-DDE	

The apparatus provided by the Cairo Laboratory to analyses pesticide residues in collected samples are as follow:

The analysis of Organochlorine and Pyrethroid Pesticide residues is realised by means of Gas Chromatography with Electron Capture Detector (GC-ECD – Hewlett Packard GC Model 6890 equipped with a Ni63 -electron capture detector). Its limit of detection (LoD) range is of 0.005-0.01µg/l. The gas chromatography is realised by means of a DB-17(J&W Scientific) capillary column (30m length x 0.32 mm internal diameter: id x 0.25µm film thickness). N_2 is injected as the carrier gas at a flow rate of 4 ml/min. The temperatures of injector and detector were respectively of 280ºC and

300ºC whereas the initial column temperature was the one of the oven (160ºC) for 2 min, then raised at 3ºC/min and finally held at 260ºC for 20 min.

Organophophorus Pesticide Residues have been analysed by means of Gas Chromatography with Flame Photometric Detection (GC-FPD – Hewlett Packard GC Model 6890 phosphorus filter). Its limit of detection ranges from 0.01 to 0.05µg/l. The chromatography is realised by means of a fused silica capillary (PAS-1701) column containing 14% cyanopropilsyloxane as stationary phase (30m length x 0.32 mm internal diameter: id x 0.25µm film thickness). As operating conditions, the injector and detector temperatures were respectively of 250ºC and 240ºC. The initial temperature was the one if the oven, 160 ºC during 2 min. The latter was then raised at 5ºC/min and held at 230 ºC during 15 min. The carrier gas was nitrogen (N_2) injected at 3 ml/min whereas hydrogen and ambient air were respectively injected at 75 and 100 ml/min as combustible in the flame detector.

Abamectin, Carbamate and Methomyl residues were analysed by means of a High Performance Liquid Chromatography equipped with a Diode Array Detector (HPLC-DAD). Its limit of detection was of 0.01µg/l. A High Performance Liquid Chromatograph (Agilent 1100 Series with work station) was also used. The U.V Diode - Array Detector was set at 220 nm whereas a Zorbax - C18, (5 µm - 4.6 x 150 mm) analytical column was used as stationary phase. The Mobile phase was a mix of Acetonitrile and Water injected at several flow rates gradient as follows:

Table D.12: HPLC-DAD Mobile Phase injection gradients

Time (min)	Acetonitrile	Water	Flow
0	50	50	0.7
2	30	70	0.5
5	50	50	0.7

D.2.2 Sri Lanka Case Study

D.i Description of sampling sites and conditions

In the selection of sampling sites, four points (2, 5, 8, and 10) were selected on *ara* at various distances from the Kachchigala tank or the upper most point of the catchment considered. The other sampling points were selected after taking into account the drainage areas that can have an effect on the water quality of Kachchigala *Ara* as listed in table D.17:

Table D.13: Sample Sites List

Site no.	Site name	Type	Site Co-ordinates	Nearest village	Surrounding crop(s)
1	Mamadala BC	Irrigation canal	N 06^0 16.326' E 080^0 52.042'	Kachchigala	paddy, coconut
2	Kachchigala *ara*	*ara*	N 06^0 15.448' E 080^0 52.544'	Uswewa	paddy
3	Metigathwala	Drainage channel	N 06^0 14.894' E 080^0 52.759'	Metigathwala	paddy
4	Metigathwala *wewa*	wewa	N 06^0 14.083' E 080^0 53.068'	Metigathwala	paddy, banana
5	Kalawelwala	*ara*	N 06^0 12.923'	Samagipura	paddy

Site no.	Site name	Type	Site Co-ordinates	Nearest village	Surrounding crop(s)
			E 080^0 54.581'		
6	Jandura *wewa*	Drainage channel within an abandoned tank	N 06^0 11.666' E 080^0 54.993'	Maha Jandura	paddy, vegetable
7	Mulanagoda	*ara*	N 06^0 10.195' E 080^0 54.603'	Angunakolapelassa	paddy
8	Handunkatuwa	*ara*	N 06^0 09.836' E 080^0 55.544'	Handunkatuwa	paddy
9	Ethbatuwa	Drainage channel	N 06^0 09.489' E 080^0 56.066'	Ethbatuwa	paddy
10	Hungama bridge	*ara*	N 06^0 06.616' E 080^0 56.213'	Hungama	wetland
11	Kalamatiya lagoon	lagoon	N 06^0 05.198' E 080^0 56.109'	Hungama	wetland
12	Siyambalakatu *ara*	*Ara* before irrigation commenced	N 06^0 12.107' E 080^0 54.863'	Kachchigala	paddy, banana

D.ii General information on laboratory procedures

In the first sampling round the water samples were collected from 19 sampling points whereas in the next 4 sampling rounds the samples were taken only from the 12 selected sampling points. Sampling was carried out once a month during the *Yala* (April to August 2005) season. Samples for microbiological analyses were collected into sterilized 150 ml brown glass bottles. Pesticide and BOD samples were collected in 1l brown glass bottles. The other parameters water samples were collected into 5l plastic cans. Soon after collection, all the samples were stored at temperature below 4^0C and transported to the Colombo central laboratory within 24 h.

As soon as the samples were handed over to the laboratory the temperatures of all the samples were recorded. Total and faecal coliforms, BOD and Nitrite analyses are carried out on the same day. Sample storage procedures and the maximum storage periods are given as follow (Table D.18):

Table D.14: Sample storage methods and maximum storage periods

Parameter	Treatment method	Maximum storage period
Nitrate	Store at 4 ^{0}C	2 days
Ammonia	Add H_2SO_4 to pH<2 and store at 4 ^{0}C	7 days
Phosphate	Store at 4 ^{0}C	2 days
Solids	Store at 4 ^{0}C	7 days
Turbidity	Store at 4 ^{0}C in dark	24 hours
Metals (general)	Filter immediately and add HNO_3 to pH<2	6 months
COD	Add H_2SO_4 to pH<2 and store at 4 ^{0}C	7 days

The samples were analysed for various water quality parameters using given standard methods.

Table D.15: Water quality parameters evaluated and the respective methods

Parameter	Test method
Turbidity,	APHA 213 0 B
Total Dissolved Solids (TDS)	CML 33
Total Suspended Solids (TSS) at103-105^{0}C	APHA 2540 D
Chloride (as Cl),	APHA 4500 – Cl B
Calcium (as Ca^{2+}),	APHA 3500 Ca – D
Sodium (as Na^+),	APHA 3111 B
Potassium (as K^+)	APHA 3111 B
Magnesium (as Mg^{++})	APHA 2340 & 3500 CaD
Ammonia as NH_3	SLS 614
Bicarbonate as $CaCO_3$	APHA 2320 B
Manganese as Mn	APHA 3111 B
Sulphate as SO_4^{3-}	APHA 4500-SO_4C
Nitrite (as N),	APHA 4500 – NO_3^-B
Nitrate (as N),	APHA 4500 – NO_2^-B
Orthophosphate (as PO_4)	APHA 4500 – PC
Total Phosphate (as PO_4)	APHA 4500-P B&C
COD,	APHA 5220 B
BOD at 30^{0}C	APHA 5210 B
Aluminium as Al	APHA 3111 D
Arsenic as As	APHA 3114 C
Lead as Pb	APHA 3111 B
Copper as Cu,	APHA 3111 B
Cadmium as Cd	APHA 3111 B
Zinc (as Zn)	APHA 3111 B
Chromium as Cr	APHA 3111 B
Cobalt as Co	APHA 3111 B
Coliforms and faecal coliforms	APHA 9221
Pesticides	CML11 (ECD / NPD)

D.iii List of pesticides analysed in Colombo Central Laboratory

As in the Egypt case study, a specific list of pesticides has been analysed in accordance with the agricultural practices in the study area. The list of pesticide analysed is given as follow:

Alachlor	Diazinon	Fenthion	p,p'-DDE	Quinalphos
Aldrin	Dieldrin	Gamma-BHC	p,p'-DDT	
Alpha-BHC	Dimethoate	Heptachlor	p,p'-TDE(DDD)	
Beta-BHC	Endosulphan I	Heptachlor Epoxide	Parathion	
Captan	Endosulphan II	Malathion	Parathion Methyl	
Carbofuran	Endosulphan sulphate	Metalaxyl	Phenthoate	
Chlorothalonil	Endrin	Monocrophtos	Pirimiphosmethyl	
Chlorpyriphos	Endrin aldehyde	o.p’ DDD	Profenophos	
Delta-BHC	Fenitrothion	o.p’ DDT	Propanil	

D.3 Quality assurance

A quality assurance system was put in place to manage the quality of the water quality monitoring in each case study. As far as in situ procedures are concerned, duplicate samples have been collected in some location within each case study. The purpose was to select a certain number of locations each months where these duplicates were collected in addition to field measurements repetition in order to provide the best data quality. Limitations were found in terms of budget, hence the limited number of duplicates taken.

Blank samples were included in the sample box handed over to the laboratories enabling a continuous quality management of the laboratory results. In addition, some duplicate samples were tested in a laboratory in the United Kingdom for control analyses on the same parameters.

The data resulting from field and laboratory analyses have also been systematically controlled by means of recognised methods such as the ion balance.

Appendix E: Egypt – Water Quality Monitoring Data

This Appendix is divided in two major parts respectively including:

- The 2005 Water Quality monitoring data in the Egypt case study by means of the in situ measurements data, the pesticides detected and two sets of graphs.
  - The in situ measurements data consist of a table presenting the parameters analysed within Insitu conditions on each location during the whole monitoring campaign.
  - The pesticides detected consist of a table presenting the biocides detected through out the monitoring campaign on several locations.
  - The first set of graph includes time series plots for selected parameters through out the whole monitoring campaign enabling a graphic illustration of seasonal variation of the parameters at each sampling site.
  - The second represents the variation of the water quality down the system for each parameter. In this particular case, the x axis represents the locations where samples have been collected down the system from the intake Bahr Yussef (location 10), through the detailed study area (locations 3 to 5) to the end at Wadi Rayan Lake (location 12). Drinking water samples are identified by location 11.

- The NAWQAM study where data collected by this organism have been plotted for each parameter under time series format. This part also includes the sampling locations and their respective descriptions.

E.1 The 2005 Water Quality Monitoring Campaign

E.1.1 In Situ Measurements data

Table E.1: In situ Measurements data – Egypt Case Study

Code	Location	Date	pH	E.C	TDS	DO
				ms/cm	mg/l	mg/l
1	Banat before mixing	Mar-05	7.1	0.7	540	9.8
		Apr-05	7.55	0.64	502	10.2
		May-05	7.58	0.664	425	4.9
		Jun-05	7.57	0.69	441	5.1
		Jul-05	7.89	0.79	505.6	4.89
		Aug-05	7.85	0.72		4.31
		Sep-05	7.63	0.706		5.01
		Oct-05				
		Nov-05	7.78	0.872		5.77
2	Hana Habib	Mar-05	8	0.85	636	13.9
		Apr-05	7.55	0.79	612	8.6
		May-05	7.58	0.724	464	5.2
		Jun-05	7.74	0.779	498	6
		Jul-05	7.99	0.89	569.6	5.8
		Aug-05	7.93	0.88		4.83
		Sep-05	7.7	0.806		4.59

			pH	E.C	TDS	DO
		Oct-05				
		Nov-05	7.94	0.904		6.031
3	Collector 1 (maize field)	Mar-05	7.3	4.47	ND	10.3
		Apr-05	7.73	3.69	2435	9.7
		May-05	7.64	3.46	2325	52
		Jun-05	7.2	3.77		4.4
		Jul-05	7.25	4.77	out of range	4.48
		Aug-05	7.18	5.16		2.99
		Sep-05	7.1	4.83		4.14
		Oct-05				
		Nov-05	7.17	5.24		4.64
4	Main drain of study area	Mar-05	8	2.9	ND	23.7
		Apr-05	7.2	2.58	1703	7
		May-05	7.19	2.67	1711	6.5
		Jun-05	7.69	2.18	1400	6.1
		Jul-05	8.11	3.35	out of range	6.1
		Aug-05	8.22	3.09		4.11
		Sep-05	7.78	2.13		6.33
		Oct-05				
		Nov-05	7.82	2.69		7.36
5	Collector 2 (cotton field)	Mar-05	7.25	3.03	ND	10.9
		Apr-05	7.55	1.06	820	9.3
		May-05	7.68	0.94	601	7.9
		Jun-05	8.04	1.28	817	7.9
		Jul-05	8.62	1.13	723.2	5.9
		Aug-05	8.85	2.21		6.31
		Sep-05	8.13	0.94		5.77
		Oct-05				
		Nov-05	8.08	1.474		6.16
6	Wadi Rayan end of tunnel	Mar-05	7.7	1.42	199	11.6
		Apr-05	7.68			
		May-05	7.99			
		Jun-05	7.59	1.31	840	5.1
		Jul-05	7.84	1.47	94.8	5.13
		Aug-05	7.86	1.42		4.43
		Sep-05				
		Oct-05	7.64	1.433		3.37
		Nov-05	7.56	1.307		3.32
7	Upstream of Waterfall	Mar-05	7.9	3.05	ND	16.3
		Apr-05				
		May-05				
		Jun-05	7.77	2.67	1718	6.2
		Jul-05	7.94	3.51	out of range	6.73
		Aug-05	7.88	3.29		5.2
		Sep-05				
		Oct-05	8.11	3.3		7.01
		Nov-05	7.89	3.14		6.77

			pH	E.C	TDS	DO
8	Nazla before mix	Mar-05	7.9	1.83	1415	10.4
		Apr-05				
		May-05				
		Jun-05	7.51	1.19	759	4.5
		Jul-05	7.89	1.71	1094.4	3.83
		Aug-05	7.77	0.96		3.04
		Sep-05				
		Oct-05	7.83	2.01		5.22
		Nov-05	7.74	1.82		5.6
9	Wadi Rayan before mix	Mar-05	7.7	1.58	1219	5.4
		Apr-05				
		May-05				
		Jun-05	7.47	1.3	835	1.5
		Jul-05	7.66	1.48	947.2	1.51
		Aug-05	7.68	1.43		1.19
		Sep-05				
		Oct-05	7.82	1.34		4
		Nov-05	7.98	1.363		2.85
10	Bahr Yussef	Mar-05	7.9	0.54	419	9.5
		Apr-05				
		May-05				
		Jun-05	7.68	0.44	280	4.3
		Jul-05	7.92	0.42	268.8	4.98
		Aug-05	7.85	0.43		4.94
		Sep-05				
		Oct-05	7.85	0.612		5.41
		Nov-05	7.99	0.605		6.04
11	Drinking Water	Mar-05	7.6	0.81	629	9.3
		Apr-05				
		May-05				
		Jun-05				
		Jul-05	7.58	0.80	512	6.79
		Aug-05	7.7	0.74		6.01
		Sep-05				
		Oct-05	7.78	0.884		7.2
		Nov-05	7.69	0.868		6.11
12	Wadi Rayan 2nd Lake	Mar-05				
		Apr-05				
		May-05				
		Jun-05				
		Jul-05	8.66	13.16		7.12
		Aug-05	8.62	13.91		5.63
		Sep-05				
		Oct-05	8.48	14.32		6.35
		Nov-05	8.38	8.53		6.26

Table E.2: Pesticides detected in 2005 in Egypt.

Pesticide	Site	Site Description	Date	Concentration (µg/l)	LoD (indicative)	WHO (µg/l) - Drinking Water	Egypt (µg/l) - Drinking Water
Abamectin	1	Banat Canal before mix	Mar-05	0.2662	0.01 - 0.05 (µg/l)	-	-
	2	Hanna Habib		0.1422			
	3	Collector 1 (maize field)		0.0674			
	3	Collector 1 (maize field)	Jul-05	0.0003			
	5	Collector 2 (cotton field)		0.0004			
	9	Wadi Rayan before mix		0.0025			
	9	Wadi Rayan before mix	Aug-05	0.0002			
	11	Drinking water		0.0004			
Aldrin	3	Collector 1 (maize field)	Mar-05	0.2040		0.03	0.03
Chlorpyriphos	1	Banat Canal before mix	Mar-05	0.1530		-	-
	2	Hanna Habib		0.2360			
Cypermethrin	4	Main drain of study area	May-05	0.0007		-	-
Dimethoate	1	Banat Canal before mix	Mar-05	0.5700		-	-
Esfenvalerate	8	Nazla before mix	Jul-05	0.0089		-	-
	1	Banat Canal before mix		0.0001			
	3	Collector 1 (maize field)		0.0013			
	11	Drinking water		0.0015			
	9	Wadi Rayan before mix	Aug-05	0.0007			
	7	Upstream of waterfall		0.0003			
Ethoprophos	2	Hanna Habib	Mar-05	0.0780			
	3	Collector 1 (maize field)		0.0660			
Gamma-BHC (Lindane)	1	Banat Canal before mix	Mar-05	0.0090		2	3
	3	Collector 1 (maize field)		0.0030			
Malathion	3	Collector 1 (maize field)	Mar-05	0.2440		-	-
Methomyl	1	Banat Canal before mix	Mar-05	0.0348		-	-

E.1.2 Seasonal Variation Graphs

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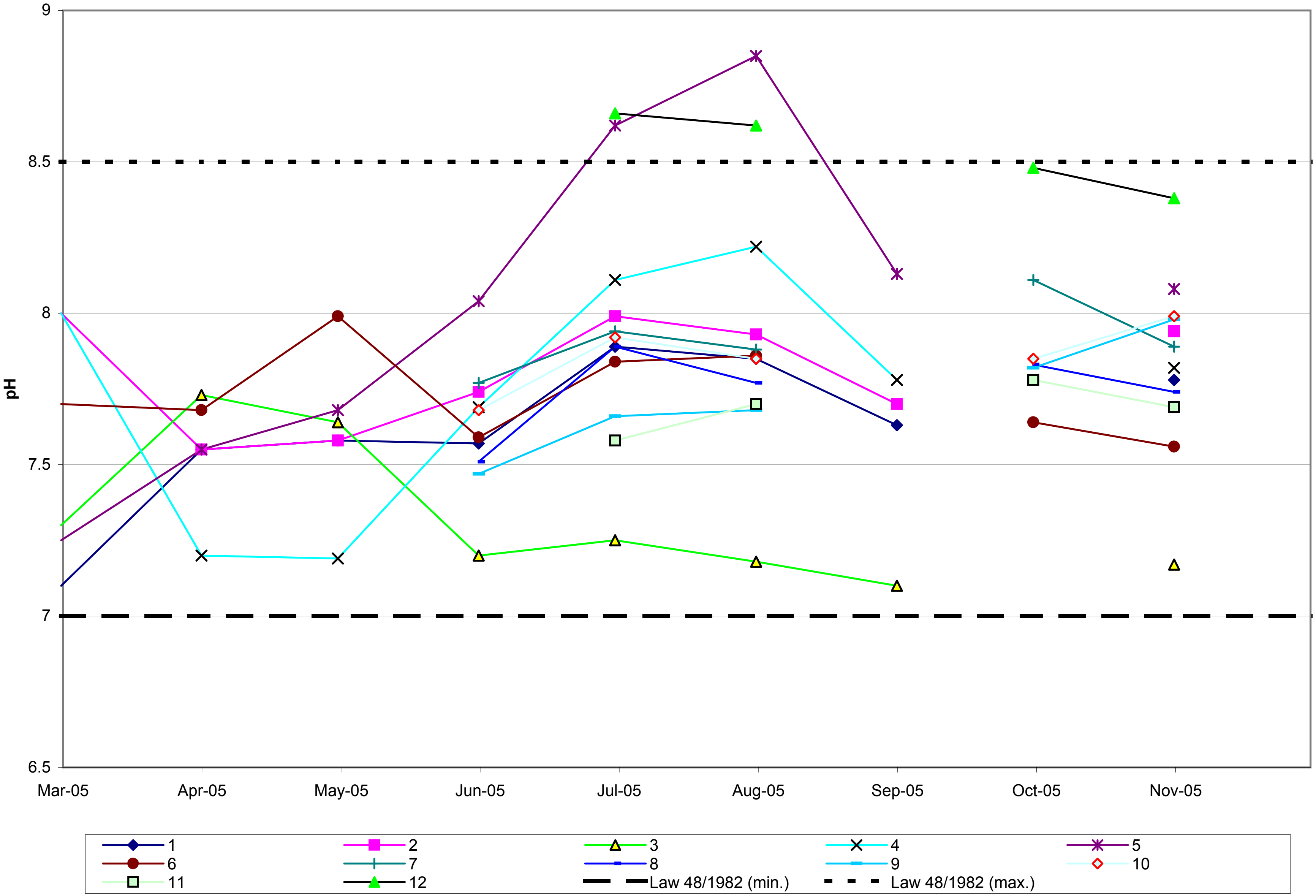

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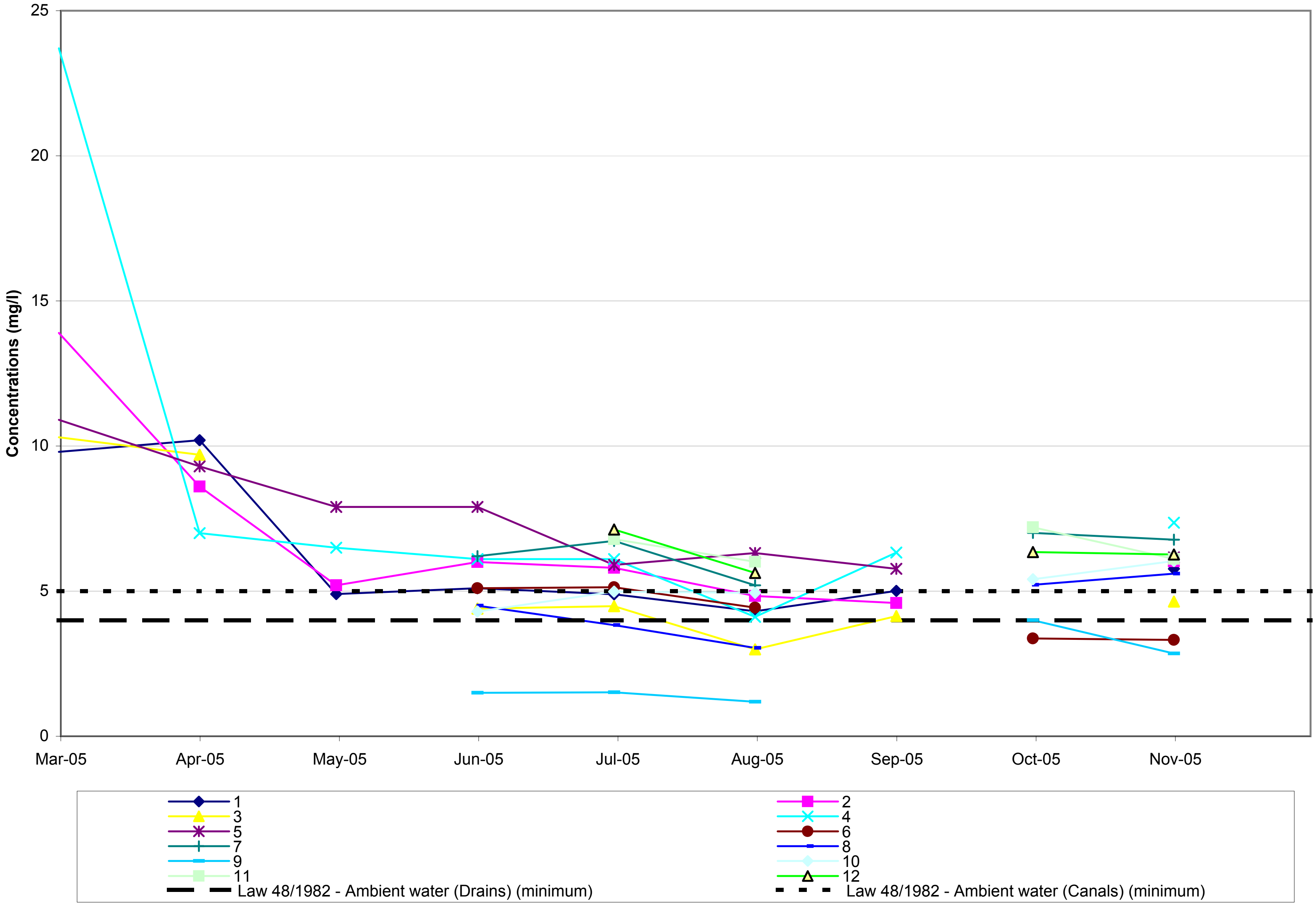
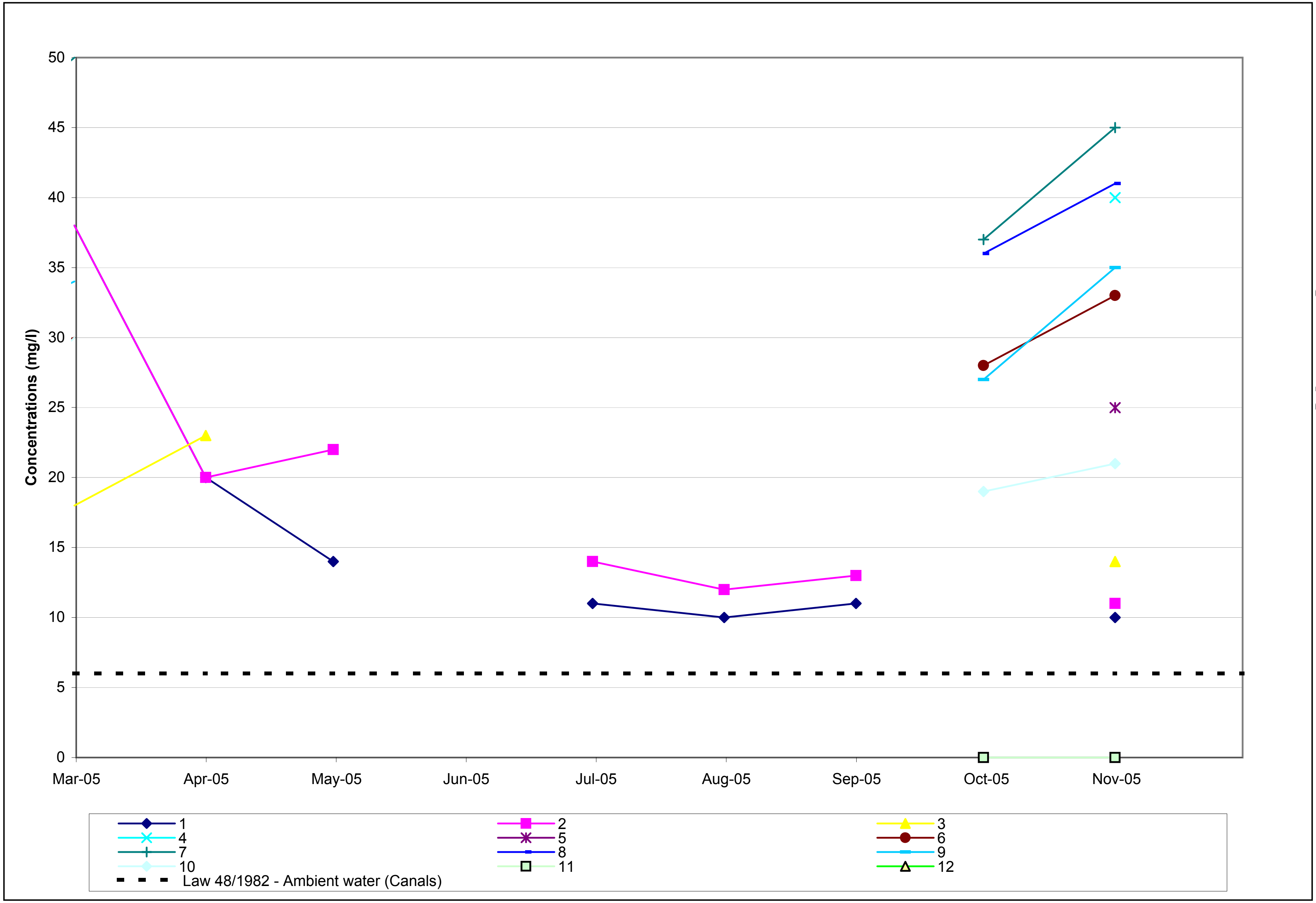
pH - Seasonal Variation

Dissolved Oxygen - DO - Seasonal Variations



Biological Oxygen Demand - BOD - Seasonal Variations



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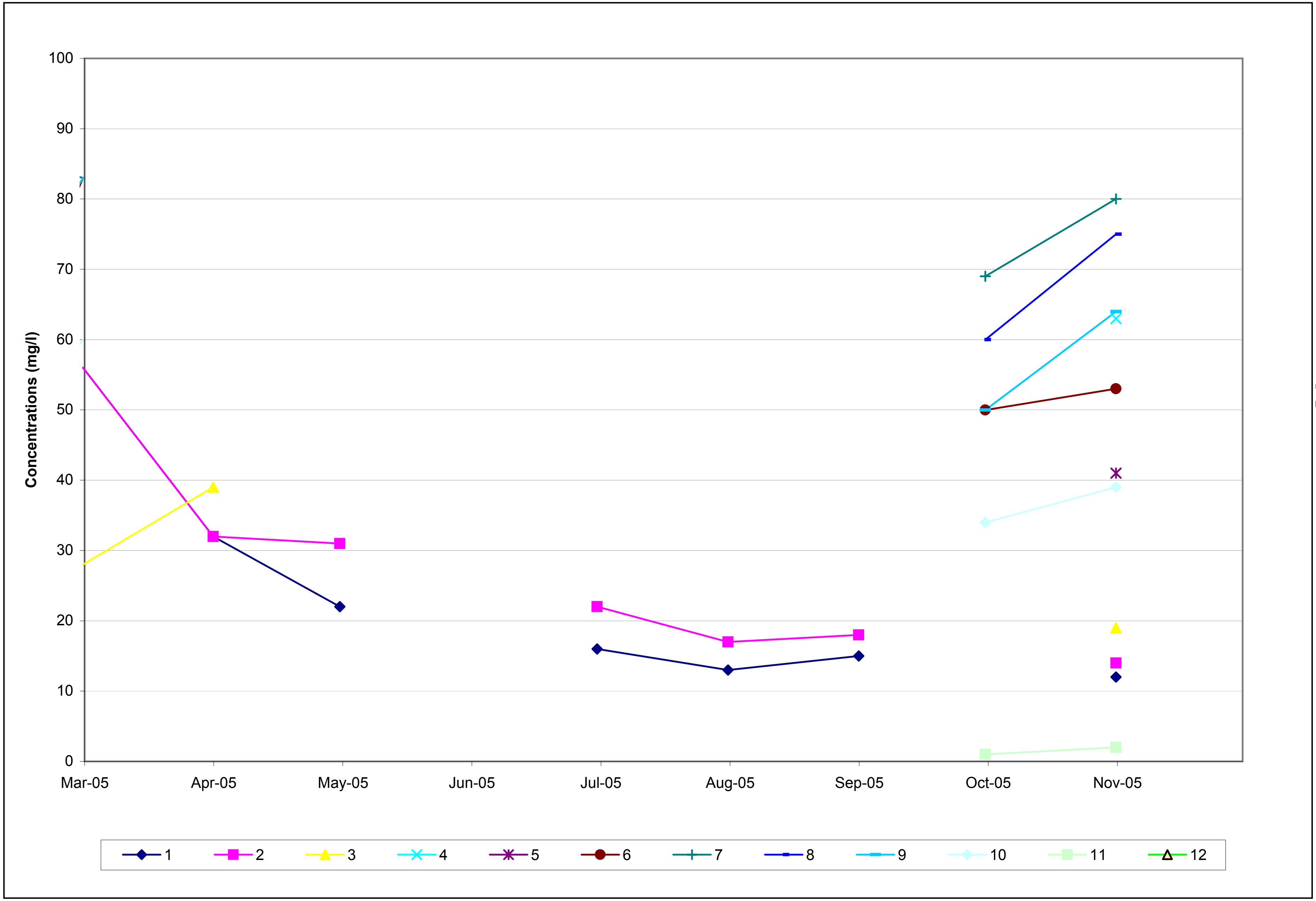
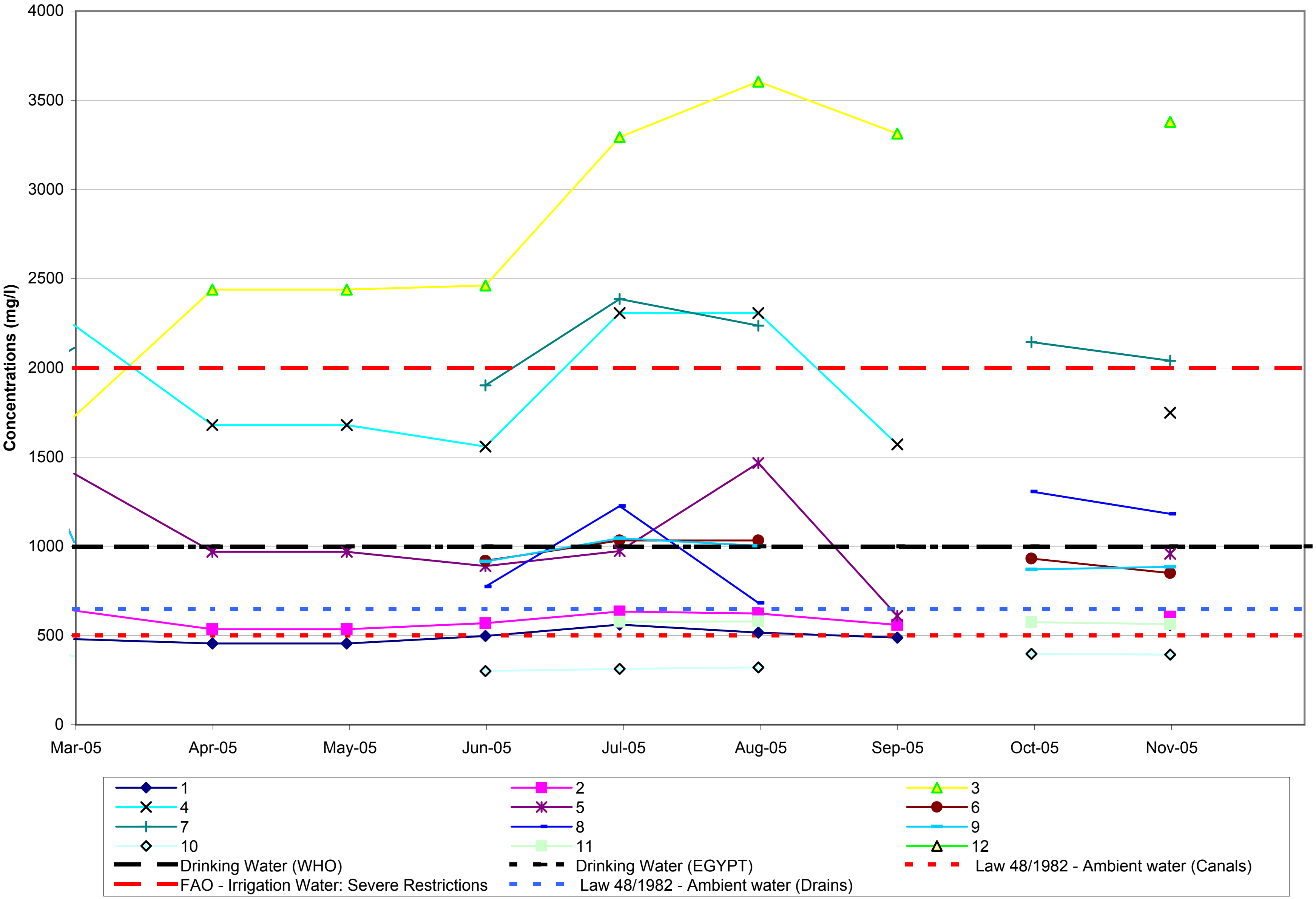
Chemical Oxygen Demand - COD - Seasonal Variations



Total Dissolved Solids - TDS - Seasonal Variations



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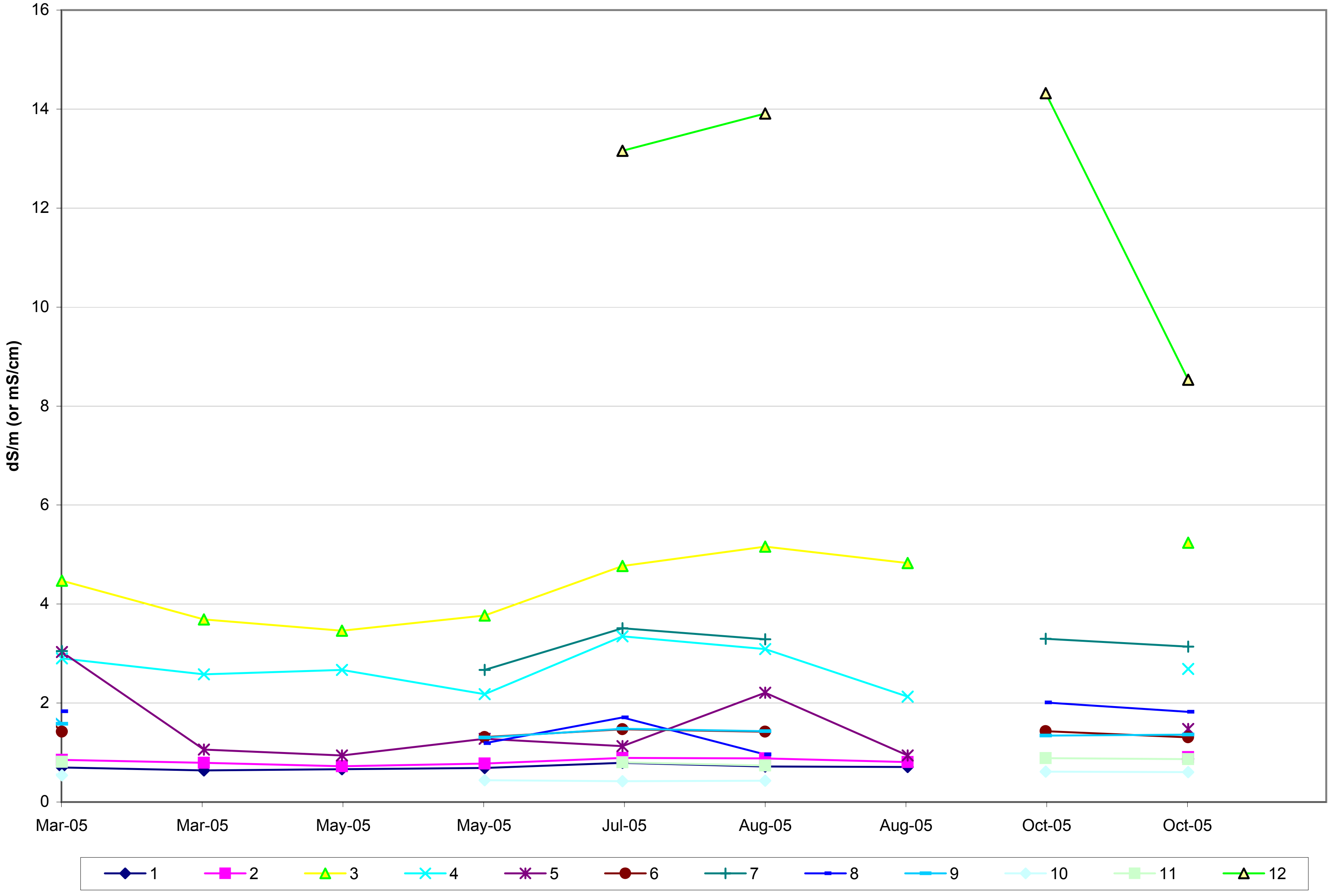
Electric Conductivity - EC - Seasonal Variations



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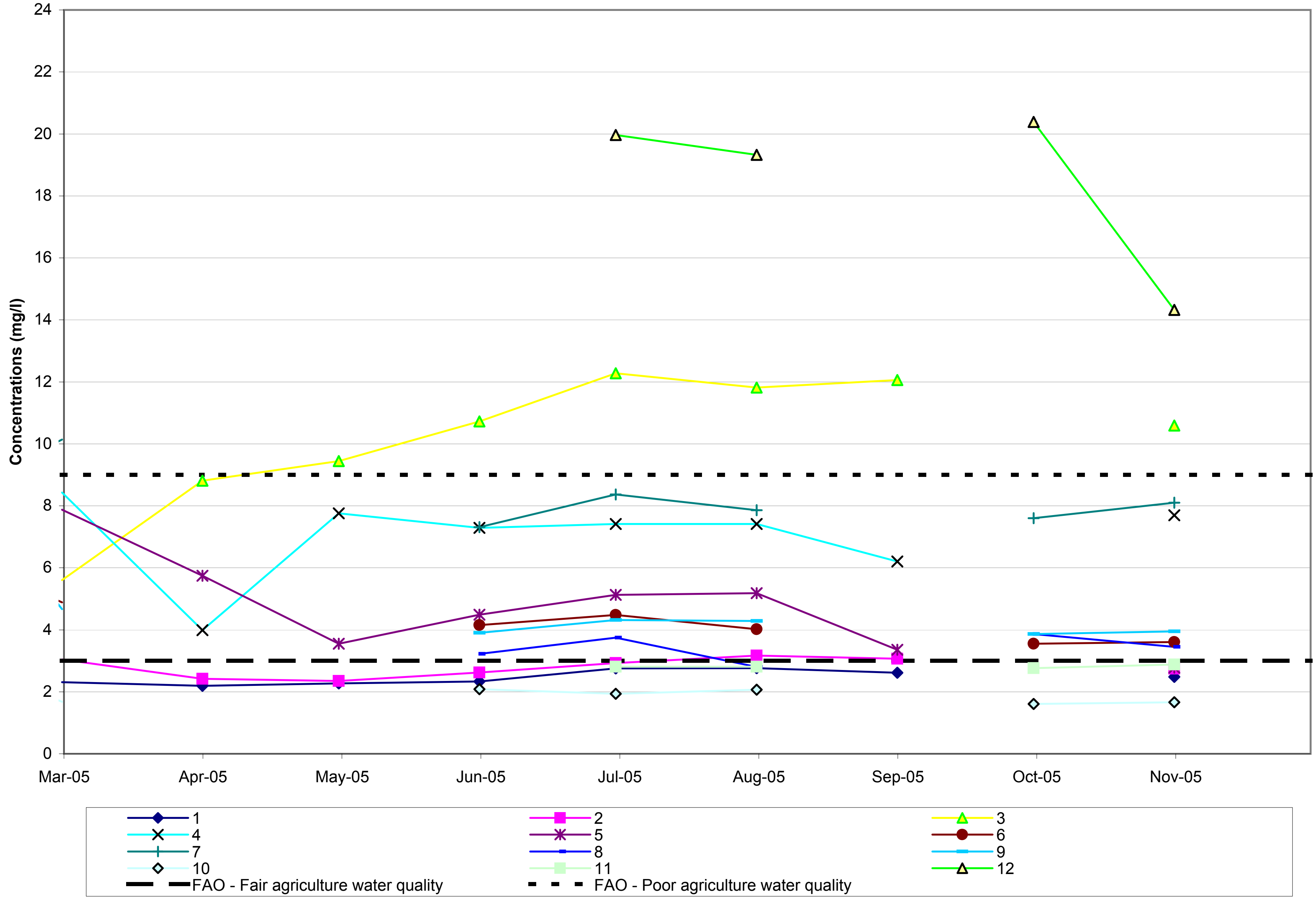
Sodium Adsorption Ratio - SAR - Seasonal Variations



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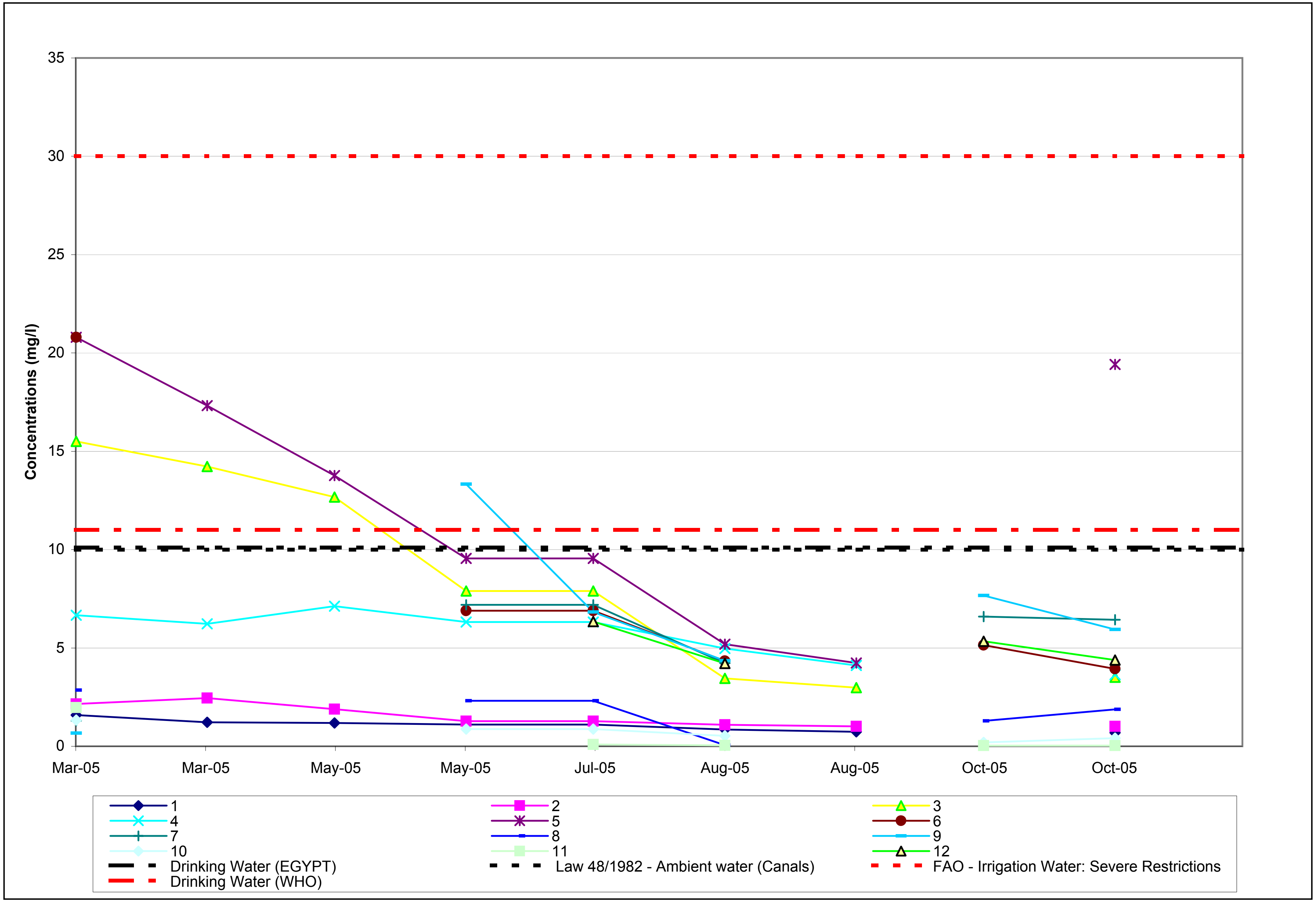
Nitrate - NO3-N - Seasonal Variations



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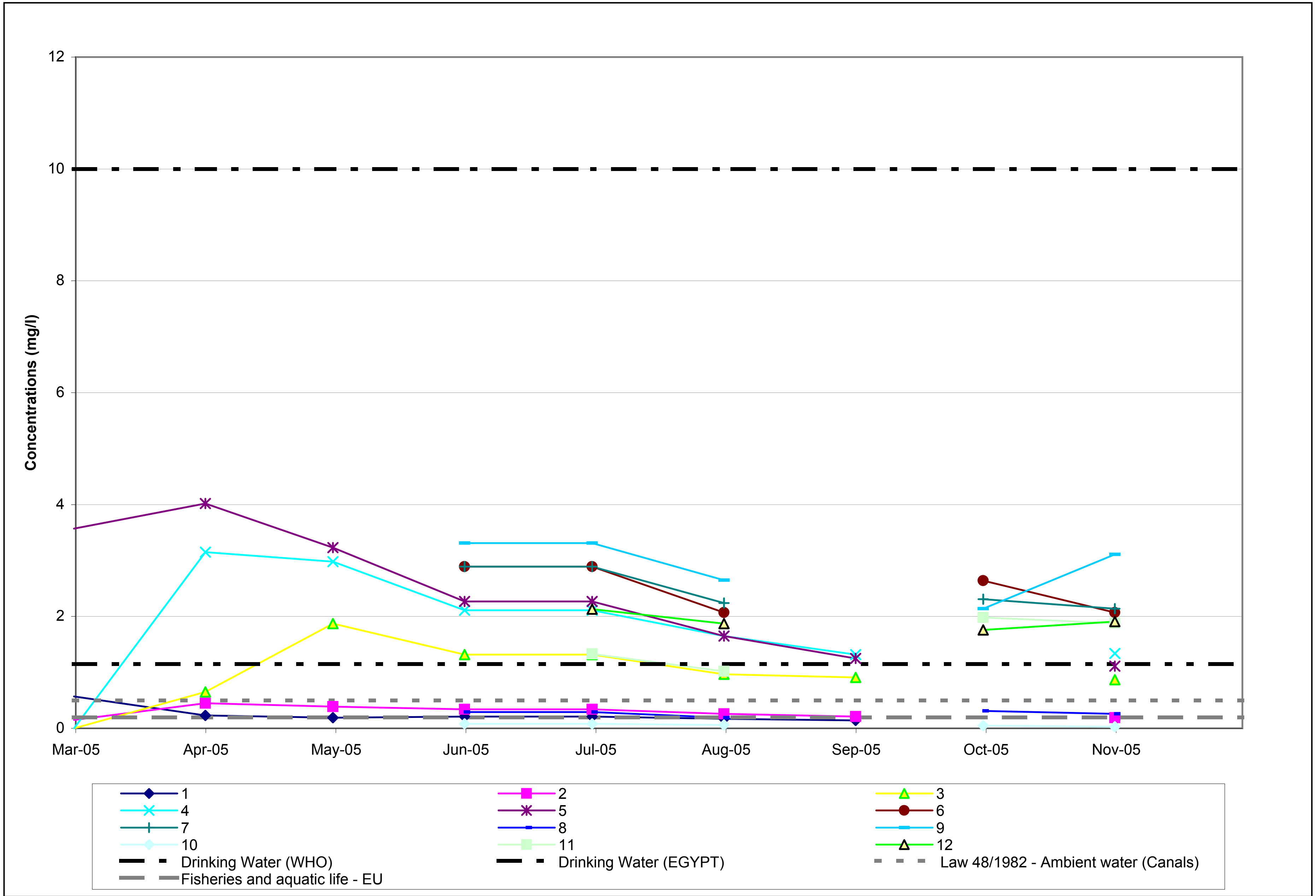

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Ammonim - NH4-N - Seasonal Variations

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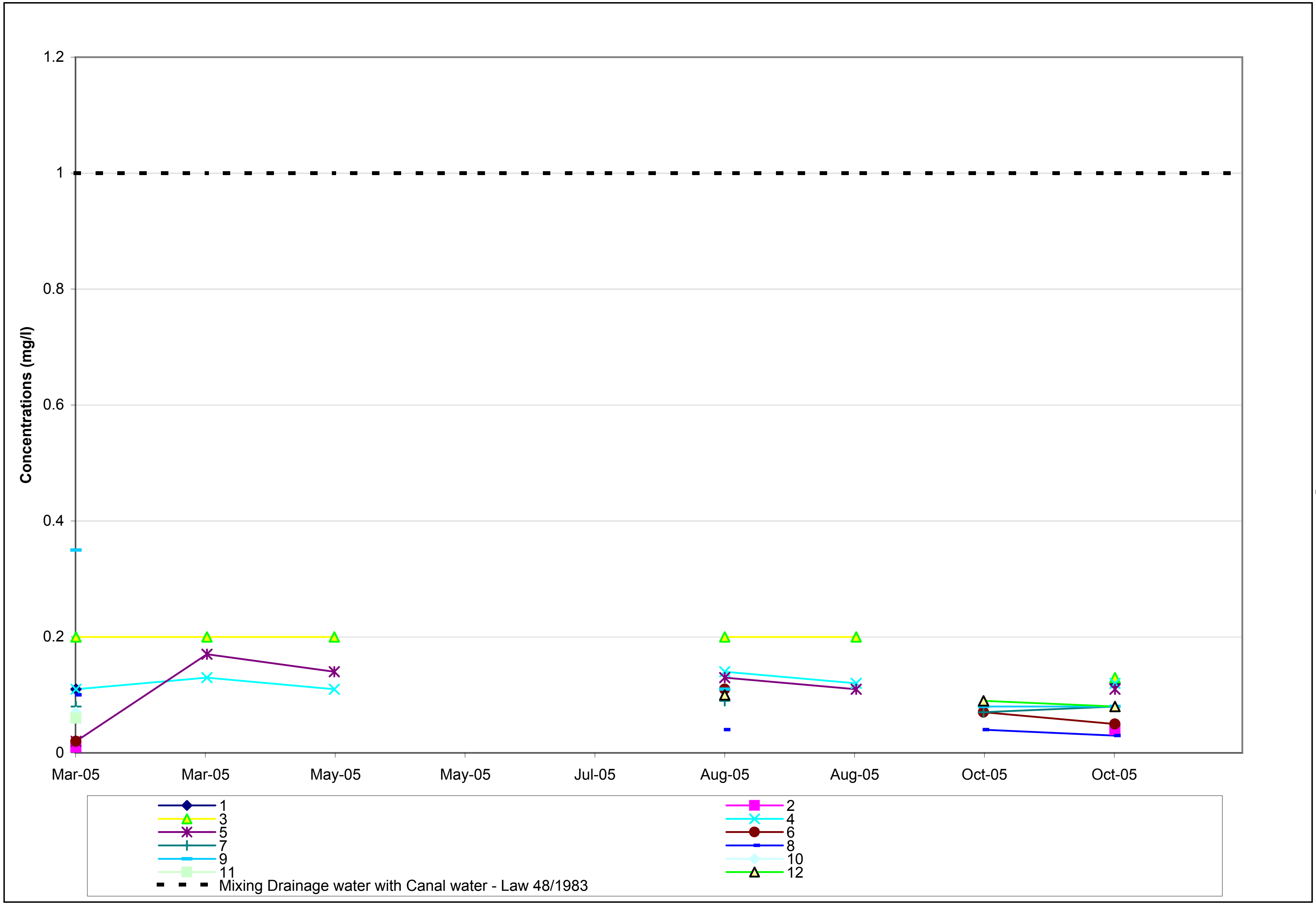
Phosphate - PO4 - Seasonal Variations



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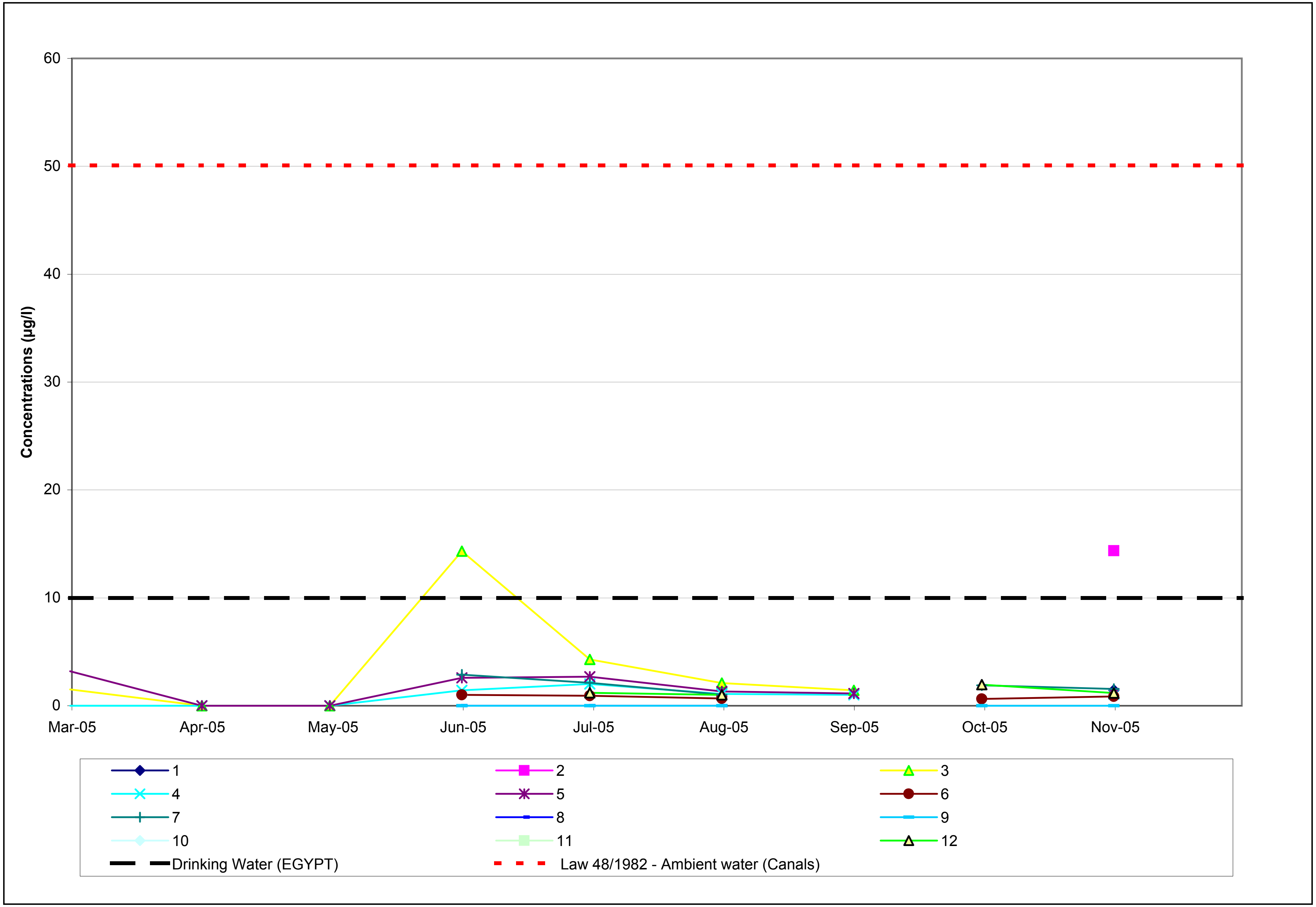

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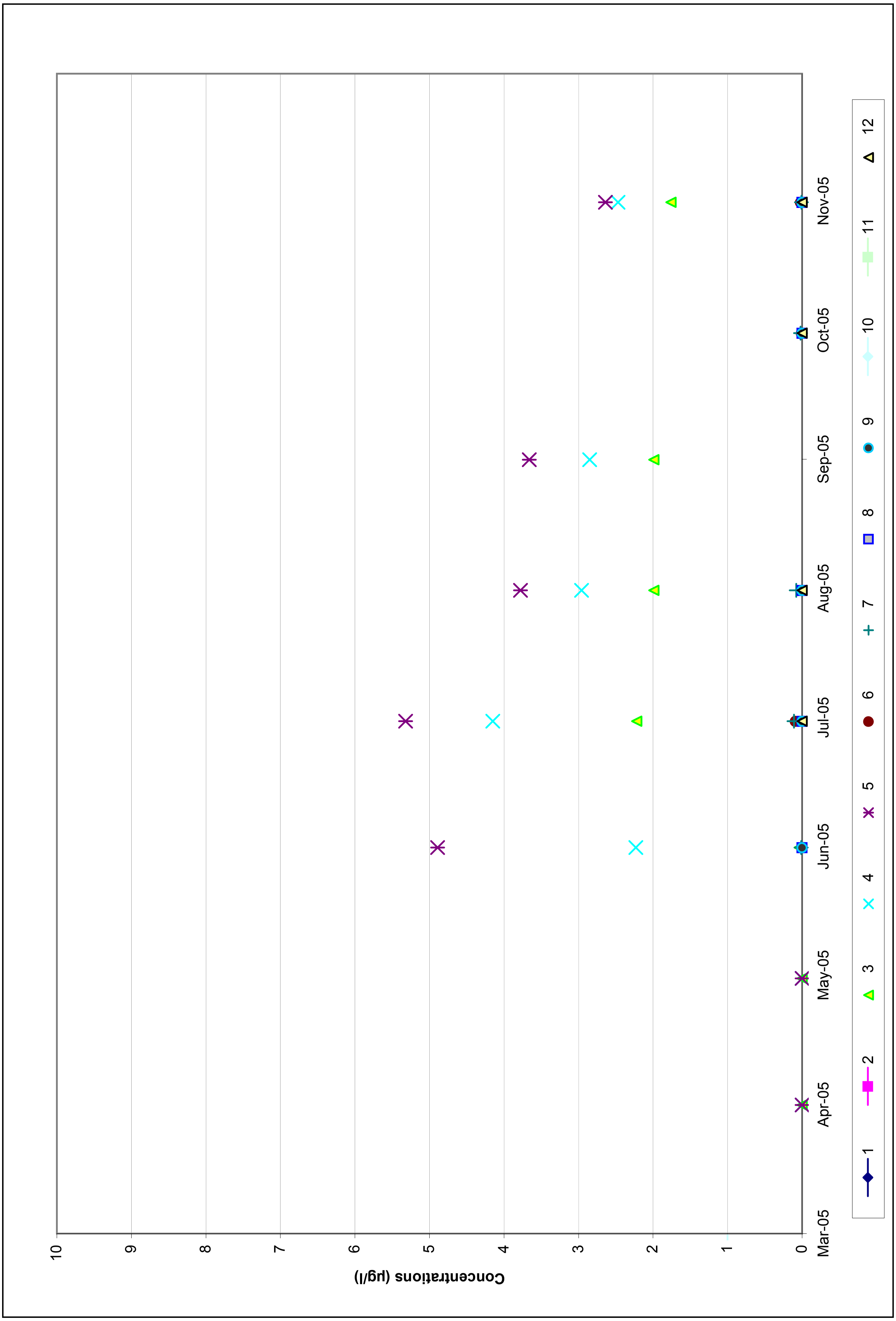
Zinc - Zn - Seasonal Variations



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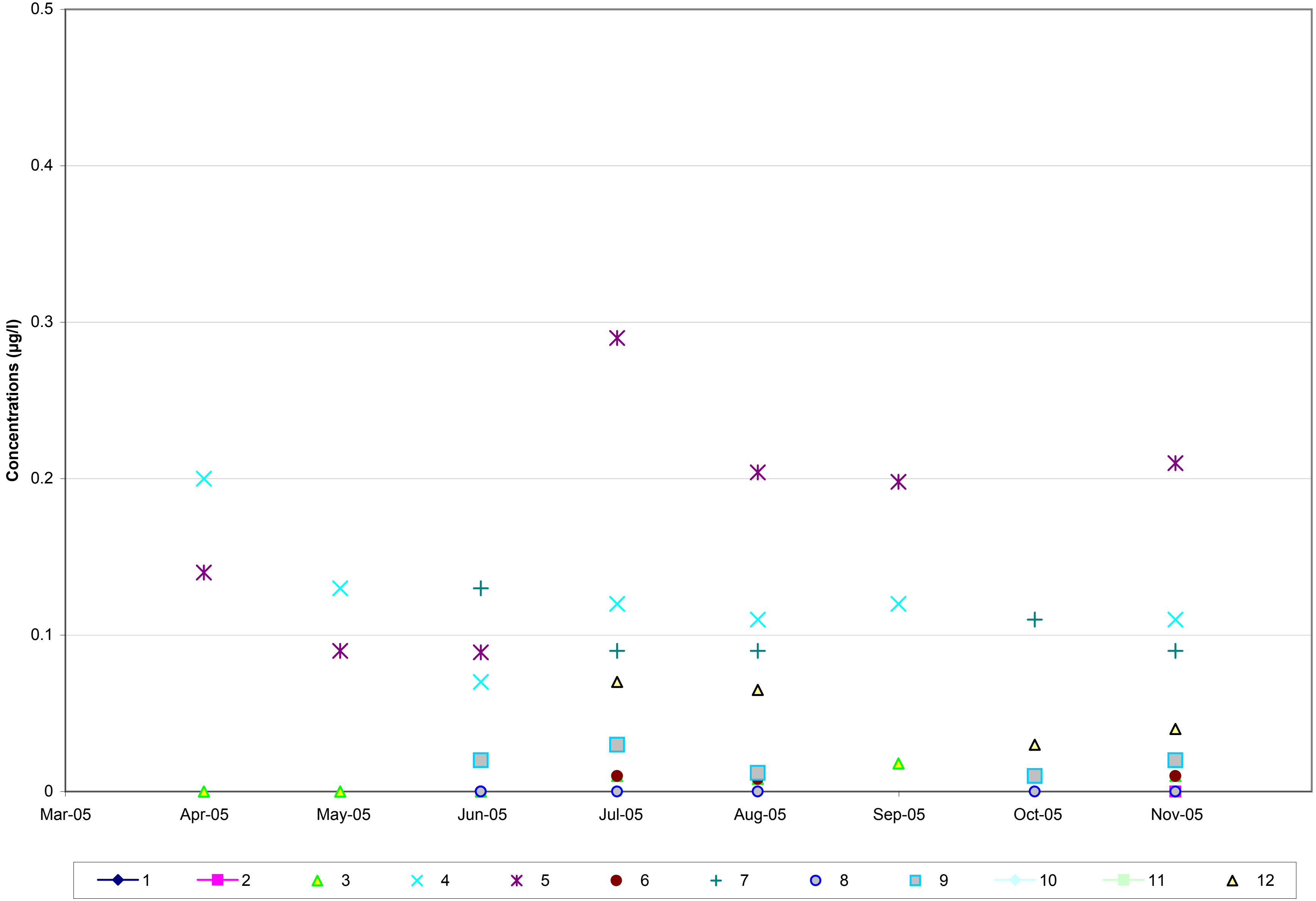
Copper - Cu - Seasonal Variations



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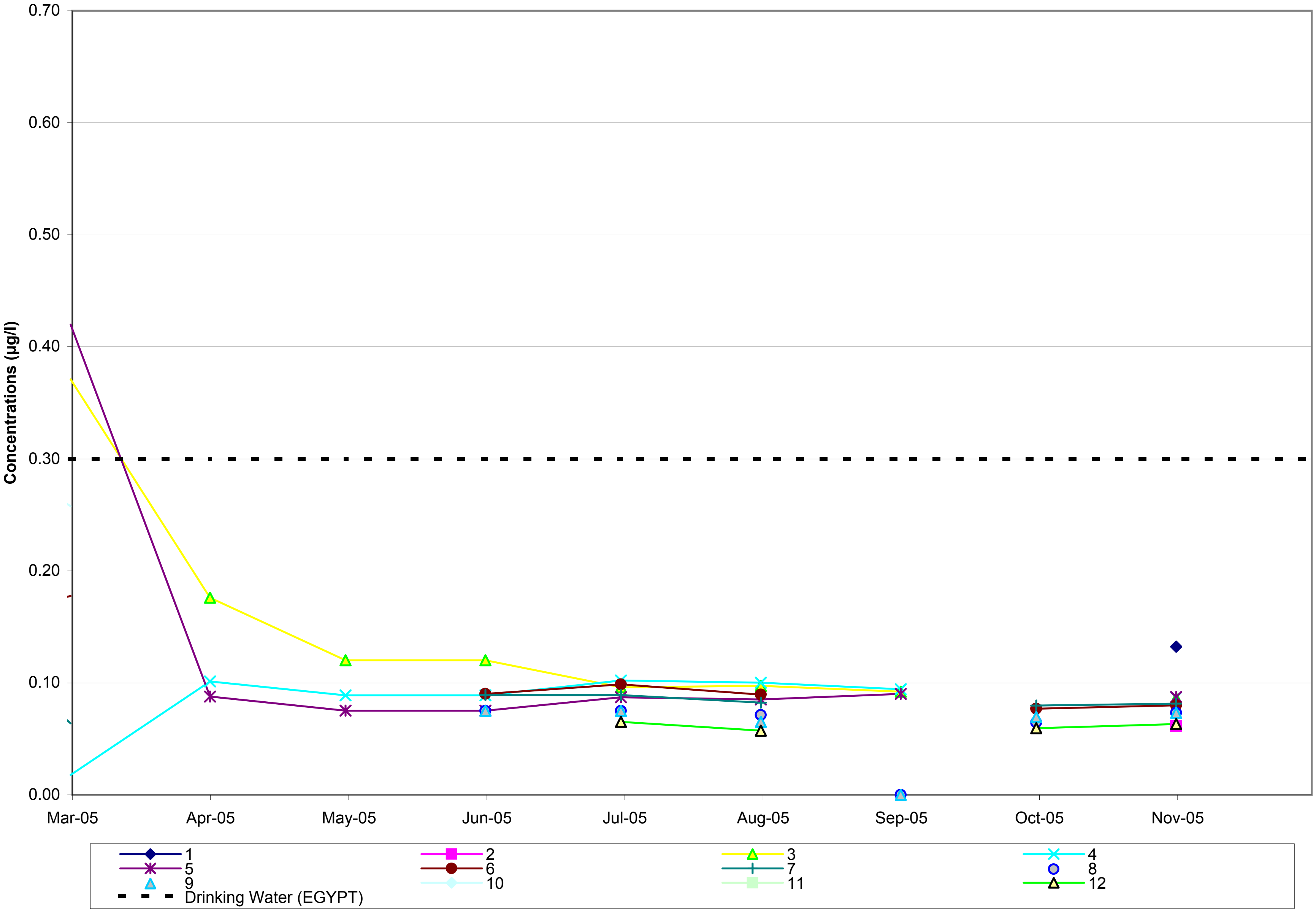
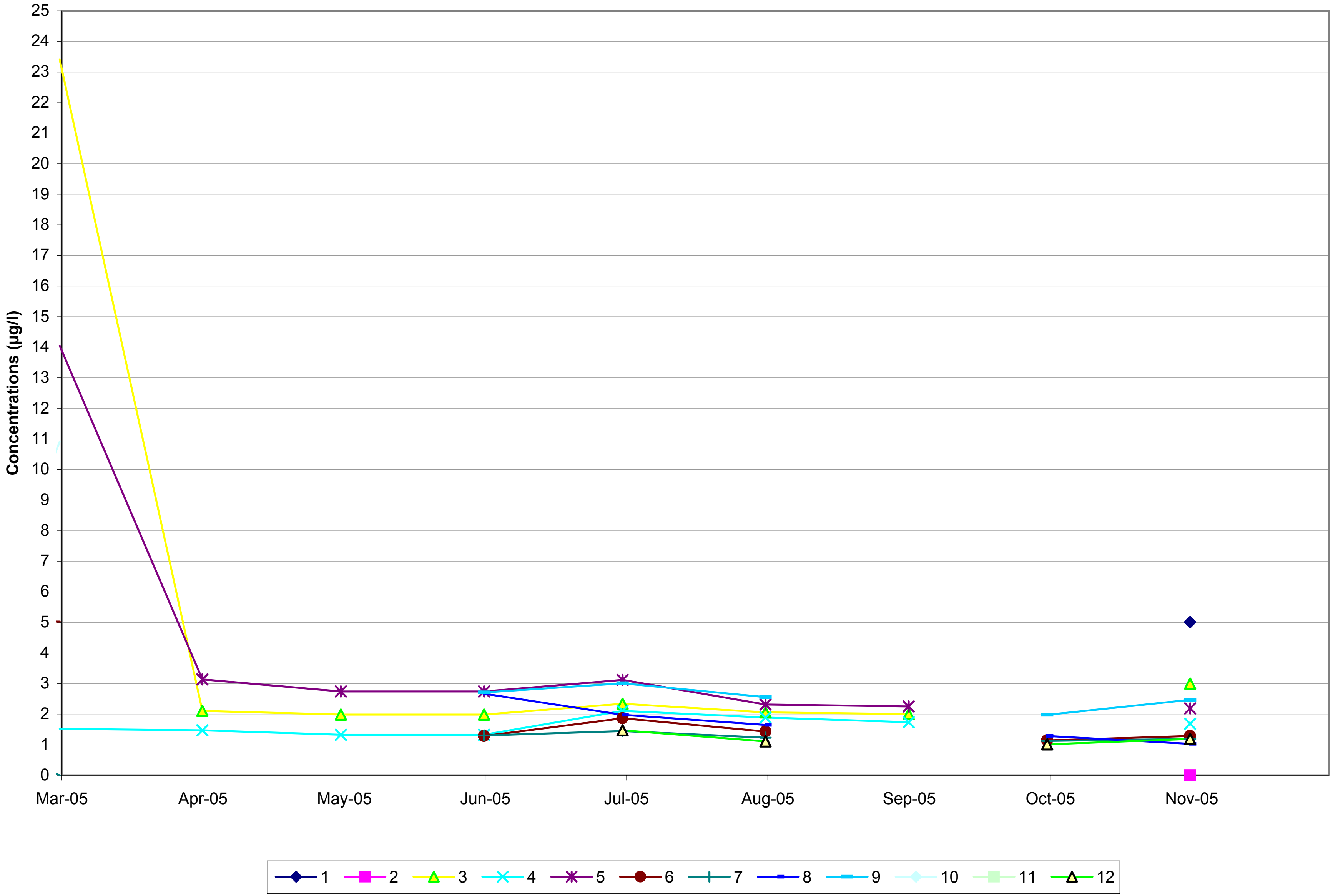
Iron - Fe - Seasonal Variations



Manganese - Mn - Seasonal Variations



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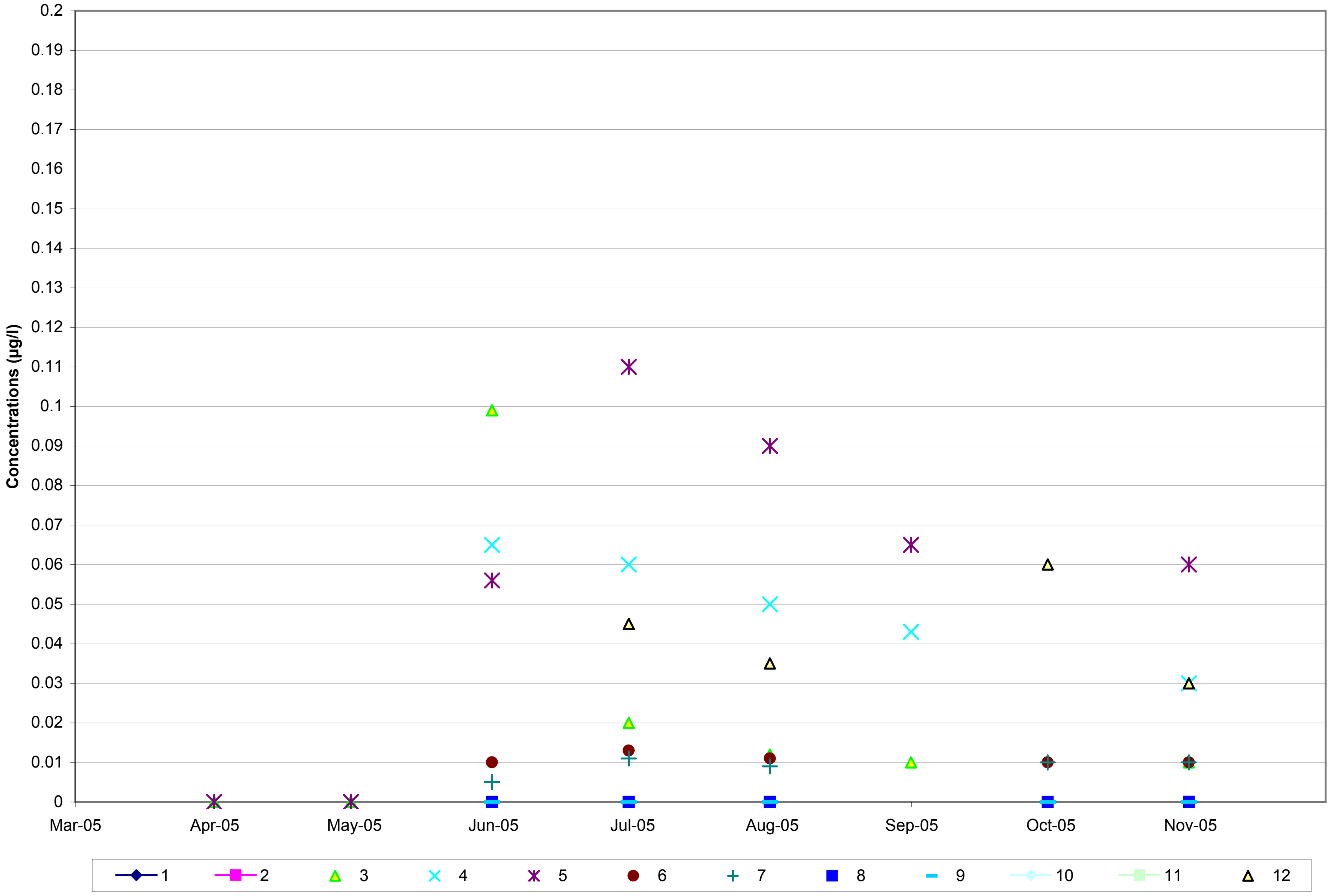
Cadmium - Cd - Seasonal Variations



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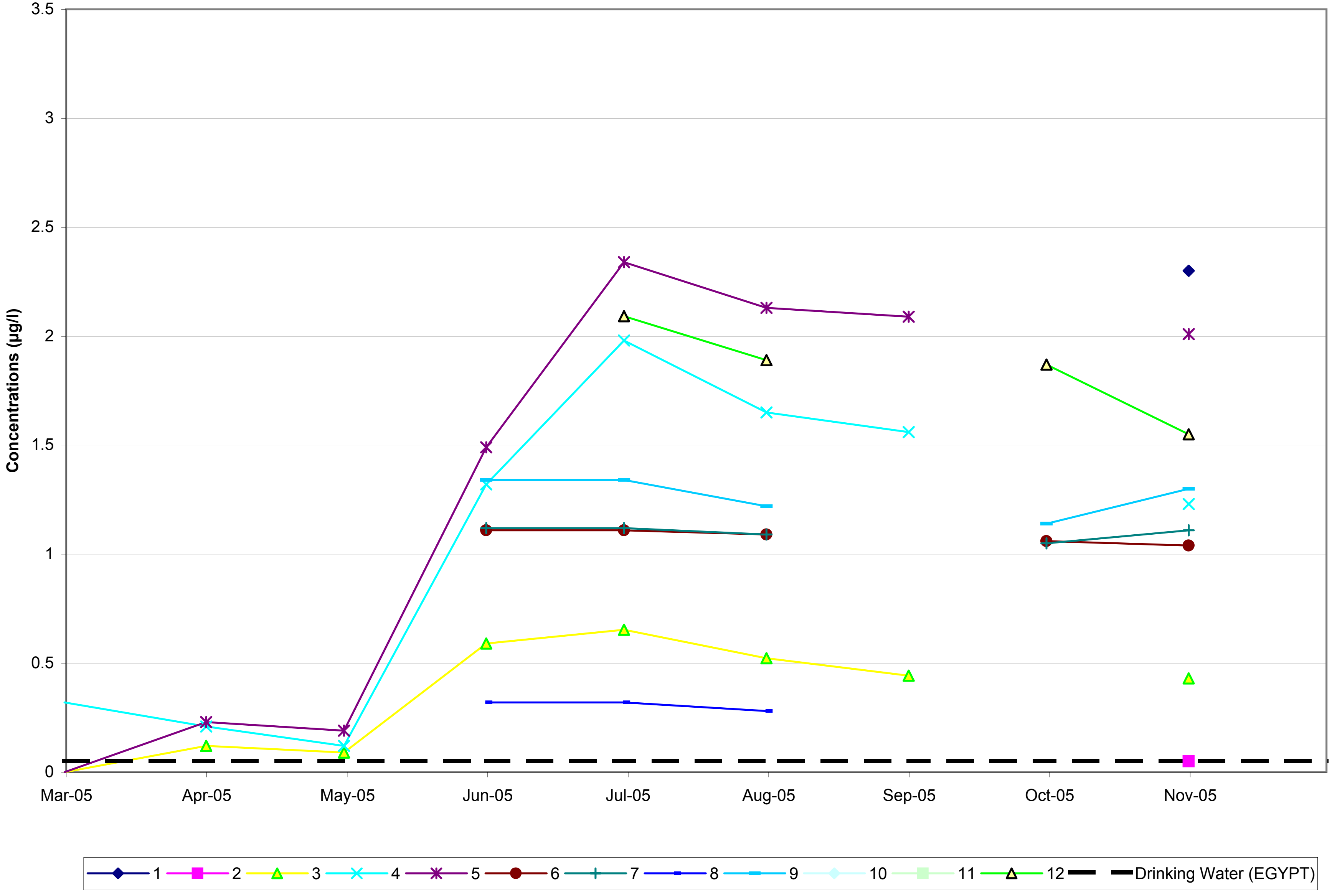
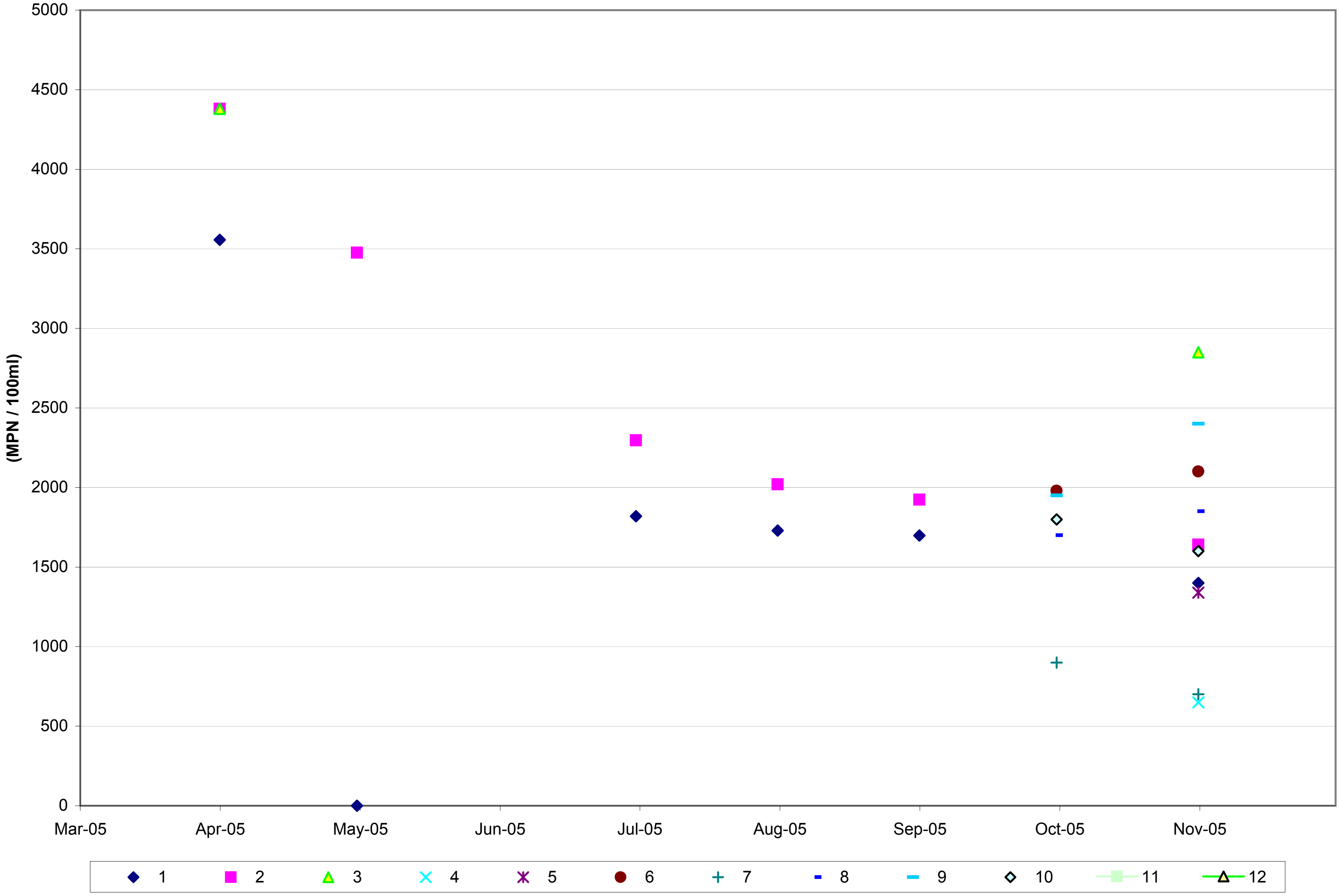
Lead - Pb - Seasonal Variations



Total Coliforms - Seasonal Variations



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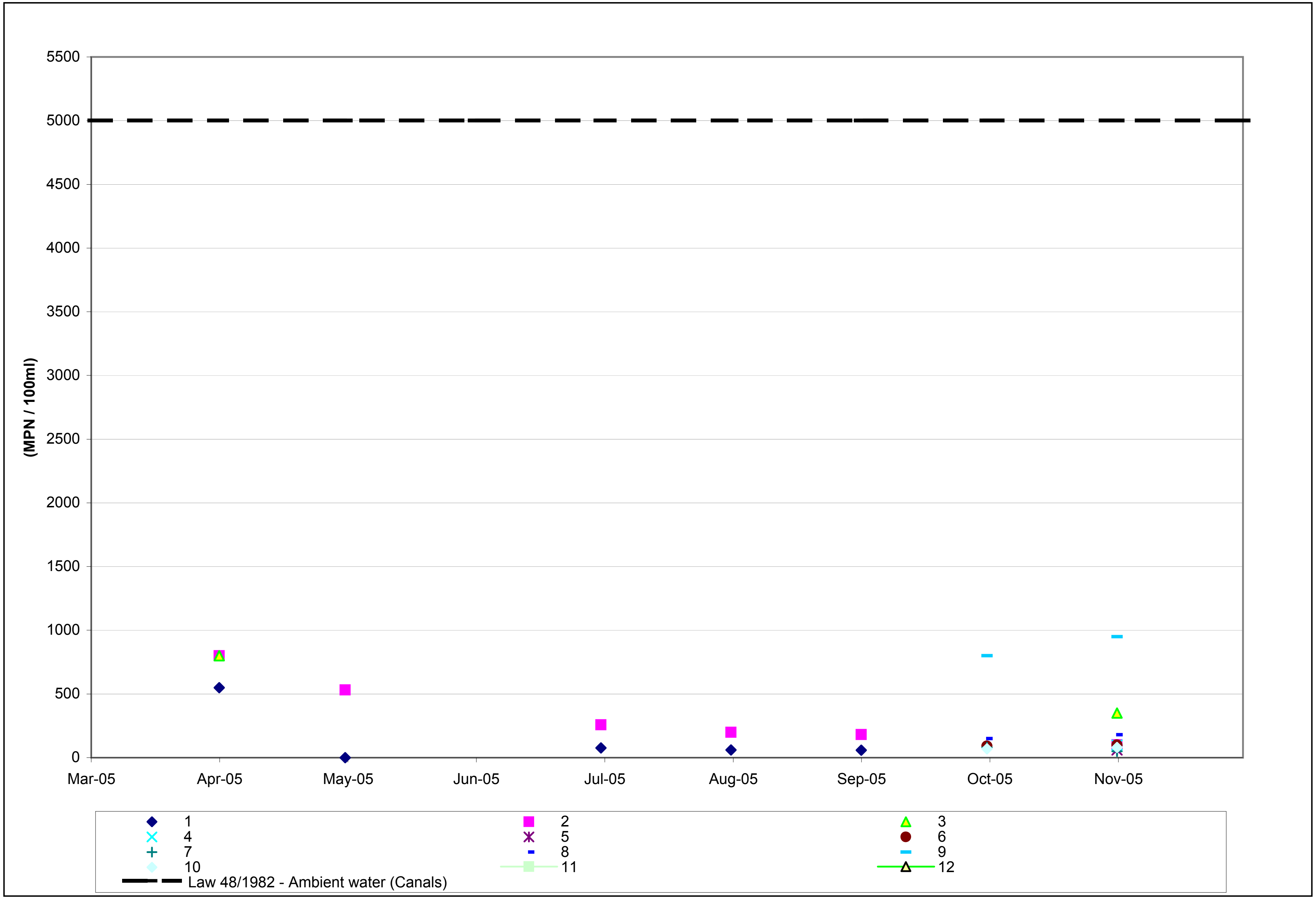
Faecal Coliforms - Seasonal Variations



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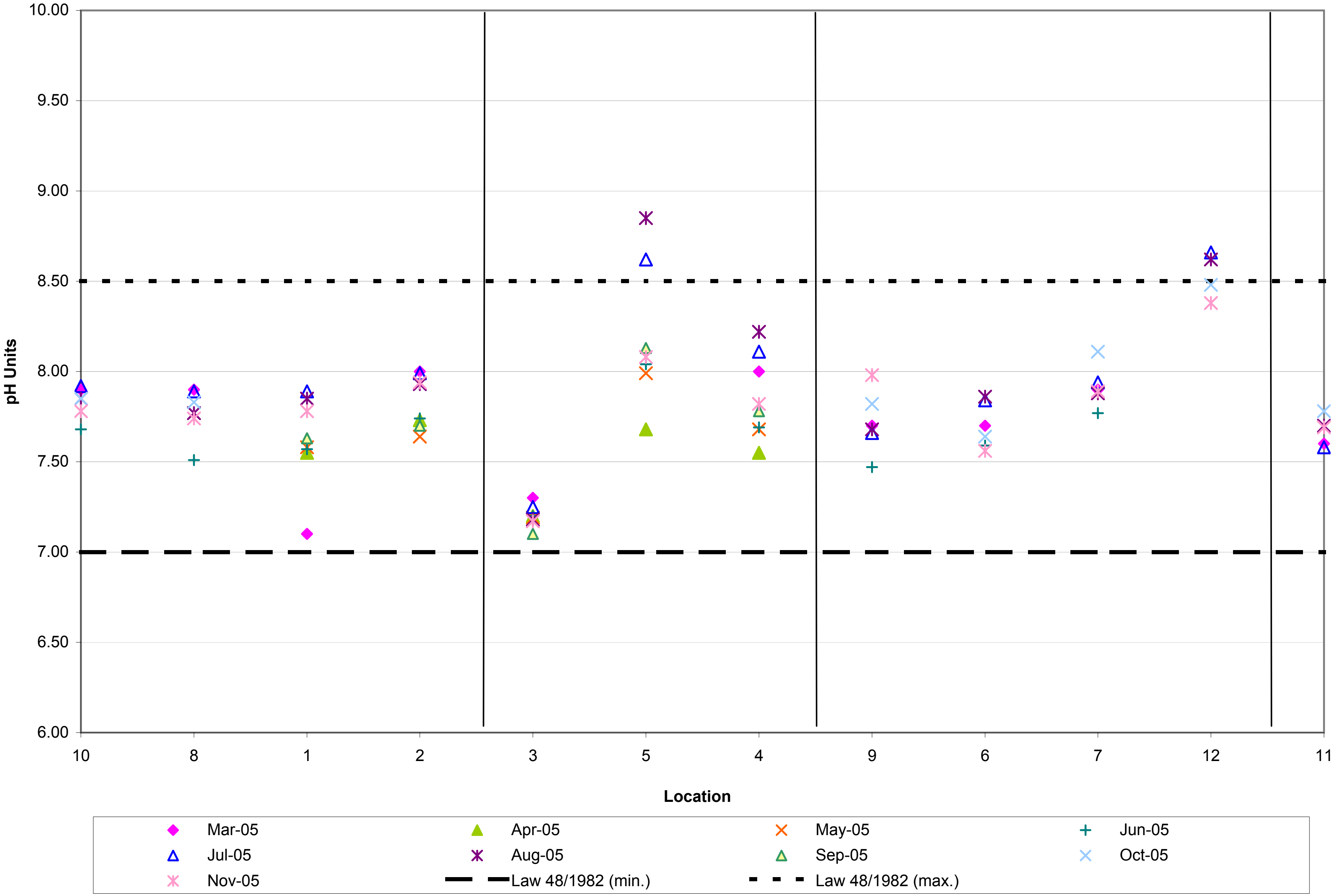
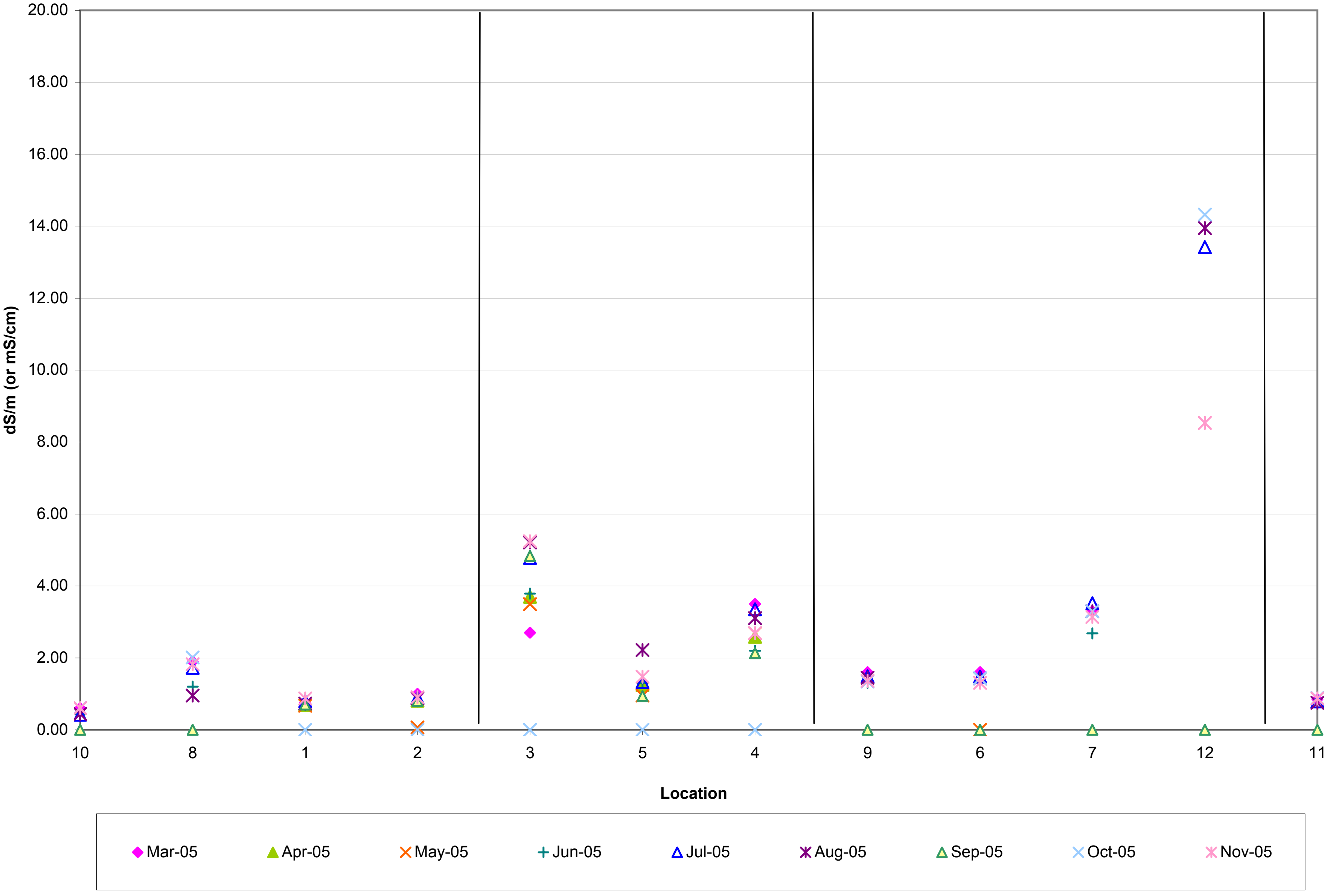
E.1.3 Spatial Variation Graphs

pH Spatial Variations



Electric Conductivity - EC - Spatial Variations



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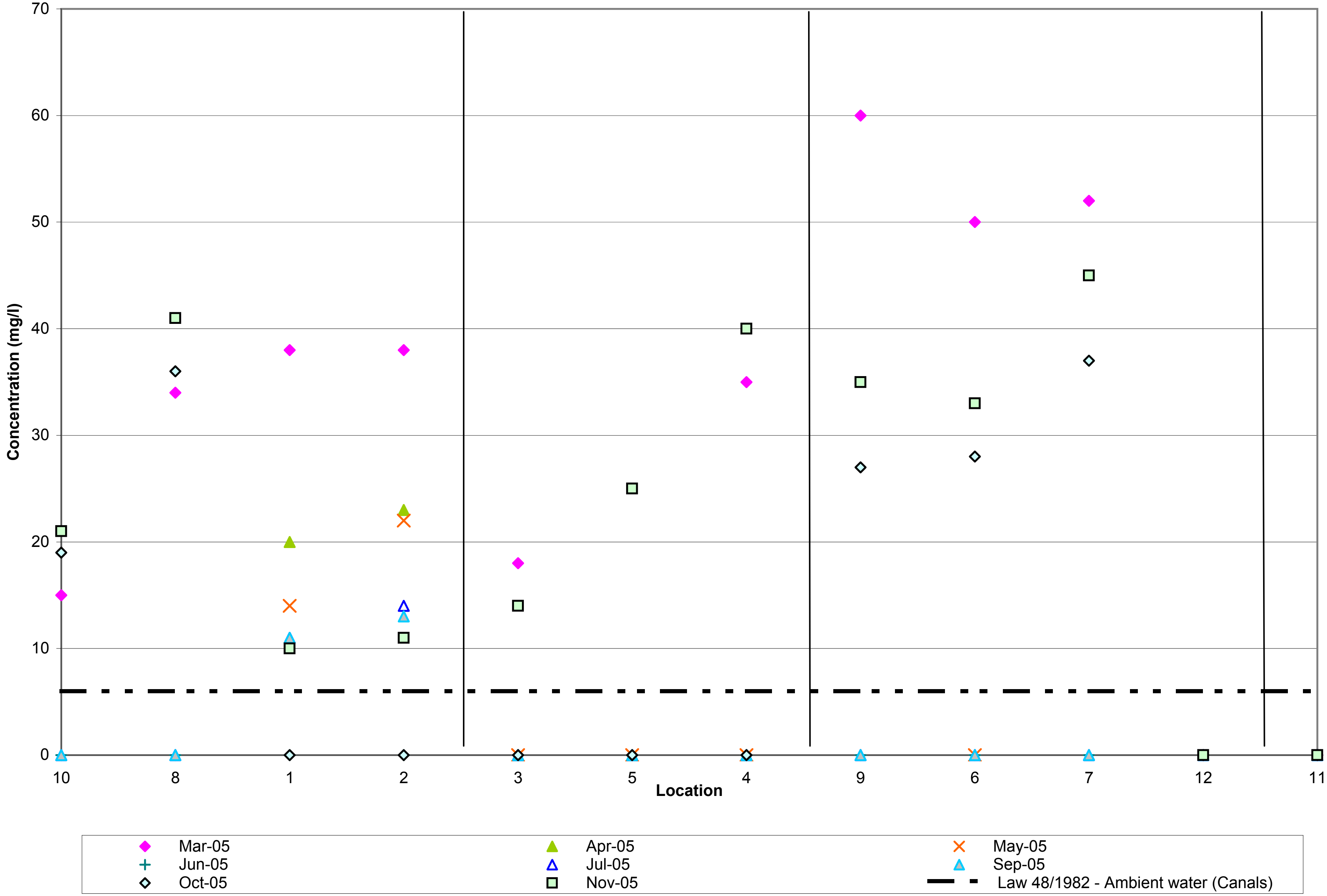
Biological Oxygen Demand - BOD - Spatial Variations



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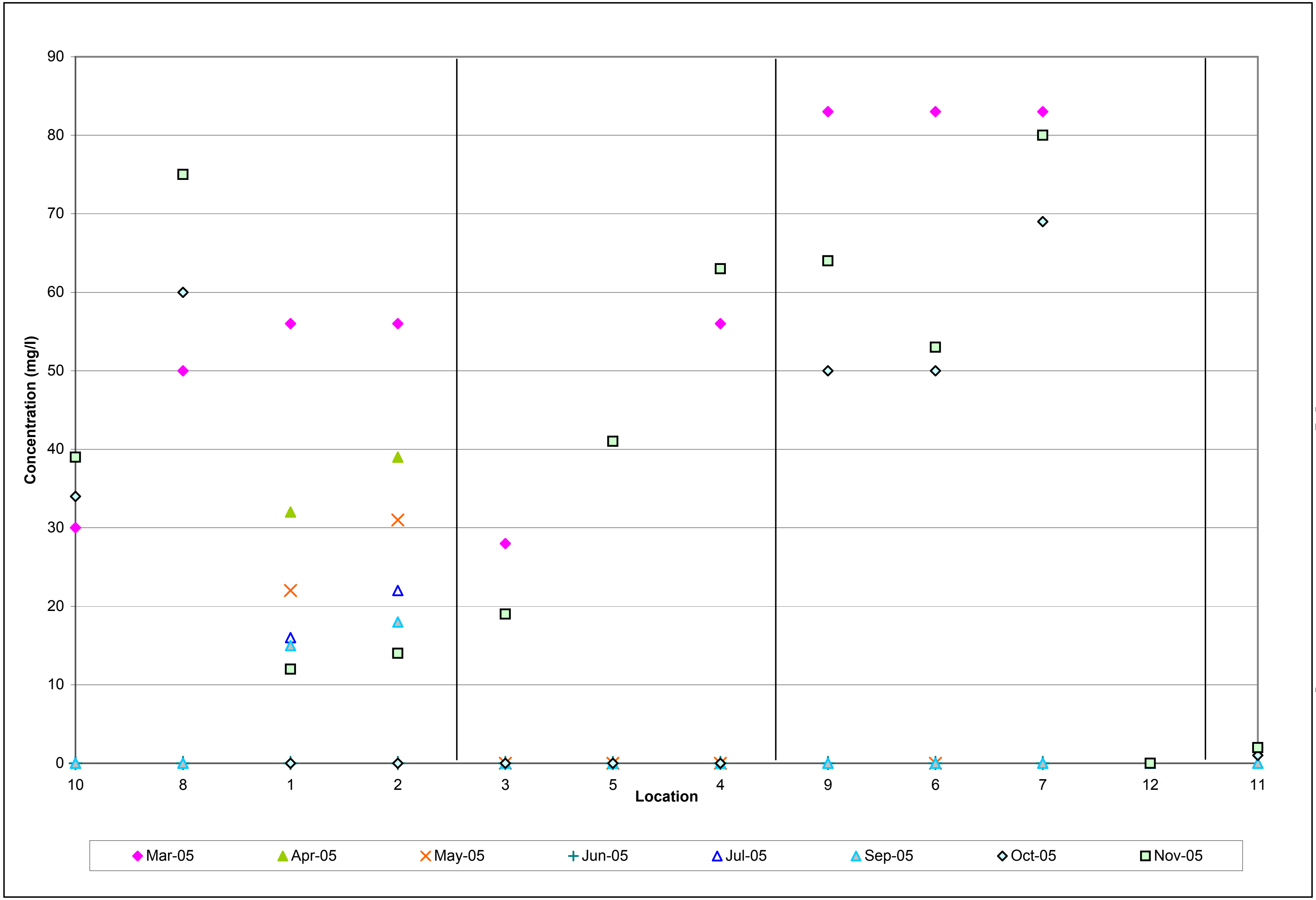
Chemical Oxygen Demand - COD - Spatial Variations



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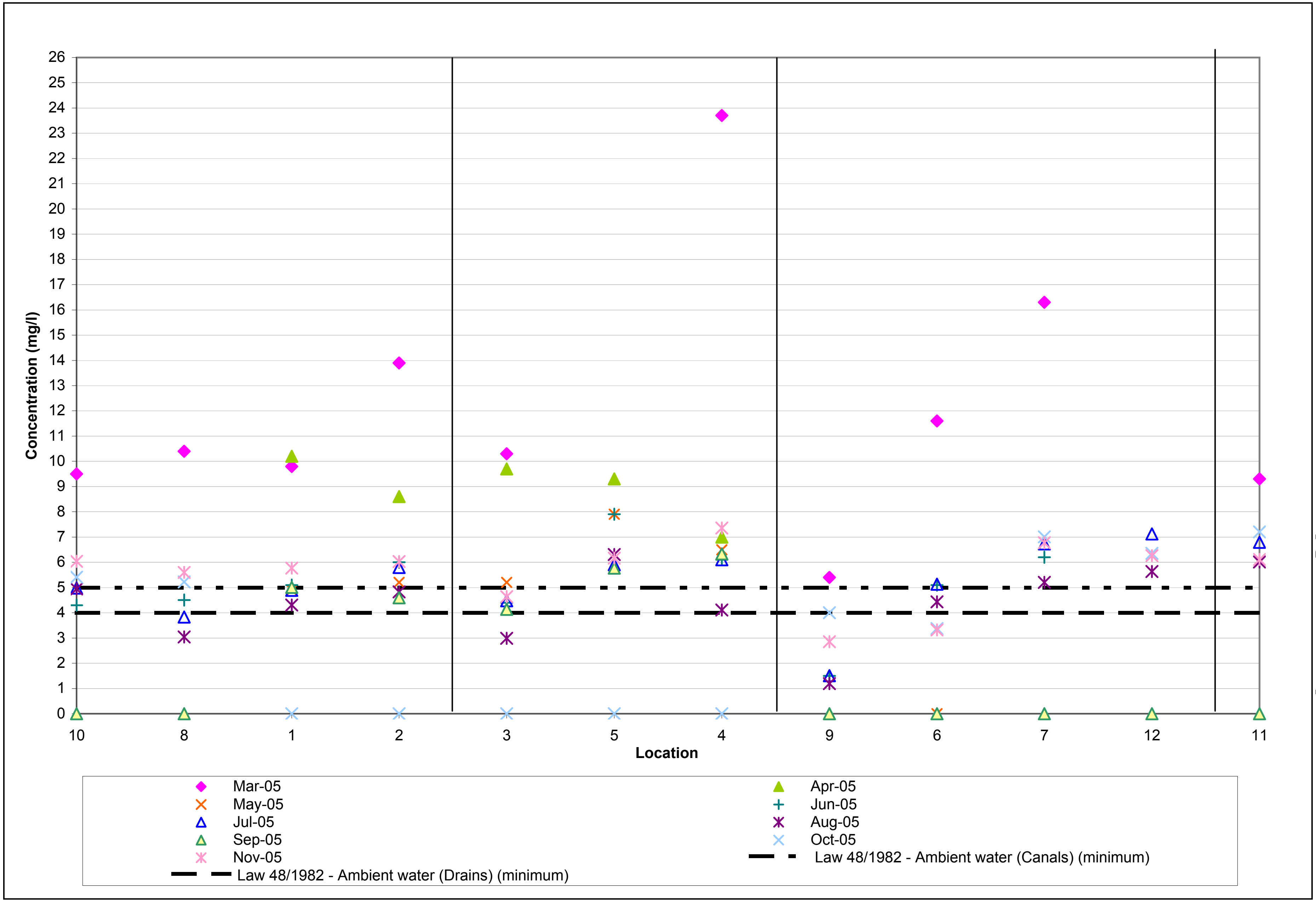
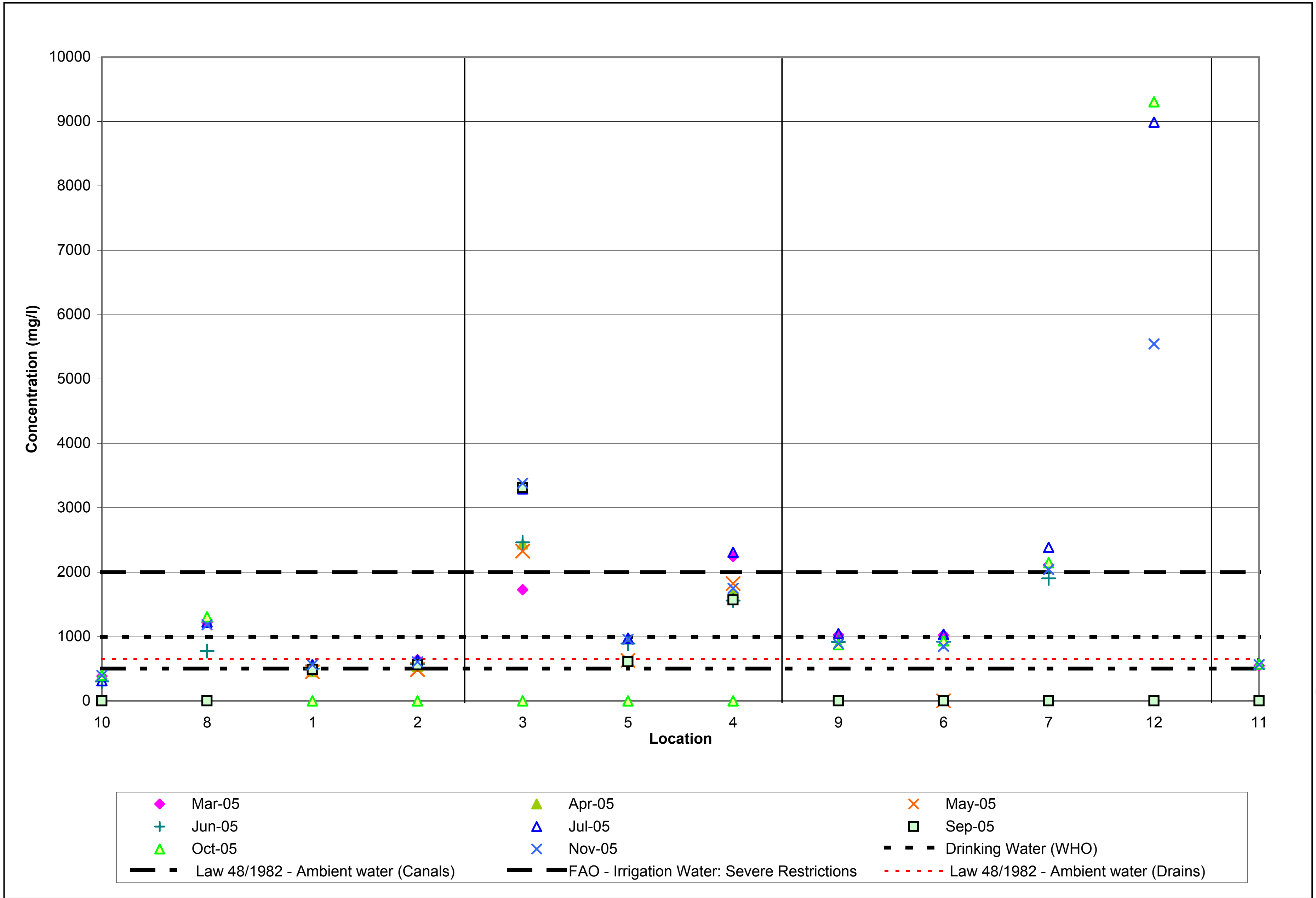
Dissolved Oxygen - DO - Spatial Variations



Total Dissolved Solids - TDS - Spatial Variations



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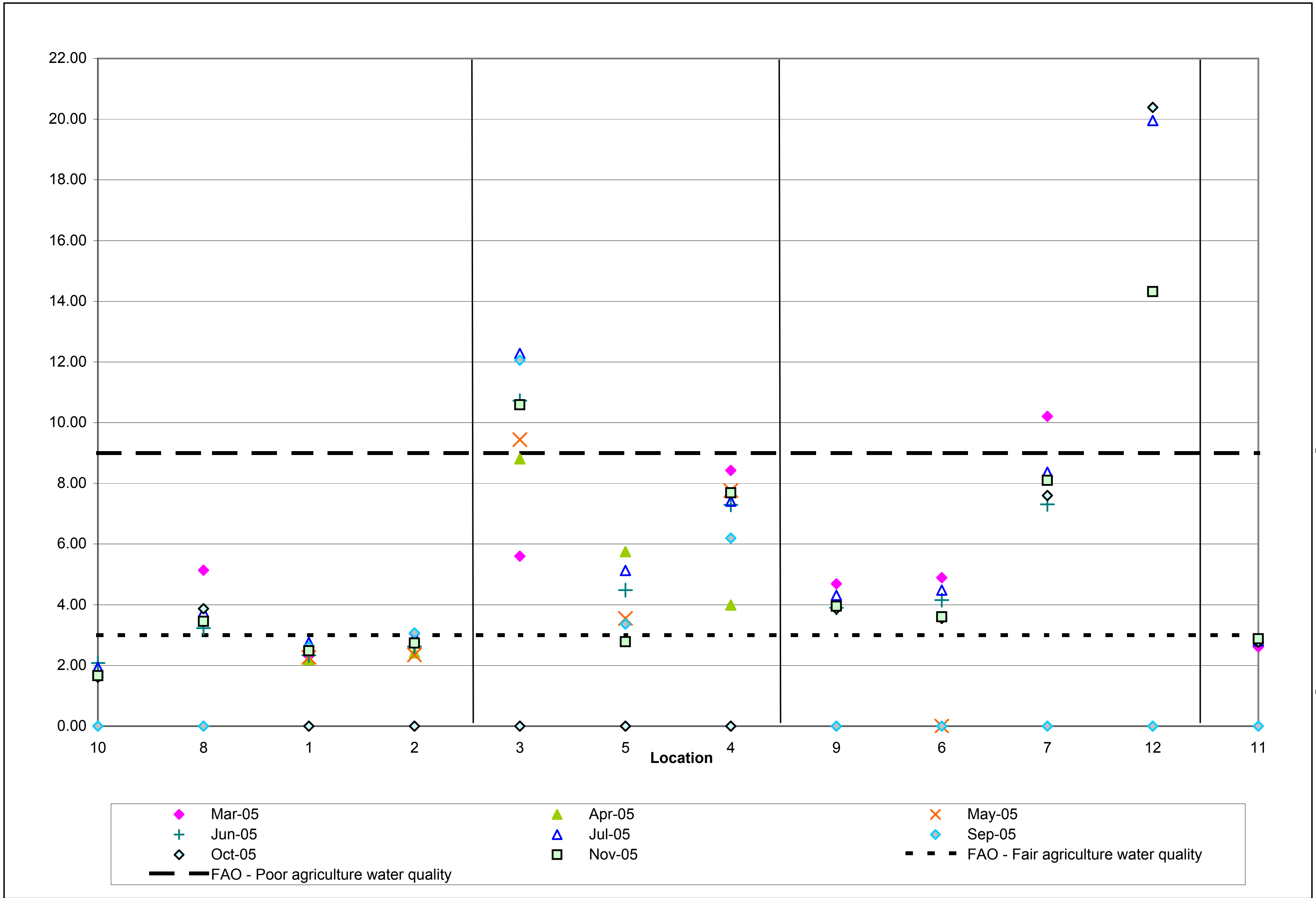
Sodium Adsorption Ratio - SAR - Spatial Variations



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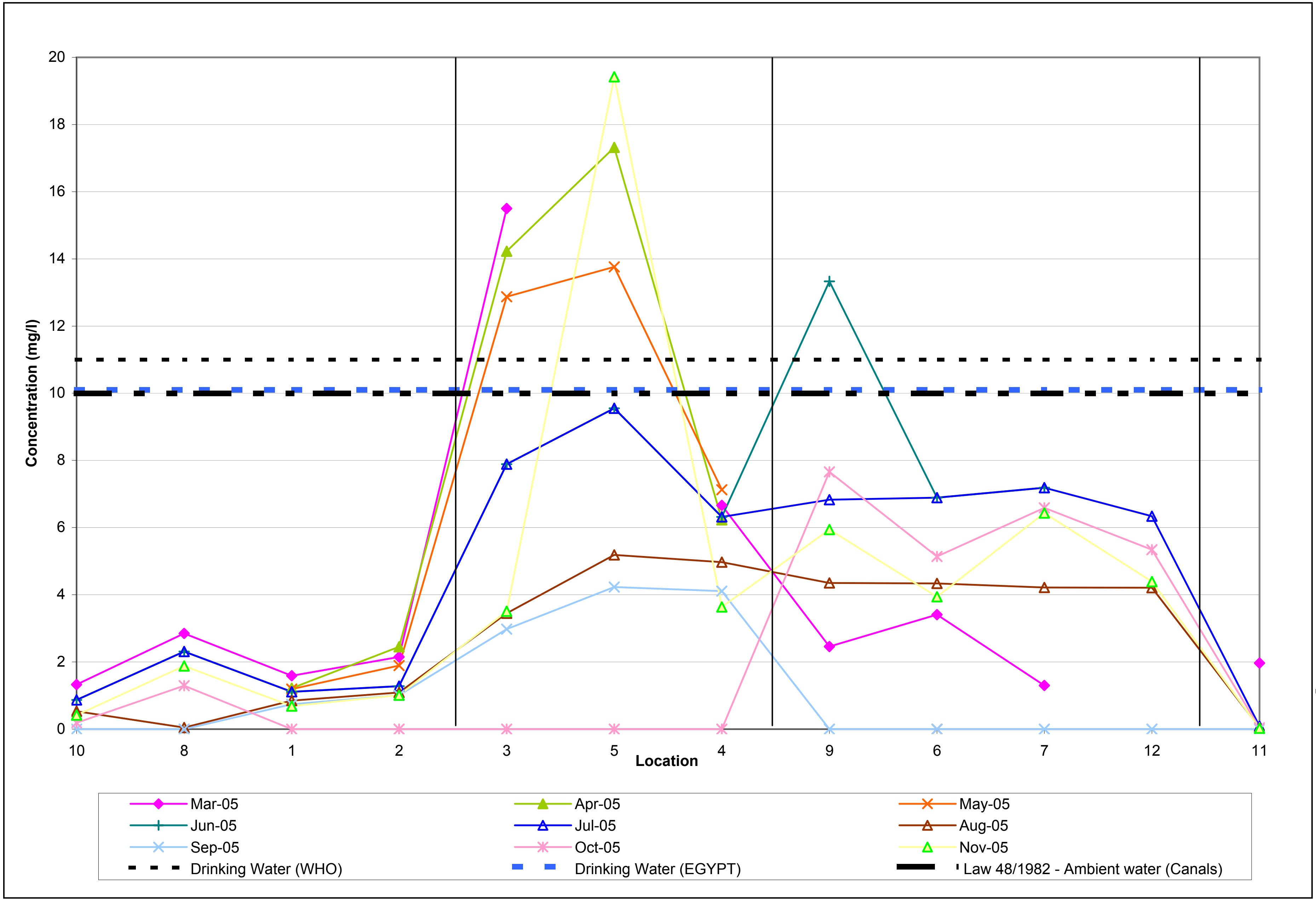
Nitrate - NO3-N - Spatial Variations



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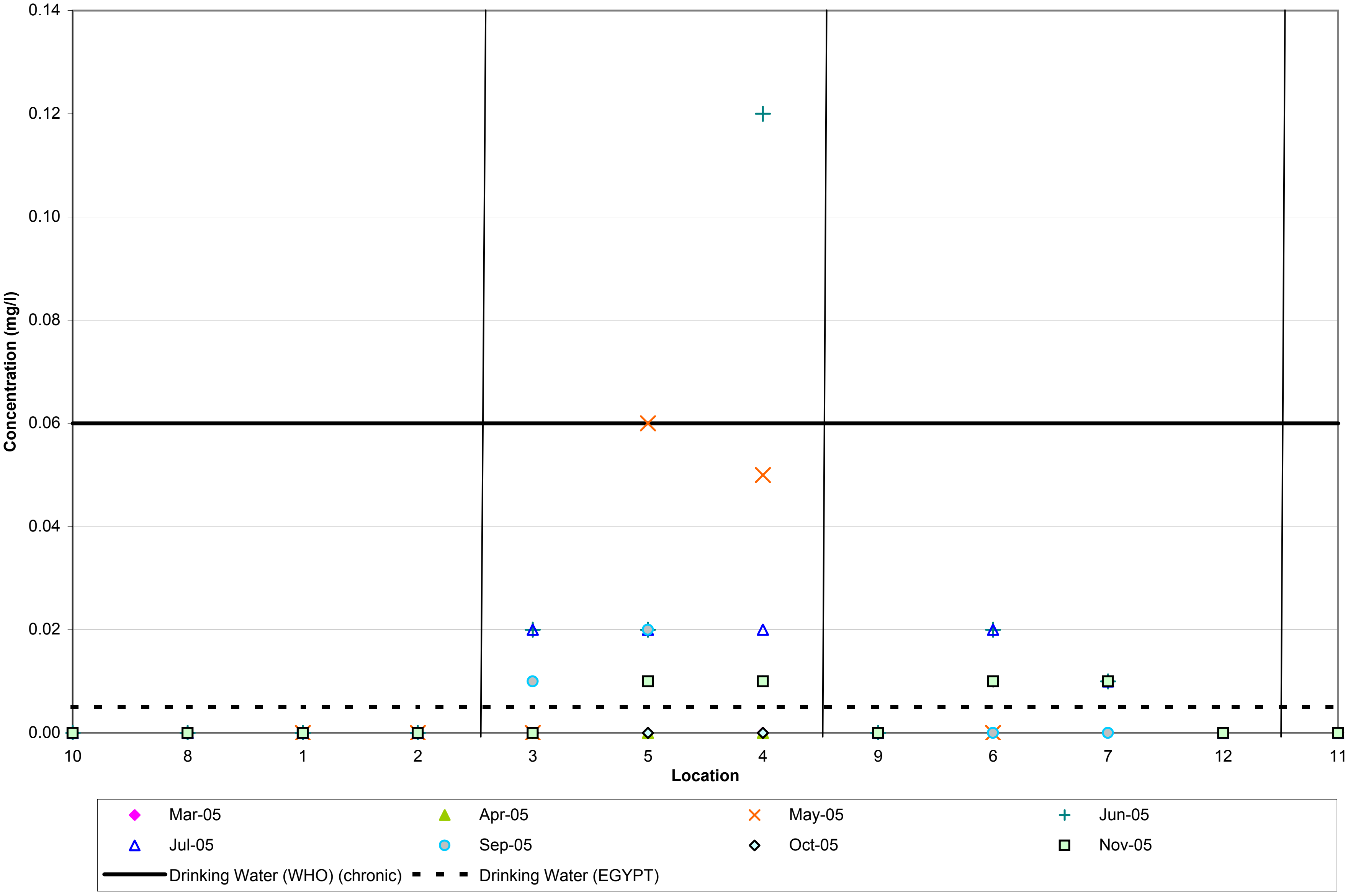
Nitrite - NO2-N - Spatial Variations



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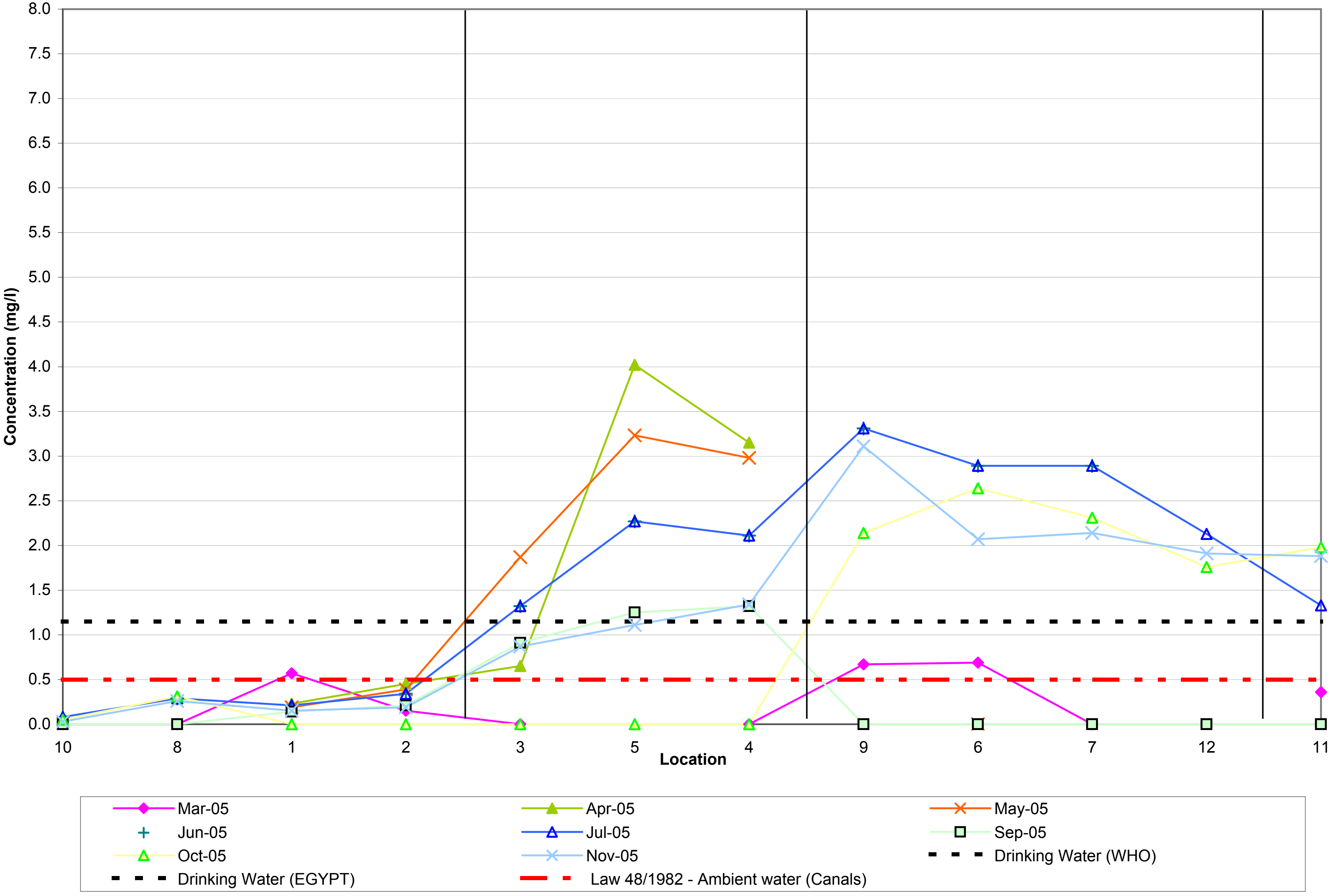
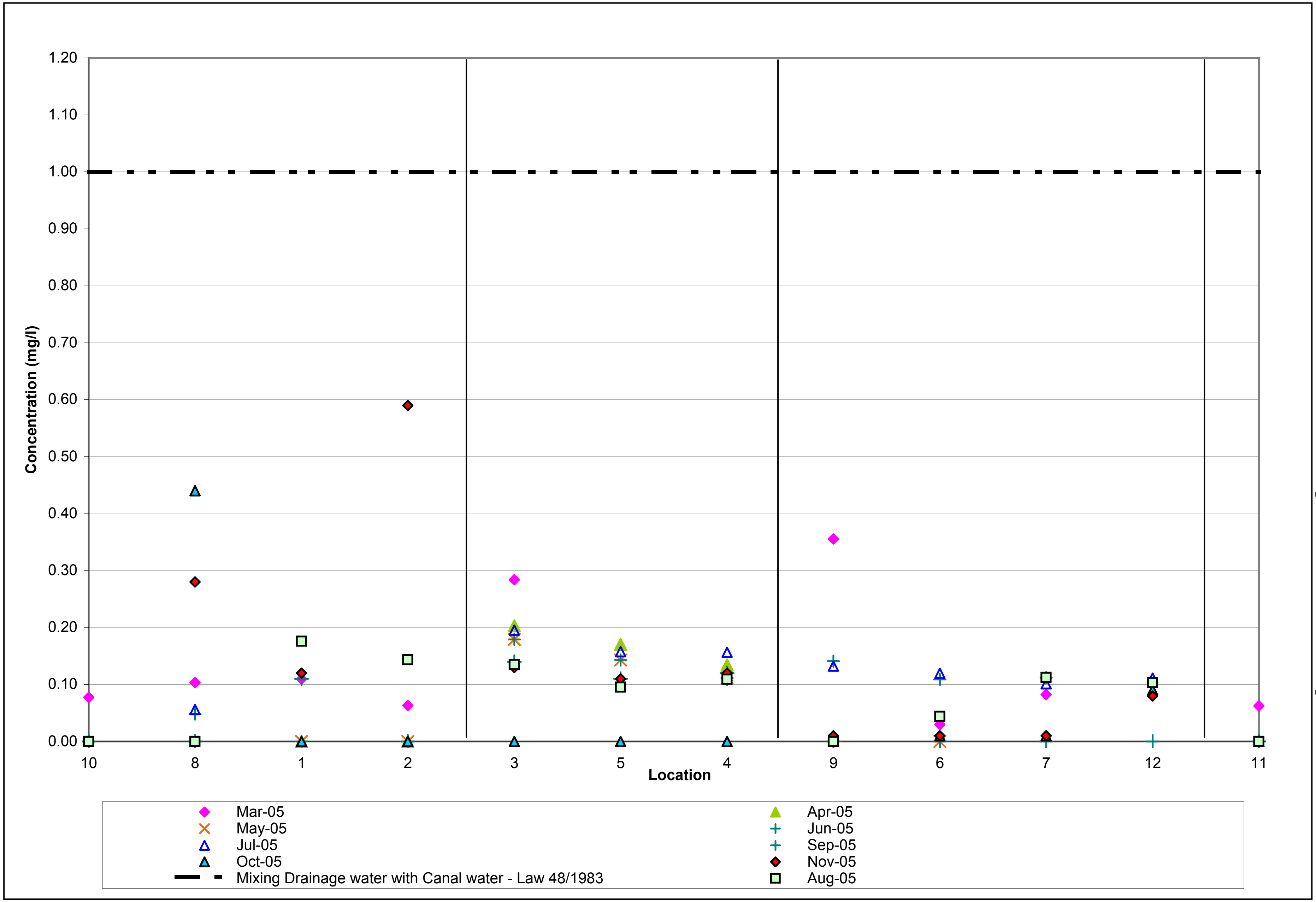
Ammonium - NH4-N - Spatial Variations



Phosphate - PO4-P - Spatial Variations



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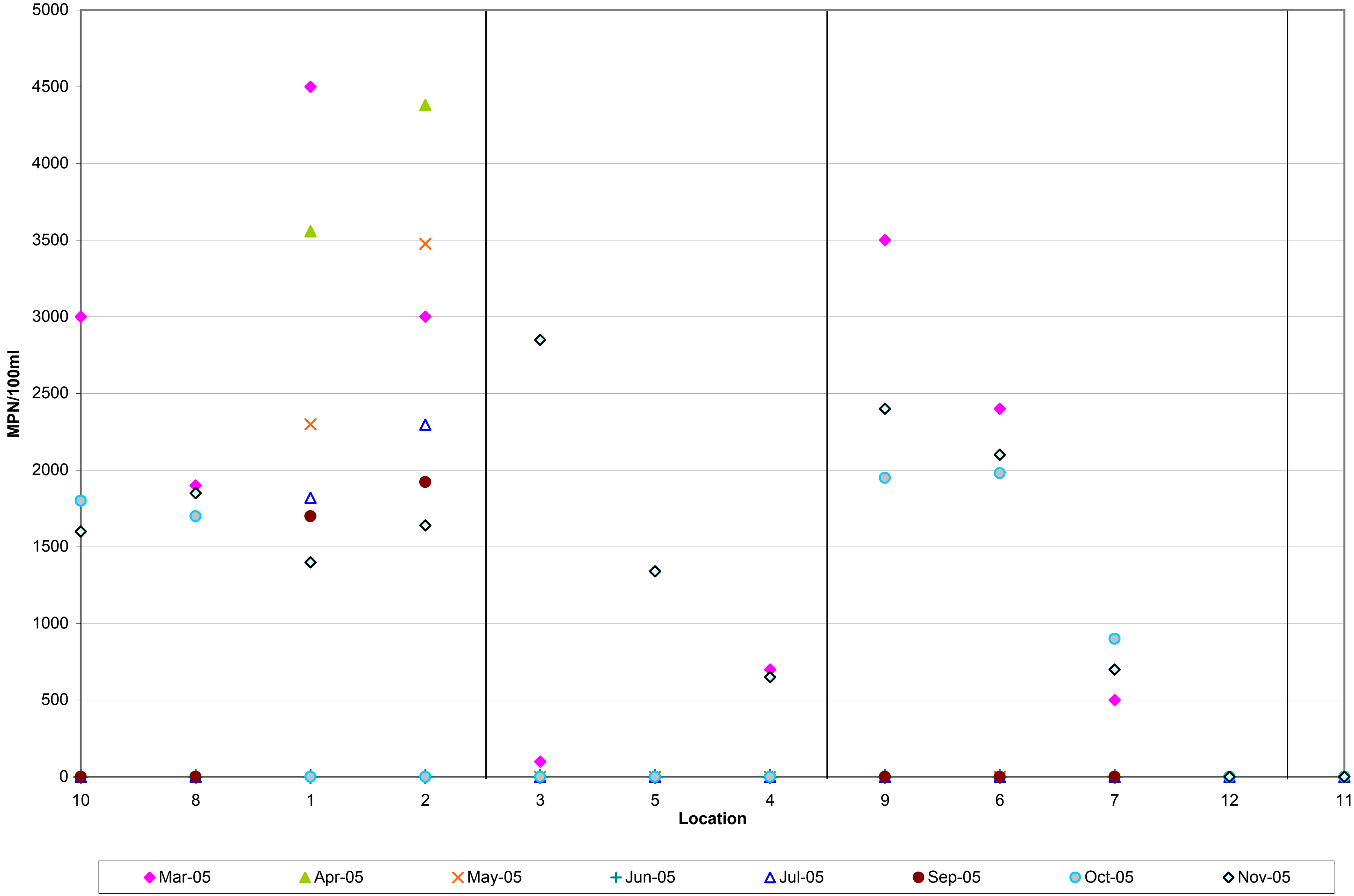
Total Coliforms - Spatial Variations



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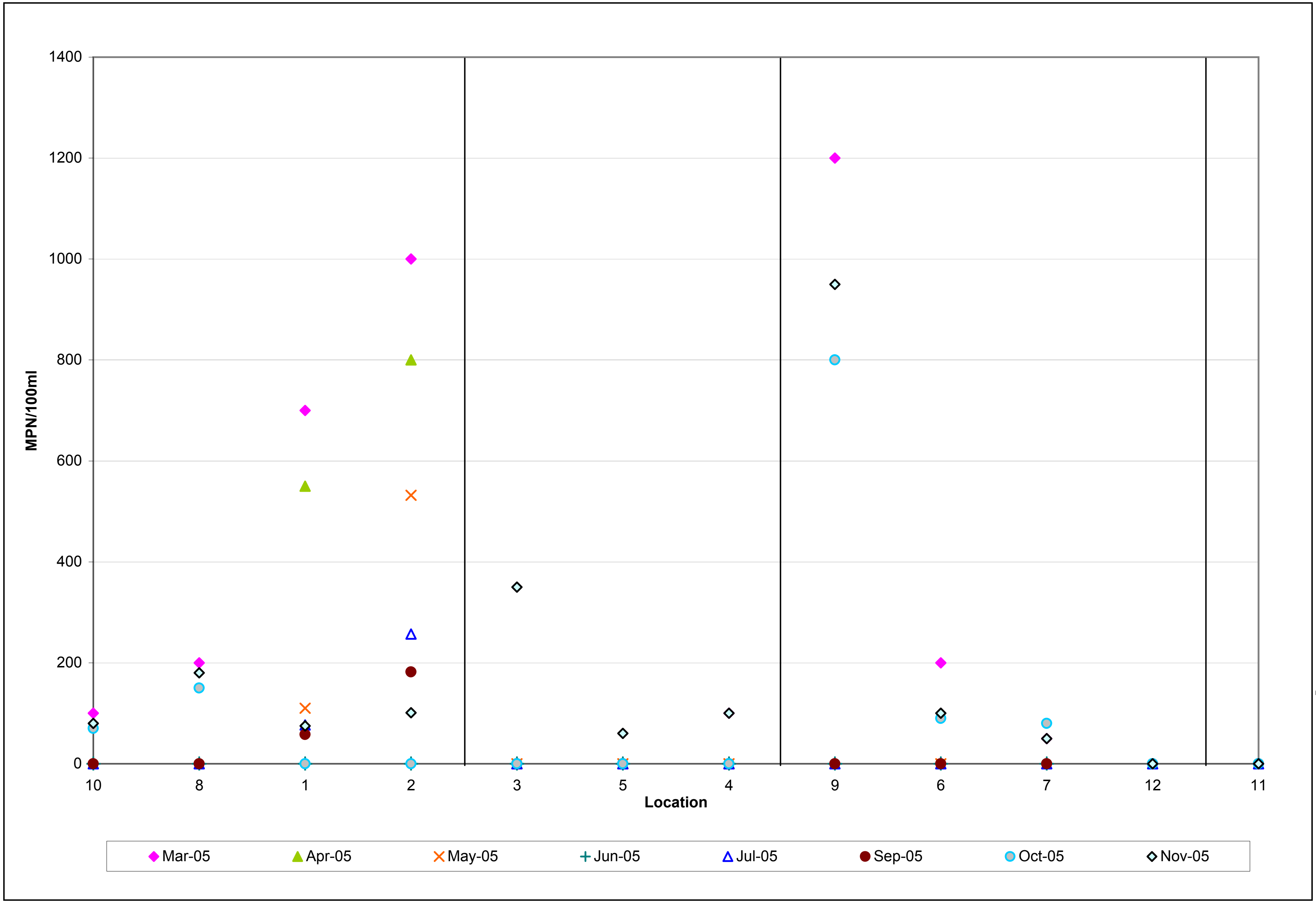
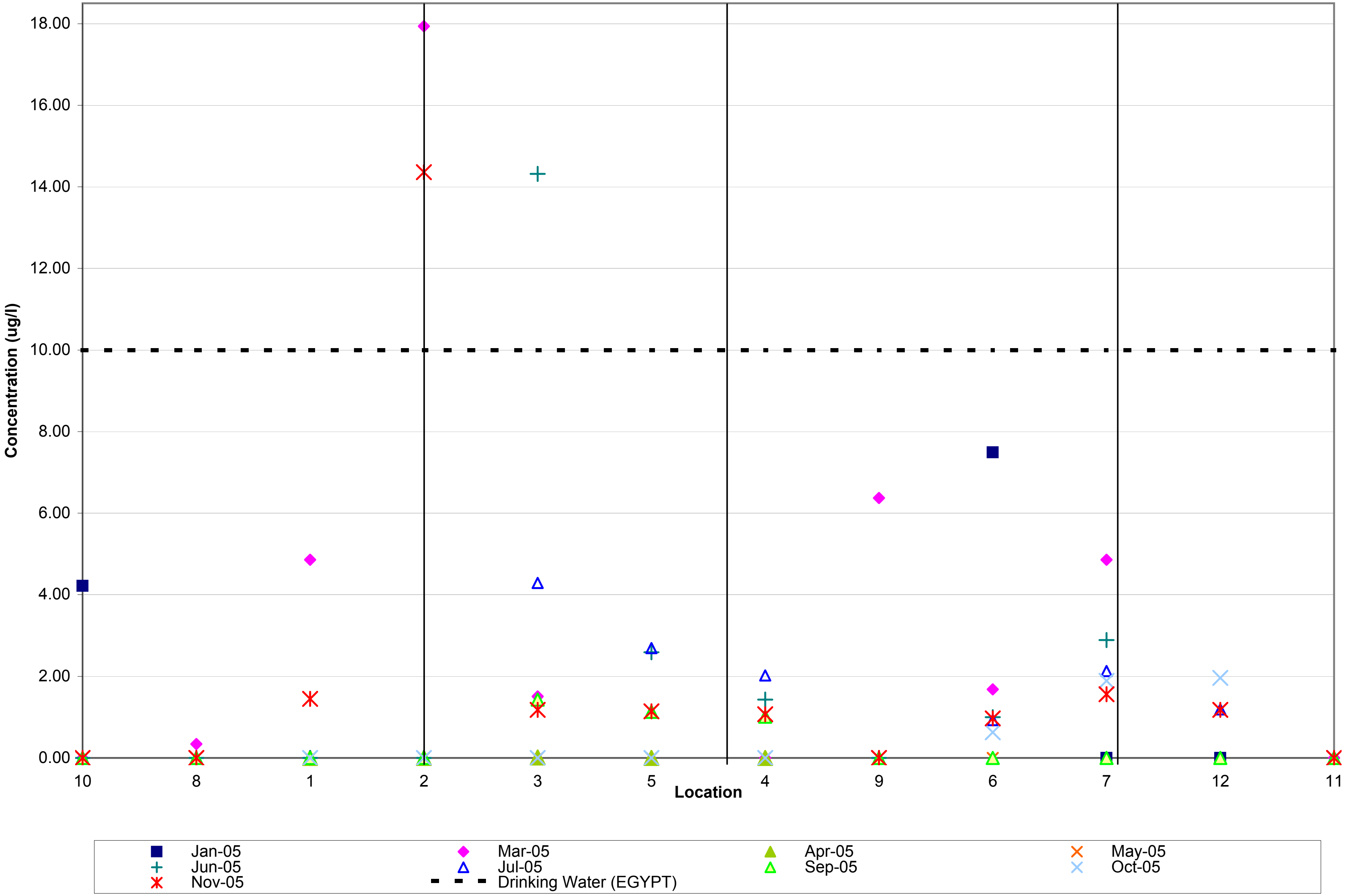
Faecal Coliforms - Spatial Variations



Arsenic - As - Spatial Variations



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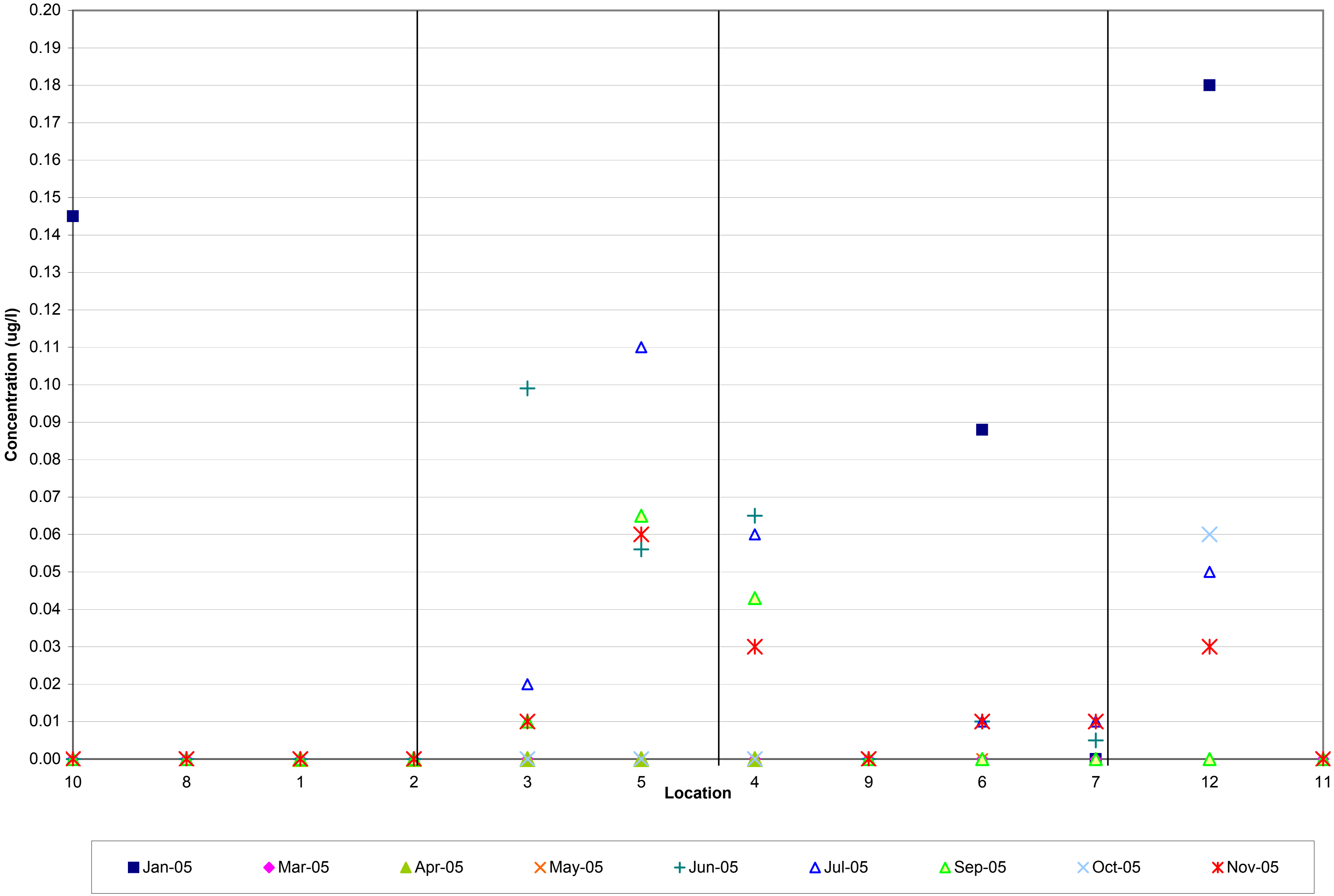
Cadmium - Cd - Spatial Variations



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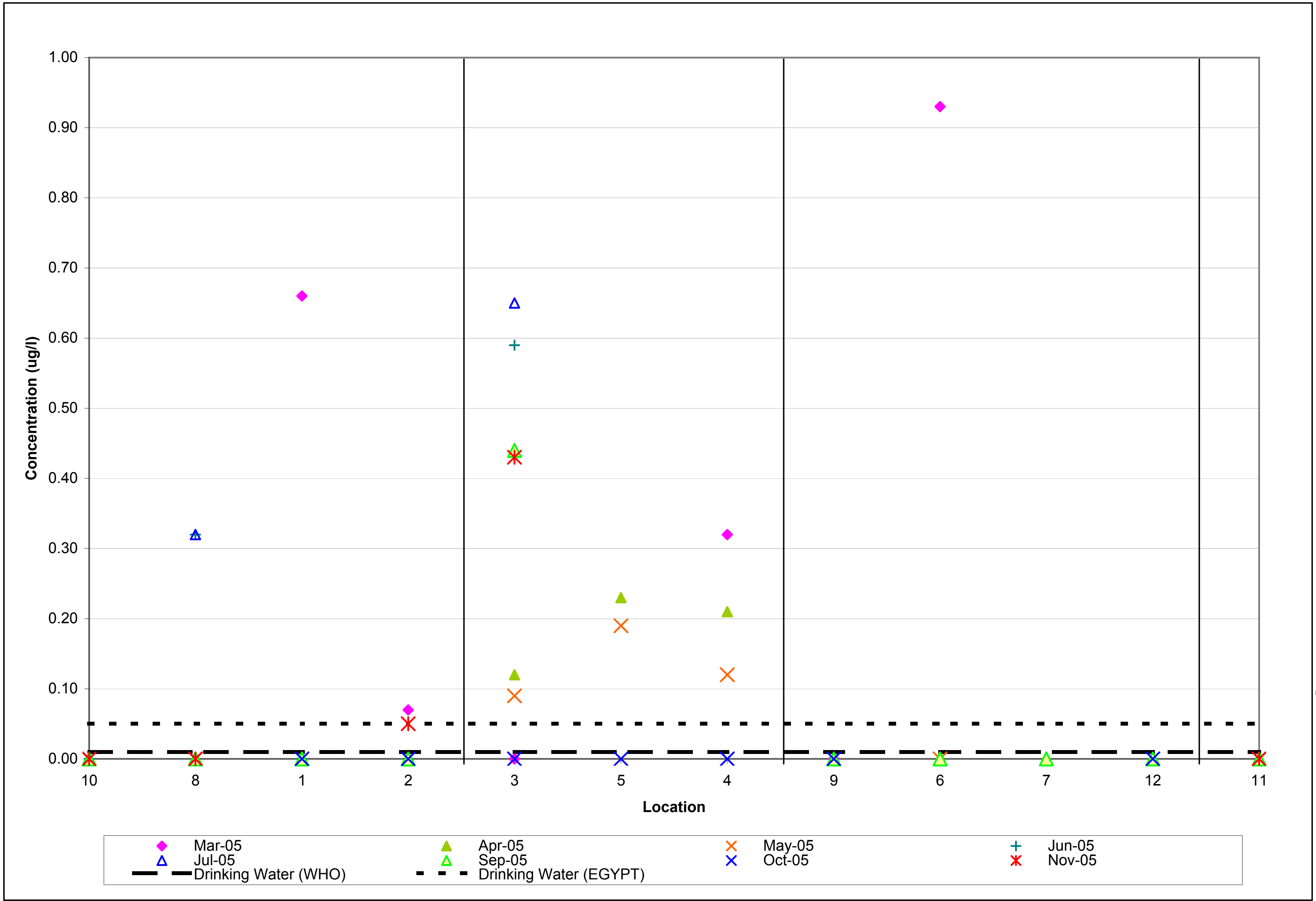
Lead - Pb - Spatial Variations



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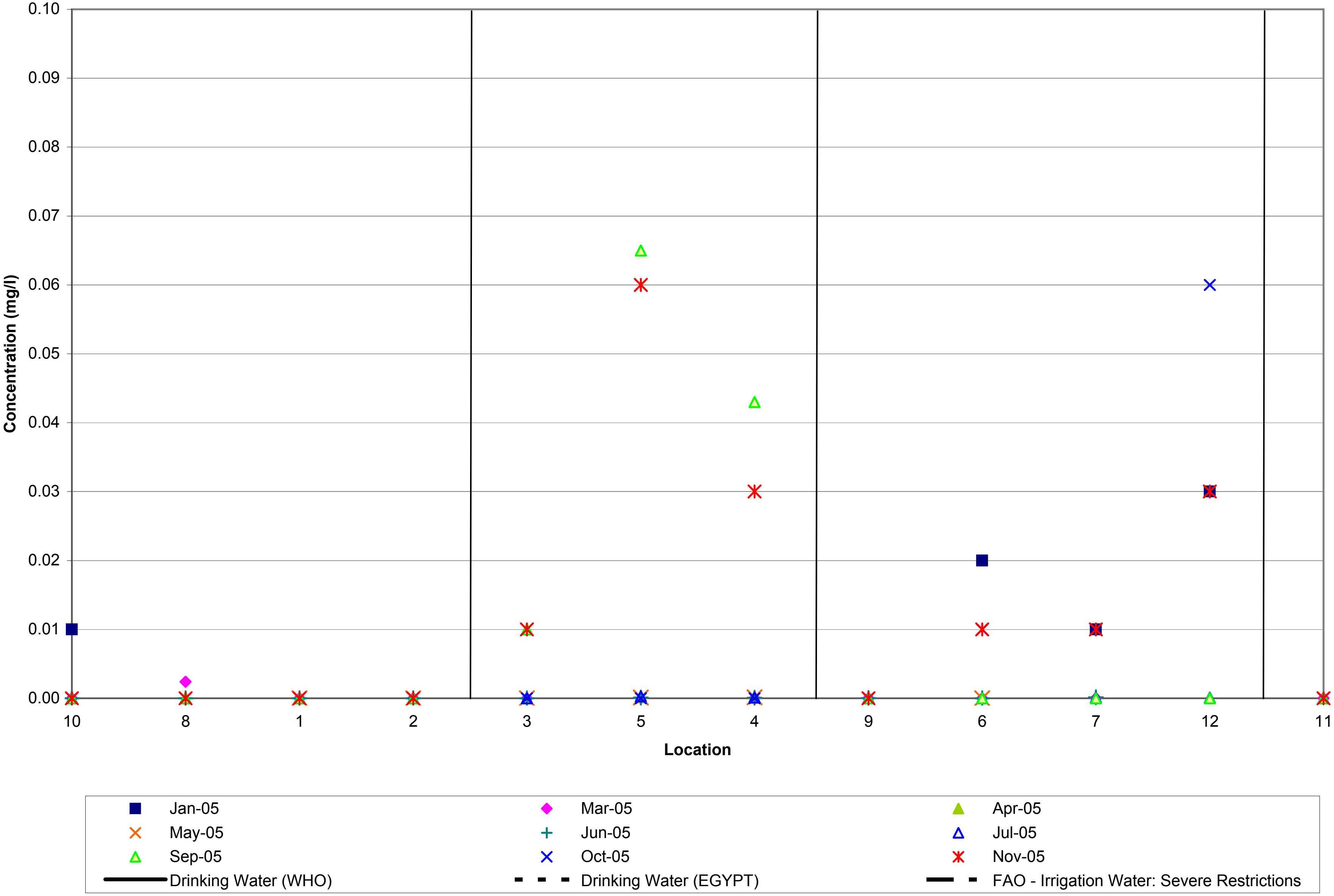
Copper - Cu - Spatial Variations



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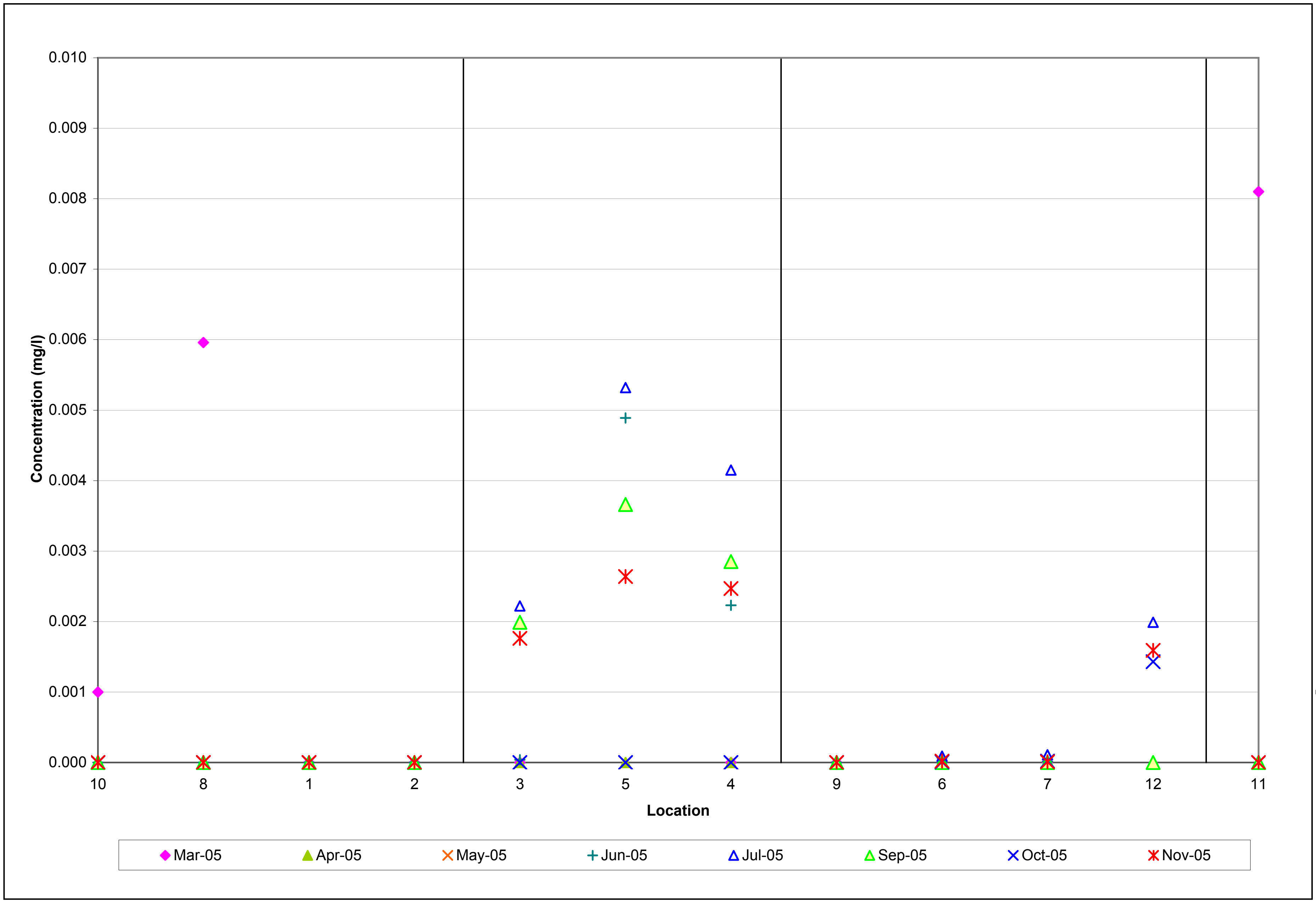
Zinc - Zn - Spatial Variations



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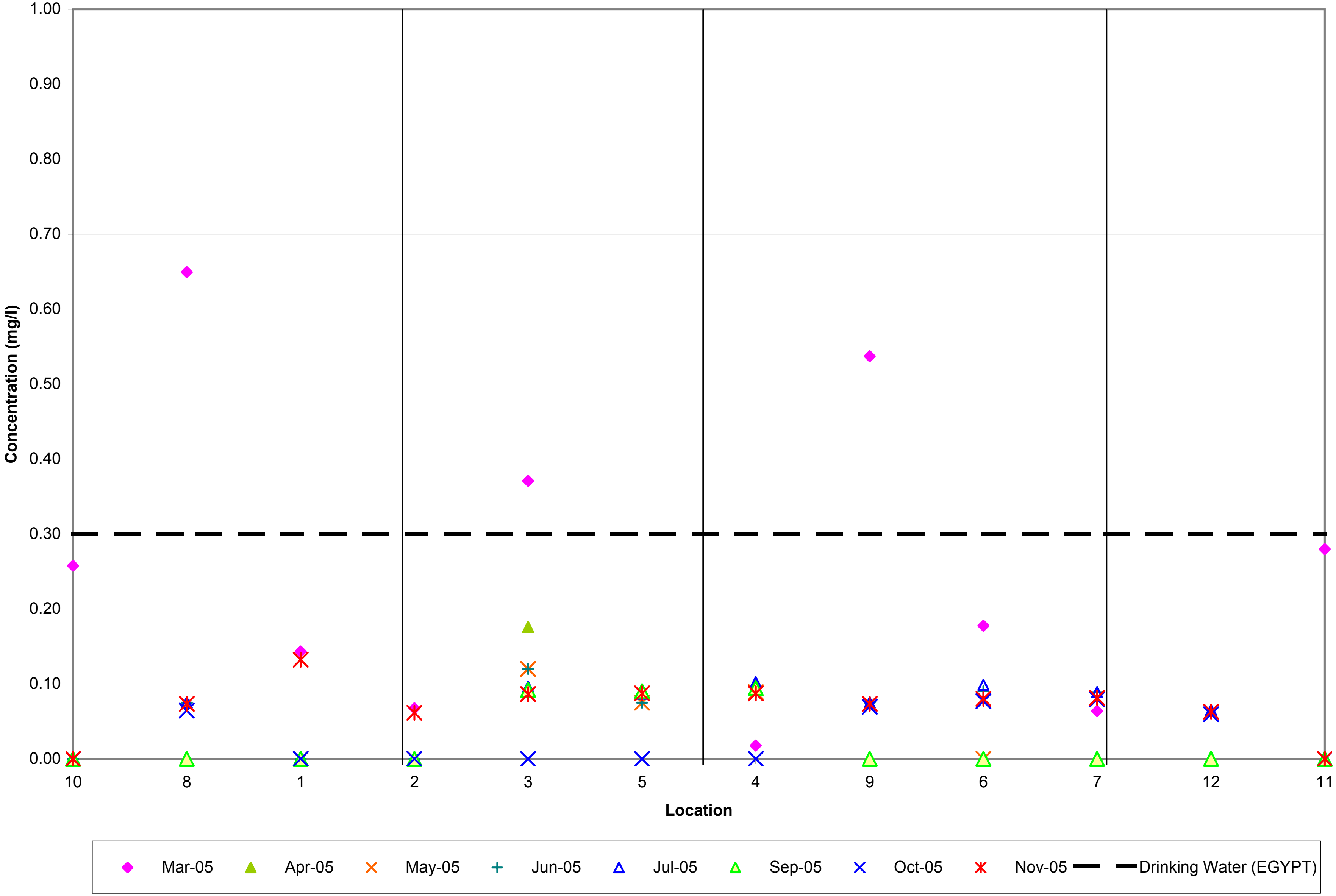
Iron - Fe - Spatial Variations



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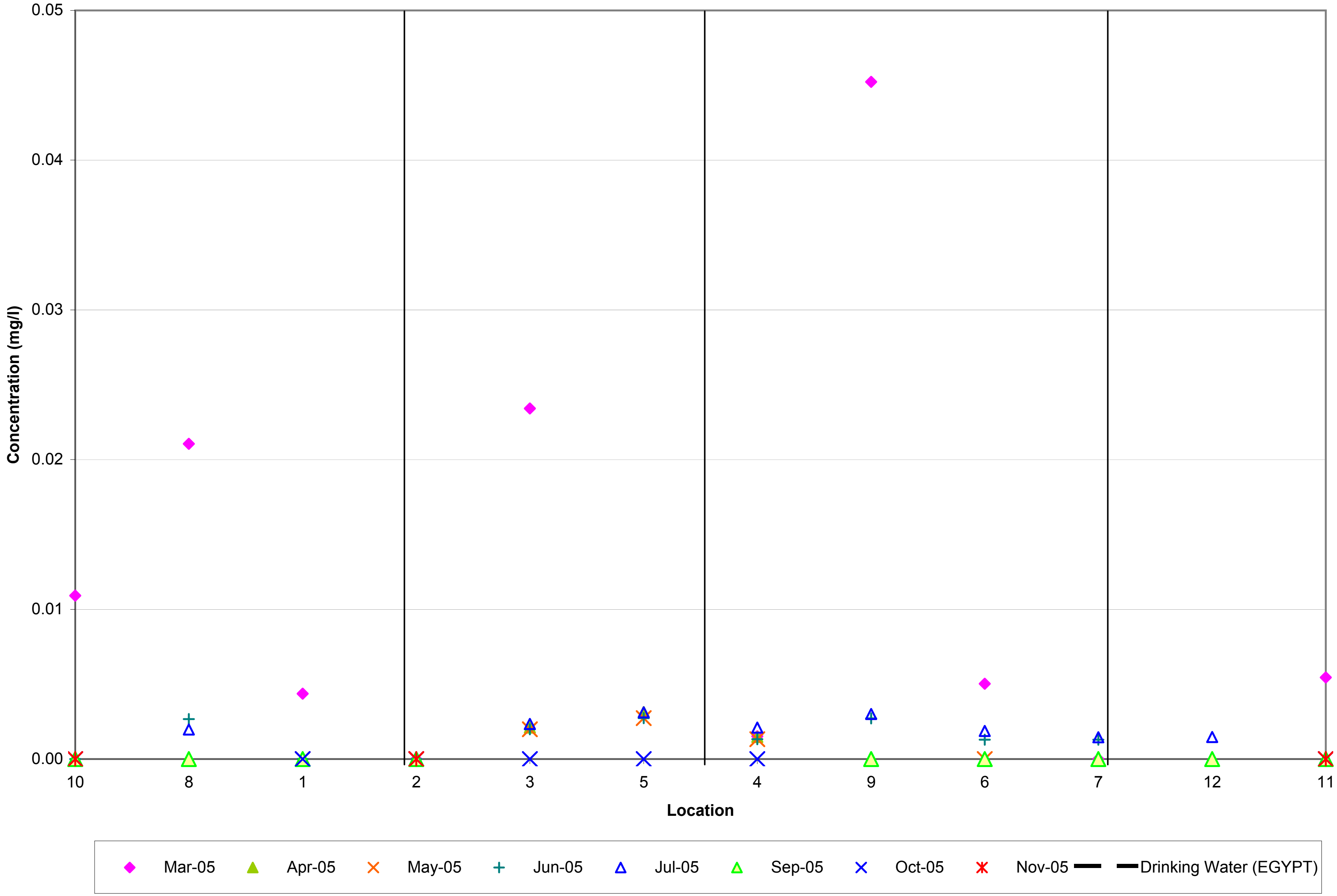
Manganese - Mn - Spatial Variations



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E.2 The NAWQAM Monitoring Campaign (1997-2004)

E.2.1 Sampling locations.

Figure E.1: The NAWQAM Water Quality Monitoring Locations in the Fayoum Area

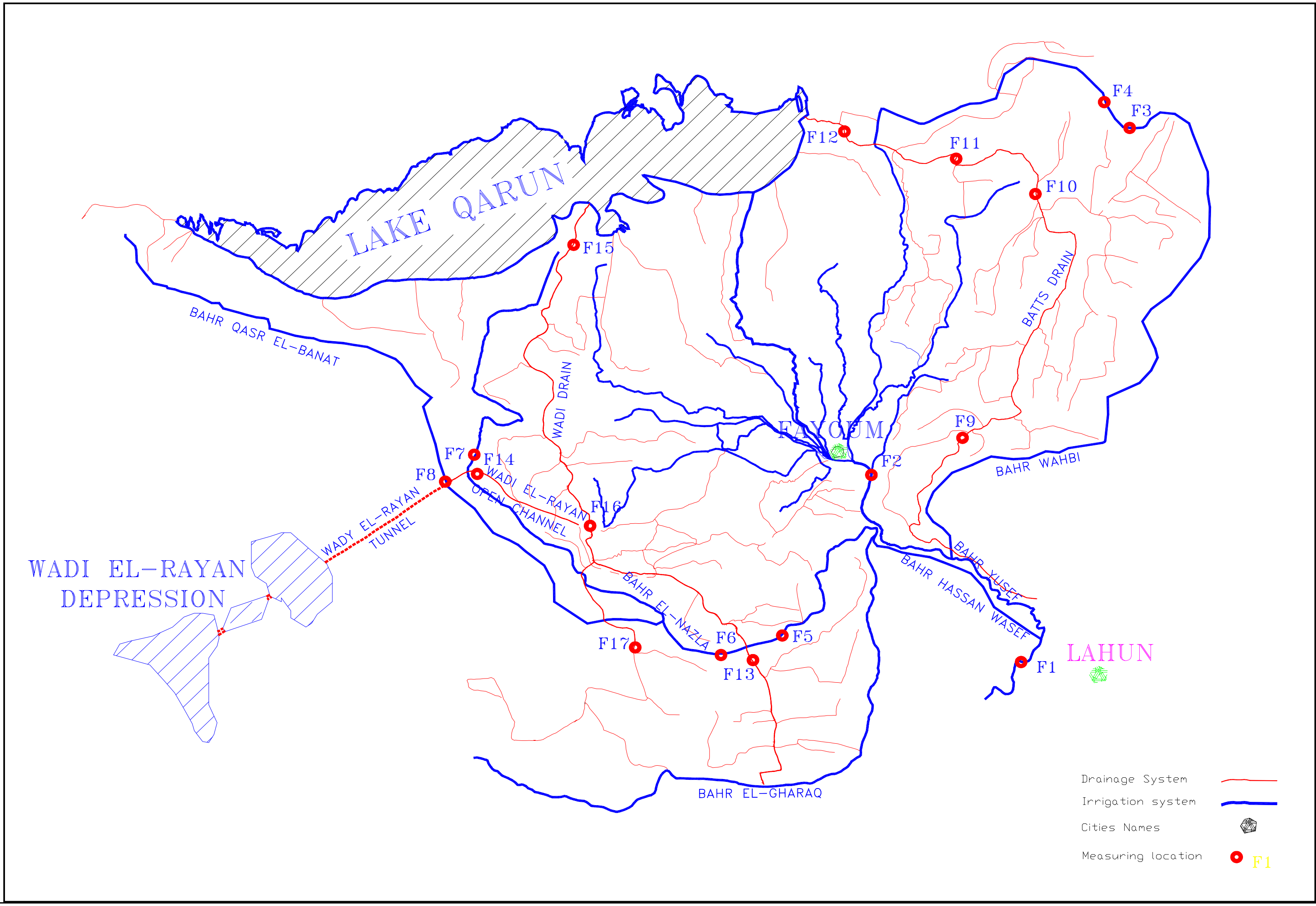
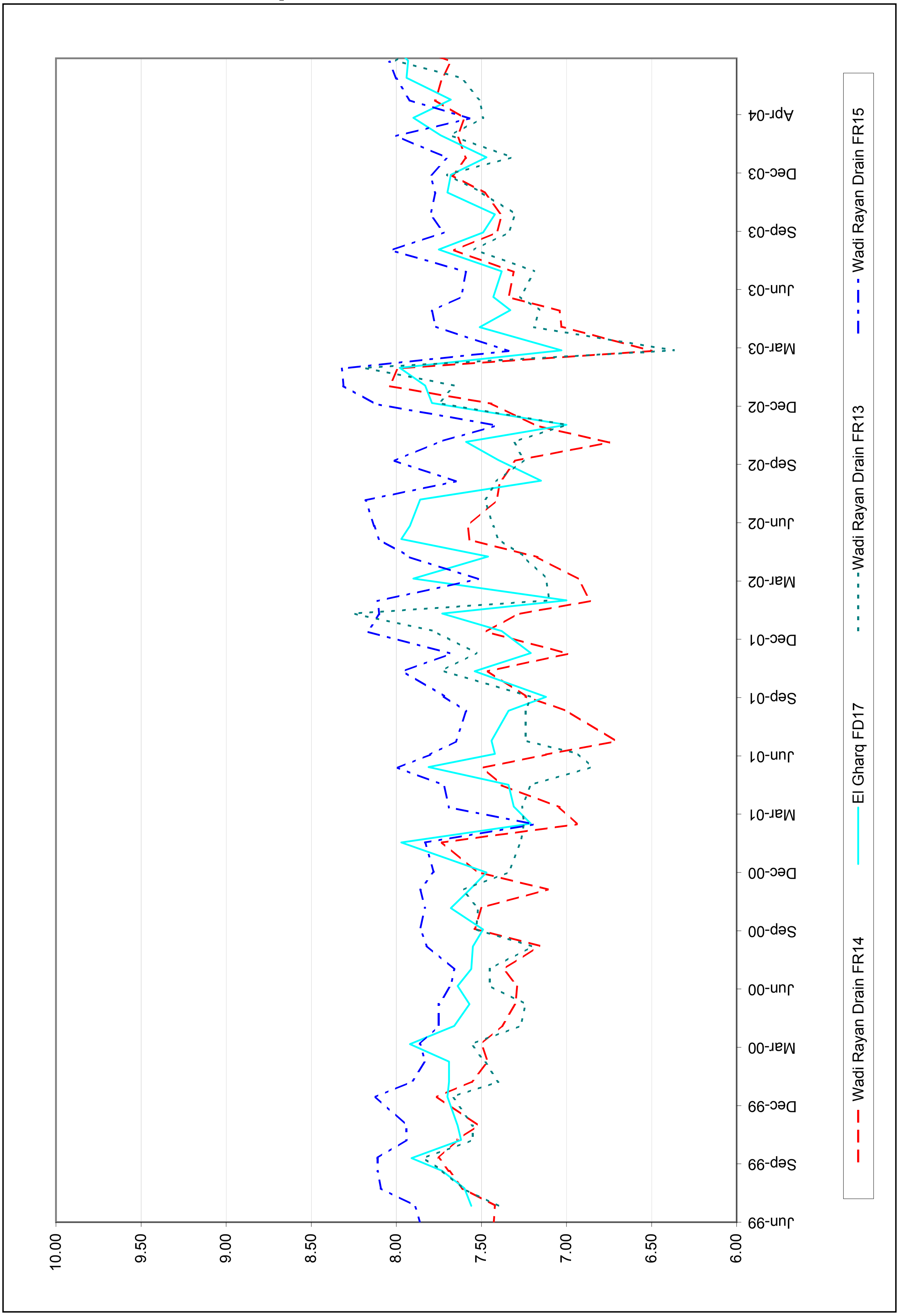


Table E.3: Catchment name codes for the different sampling locations in the Fayoum Area

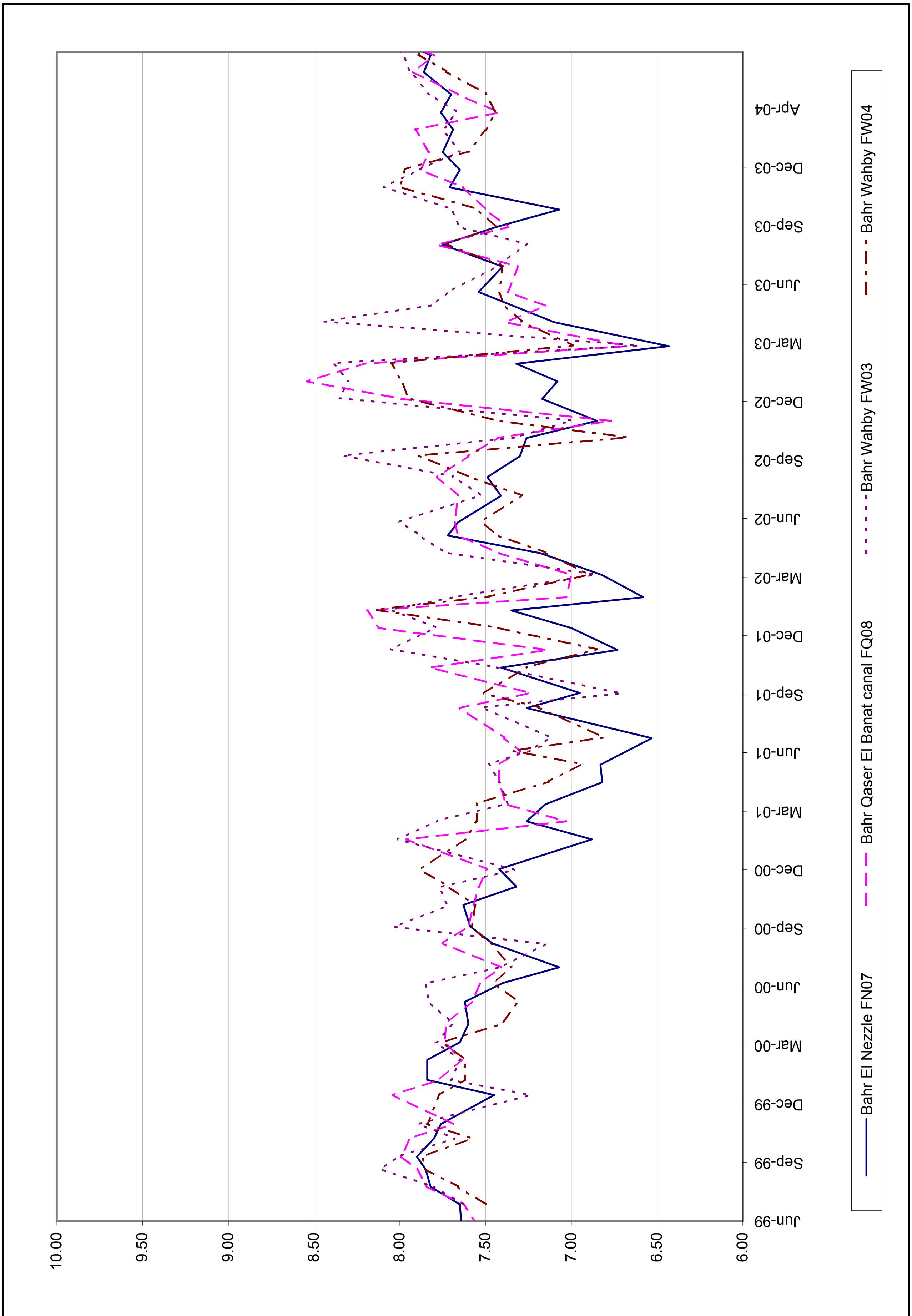
CATCHMENT NAME	LOCATION_CODE	LOCATION_ NAME	TYPE	Description	LOCATION_FUNCTION
Batss drain	FB09	Batss drain	Open Location	Dumo	Batss drain after Fayoum city.
Batss drain	FB10	Batss drain	Reuse P.S.	Tamia	Tamya P.S. and Reuse to Bahr Wahby.
Batss drain	FB12	Batss drain	Open Location	Khalaf	Outfall of Batss to Qaraun Lake.
El Gharq drain	FD17	El Gharq drain	Reuse P.S.	El-Gharaq P.S	Reuse P.S. to Bahr El Nezla.
Wadi Rayan drain	FR13	Wadi Rayan drain	Reuse P.S.	El-Tagin	Tagen P.S. to Bahr El Nezla (Reuse).
Wadi Rayan drain	FR14	Wadi Rayan drain	Open Location	Wadi Rayan Drain	Wadi Rayan outfall to Qaraun Lake.
Wadi Rayan drain	FR15	Wadi Rayan drain	Open Location	Wadi Drain	Out fall drain Wadi Rayan to Wadi Rayan Lake.
Wadi Rayan drain	FR16	Wadi Rayan drain	Open Location	Wadi Drain	Location in the middle of Wadi Rayan drain.

CATCHMENT NAME	LOCATION_CODE	LOCATION_ NAME	Description	LOCATION_FUNCTION
Irrigation Canal	FI03	Bahr Wahby canal	Upstream of Tamiya mixing station	Bahr Wahby before mix P.S. (FB10).
Irrigation Canal	FI04	Bahr Wahby canal	Downstream of Tamiya mixing station	Bahr Wahby after mix P.S. (FB10).
Irrigation Canal	FI07	Bahr El Nezla canal	at Rayan drain syphon	Bahr El Nezla after mix Wadi Rayan drain.
Irrigation Canal	FI08	Bahr Qaser El Banat canal	at the crossing with Rayan tunnel	Bahr Qaser El Banat after mix Wadi Rayan drain.

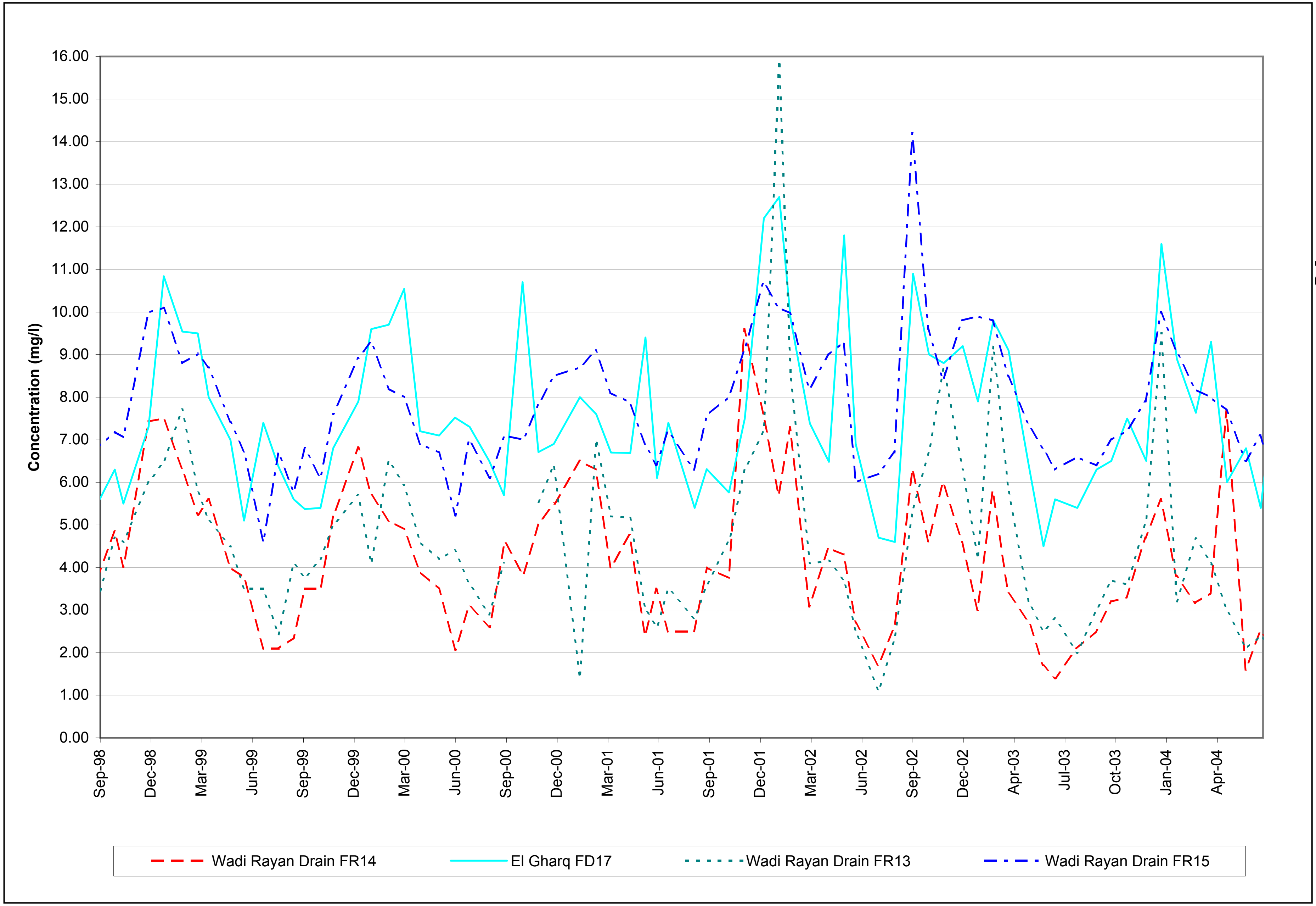
pH Seasonal Variations in Drains (NAWQAM Data)



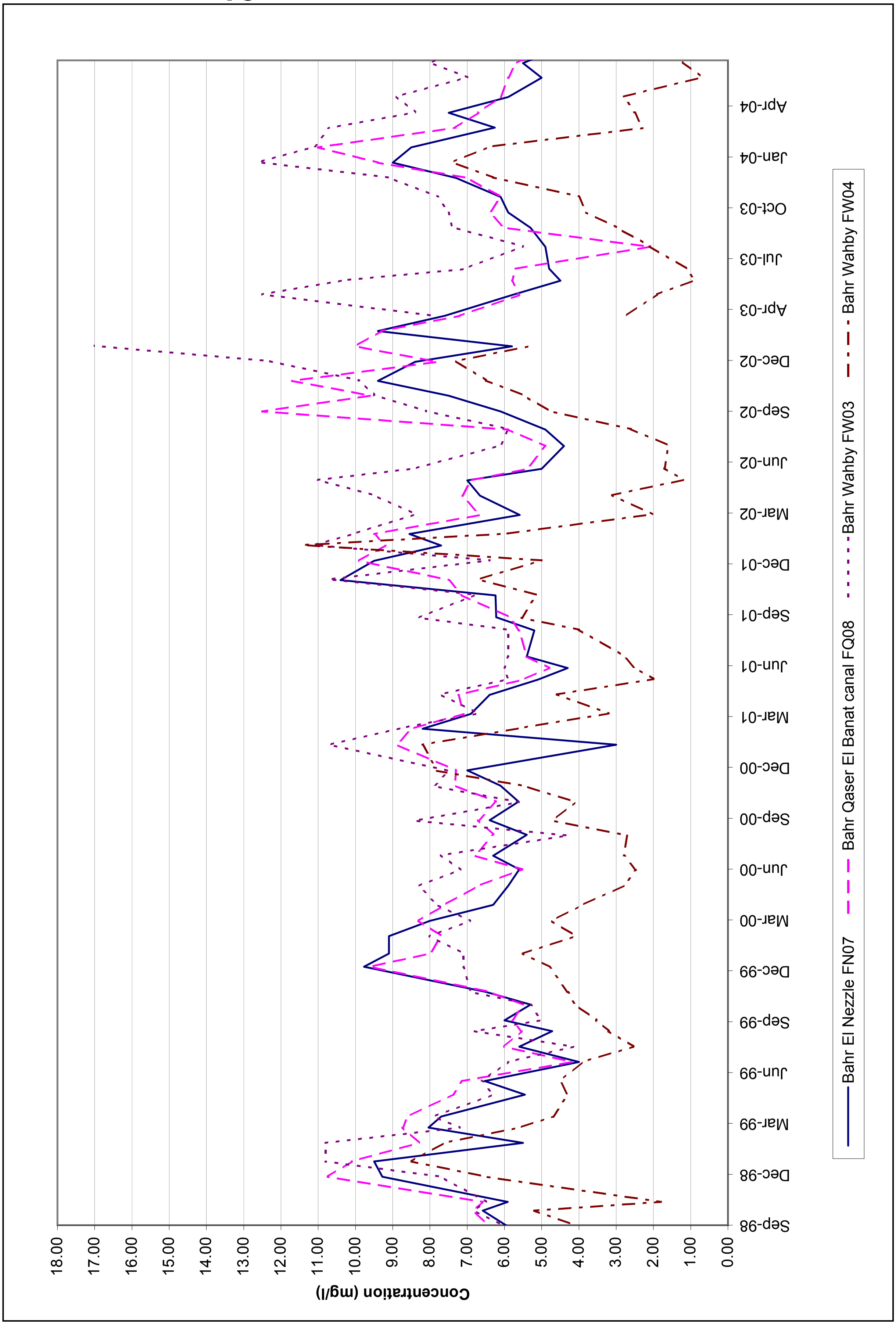
pH Seasonal Variations in Canals (NAWQAM Data)



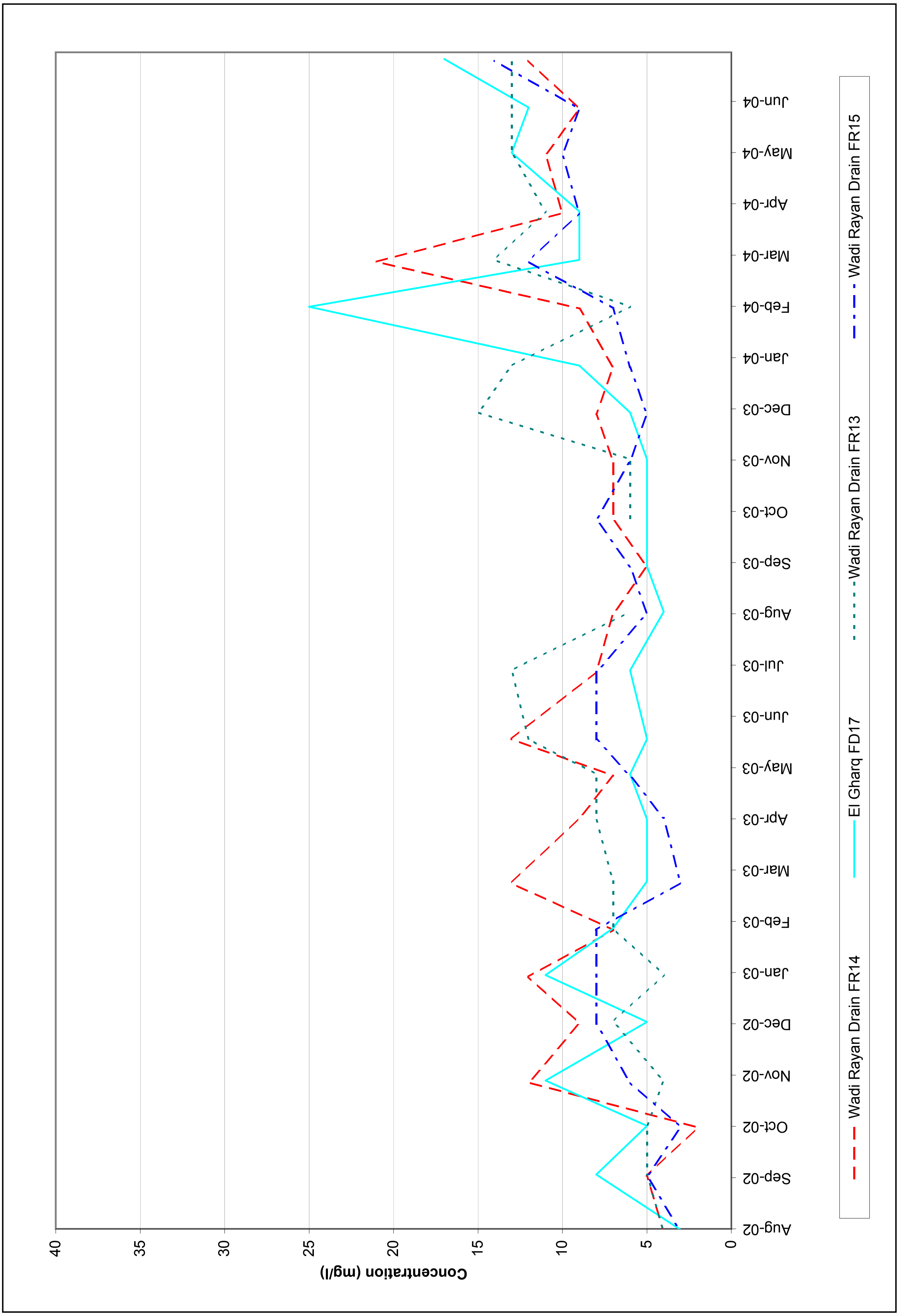
Dissolved Oxygen Seasonal Variations in Drains (NAWQAM Data)



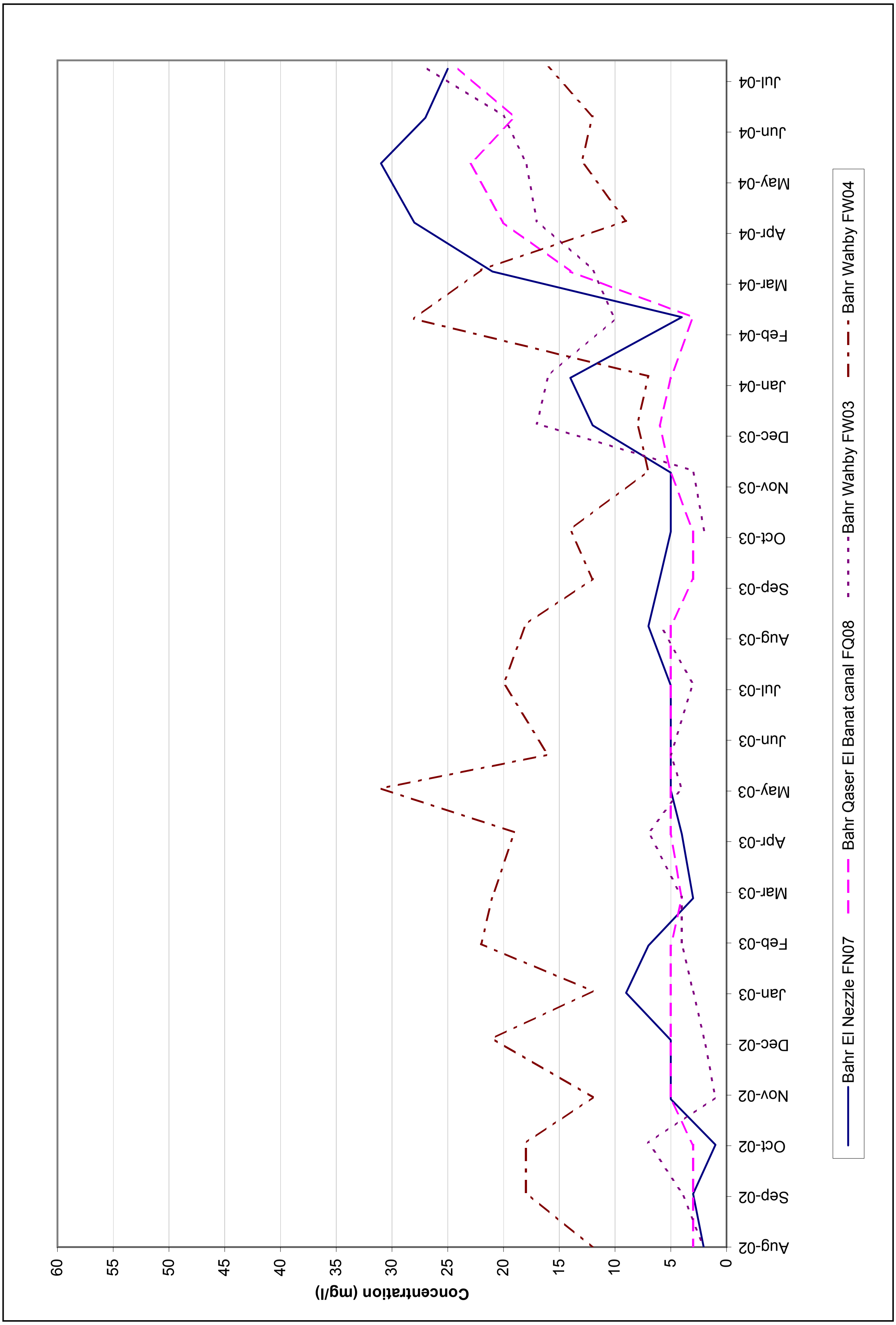
Dissolved Oxygen Seasonal Variations in Canals (NAWQAM Data)



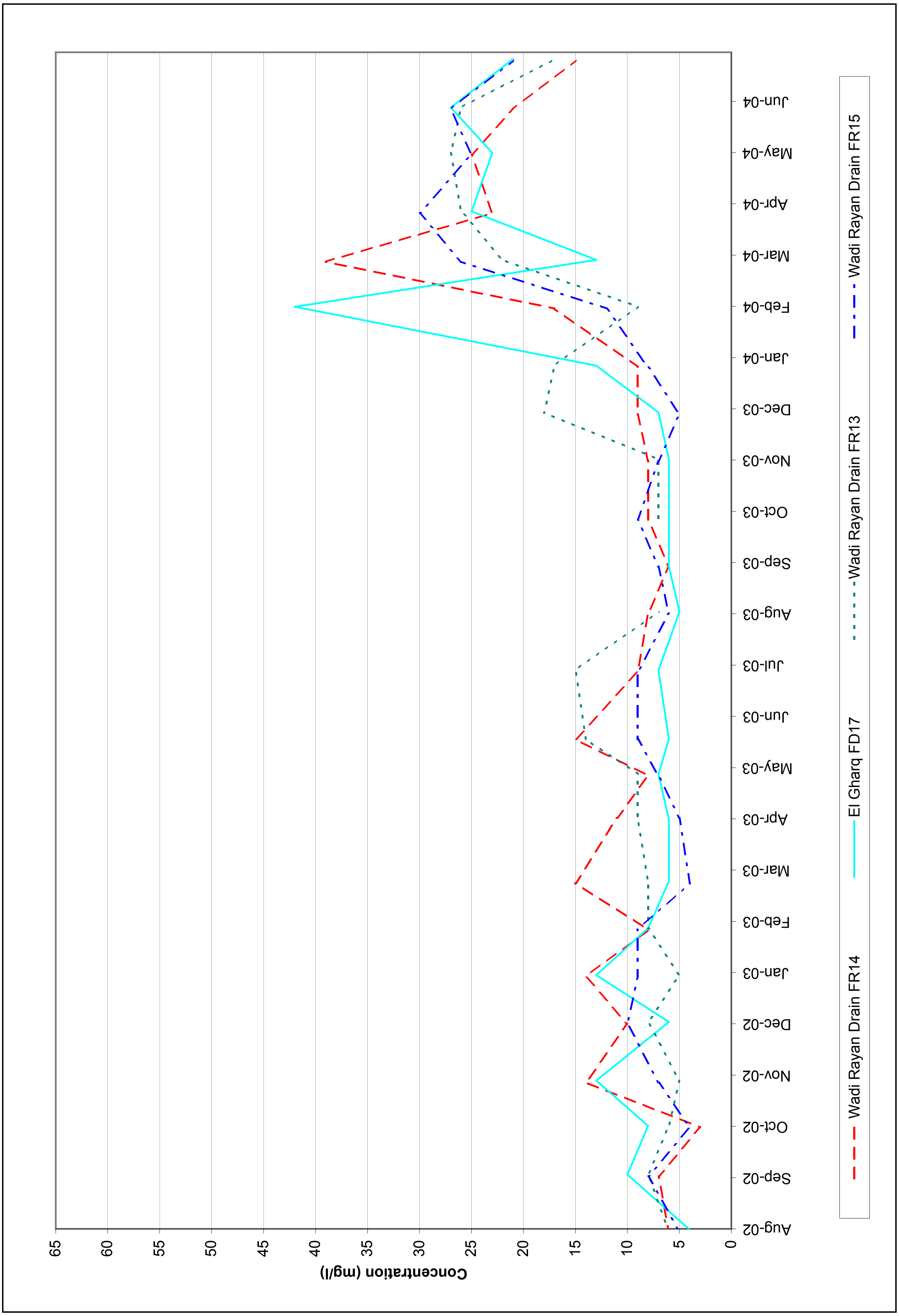
Biological Oxygen Seasonal Demand Variations in Drains (NAWQAM Data)



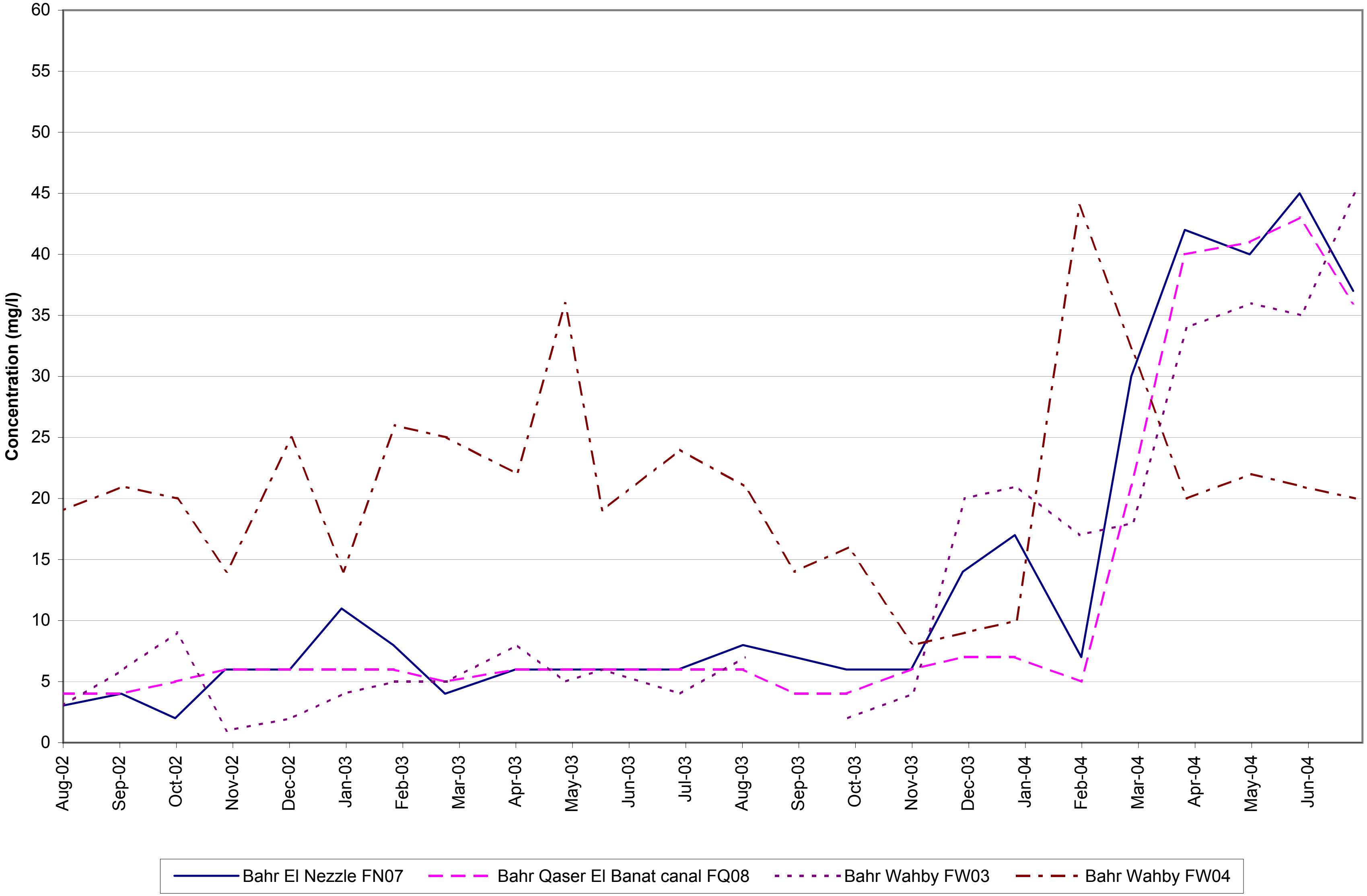
Biological Oxygen Demand Seasonal Variations in Canals (NAWQAM Data)



Chemical Oxygen Demand Seasonal Variations in Drains (NAWQAM Data)



Chemical Oxygen Demand Seasonal Variations in Canals (NAWQAM Data)



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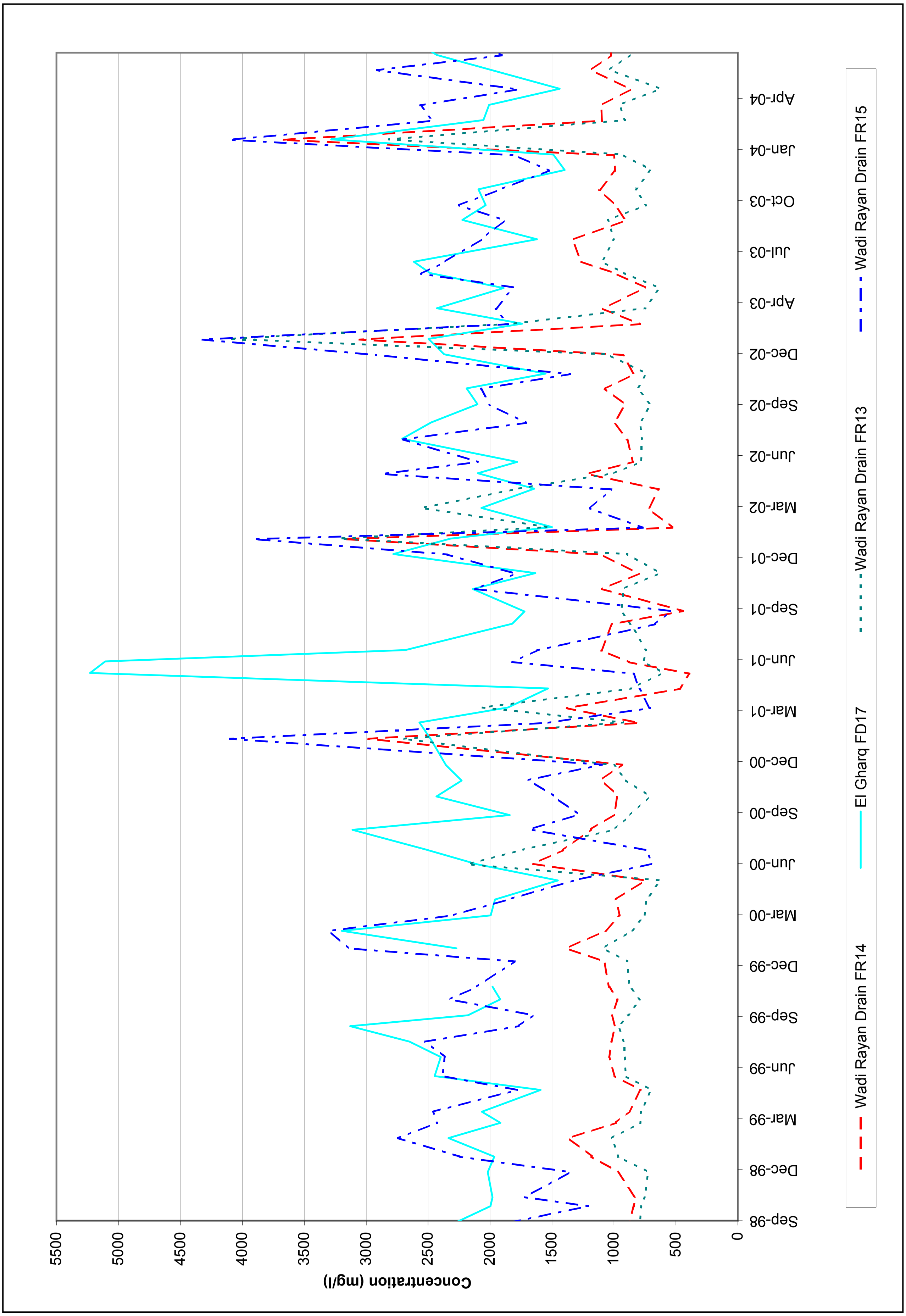
TDS Seasonal Variations in Drains (NAWQAM Data)



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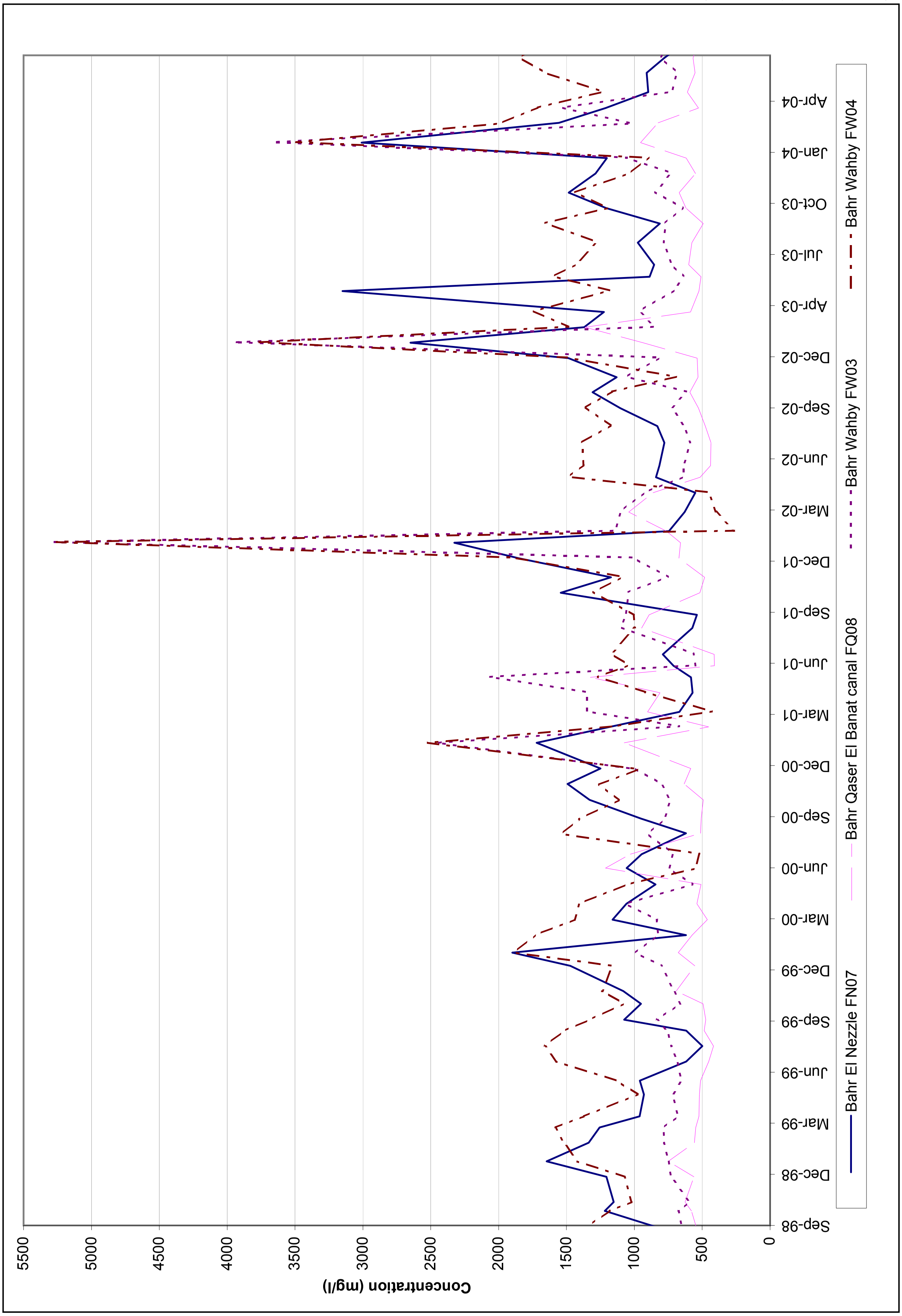
TDS Seasonal Variations in Canals (NAWQAM data)



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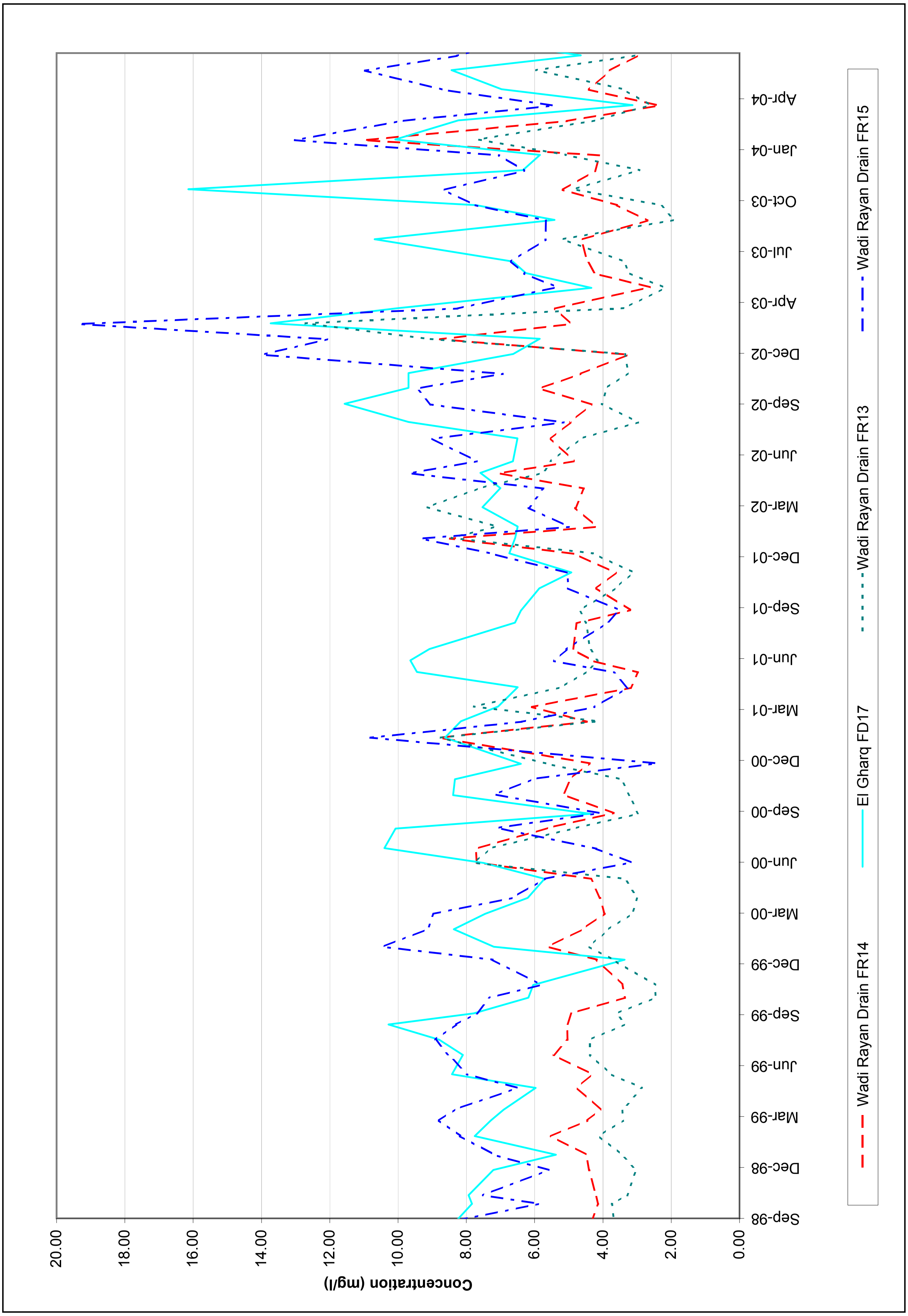
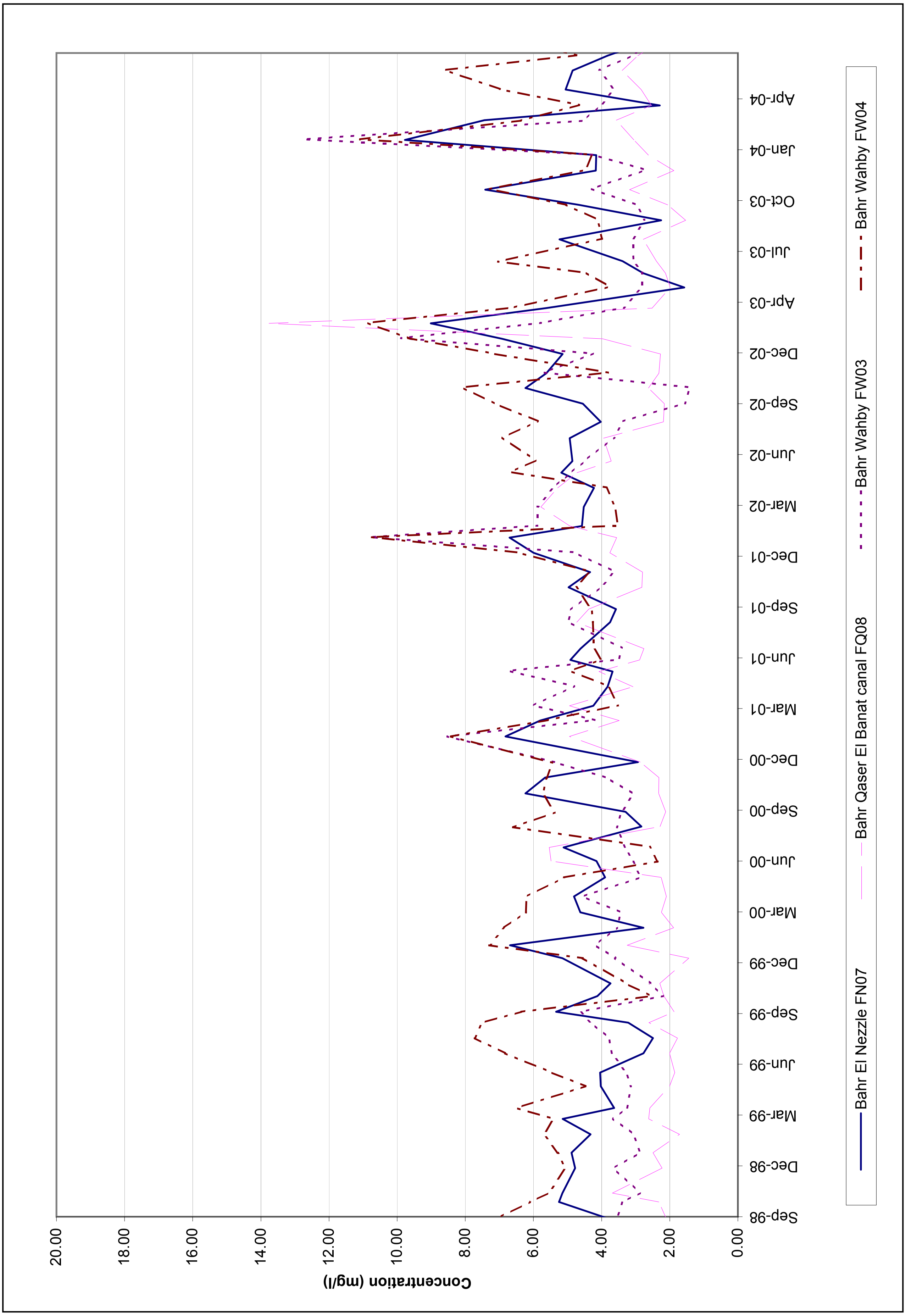
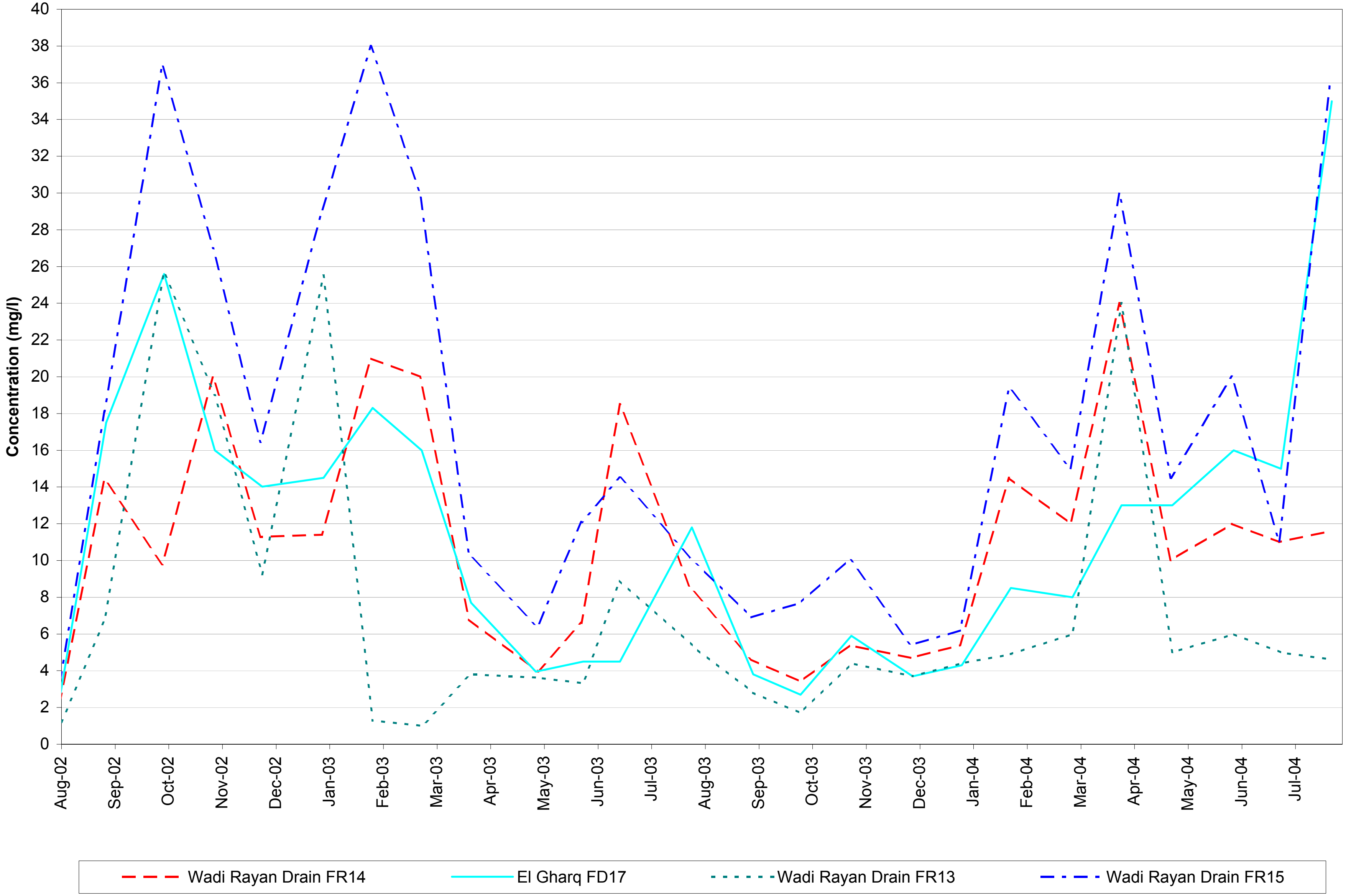
SAR Seasonal Variations in Drains (NAWQAM data)



SAR Seasonal Variations in Canals (NAWQAM data)



Nitrate Seasonal Variations in Drains (NAWQAM data)



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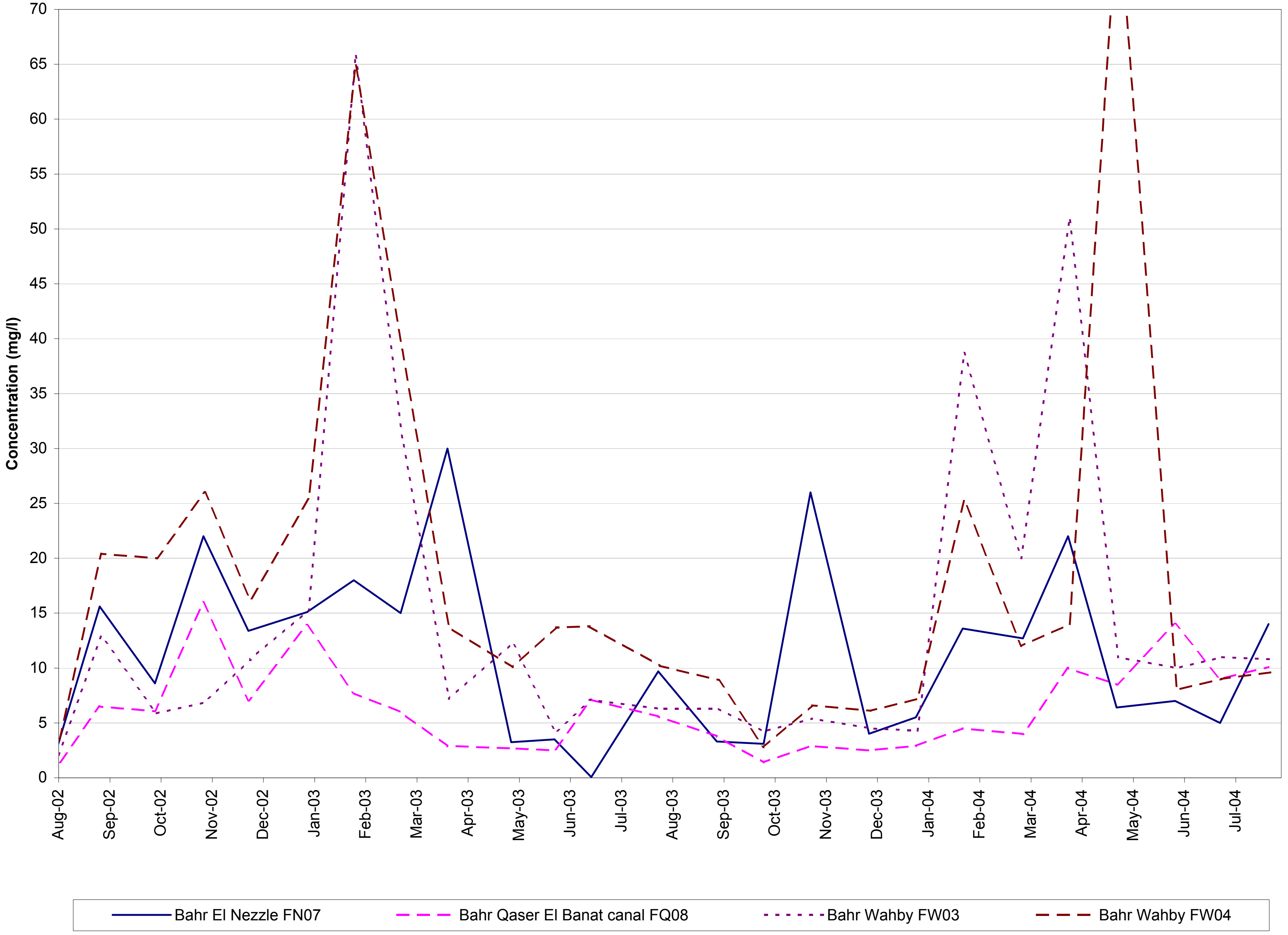
Nitrate Seasonal Variations in Canals (NAWQAM data)



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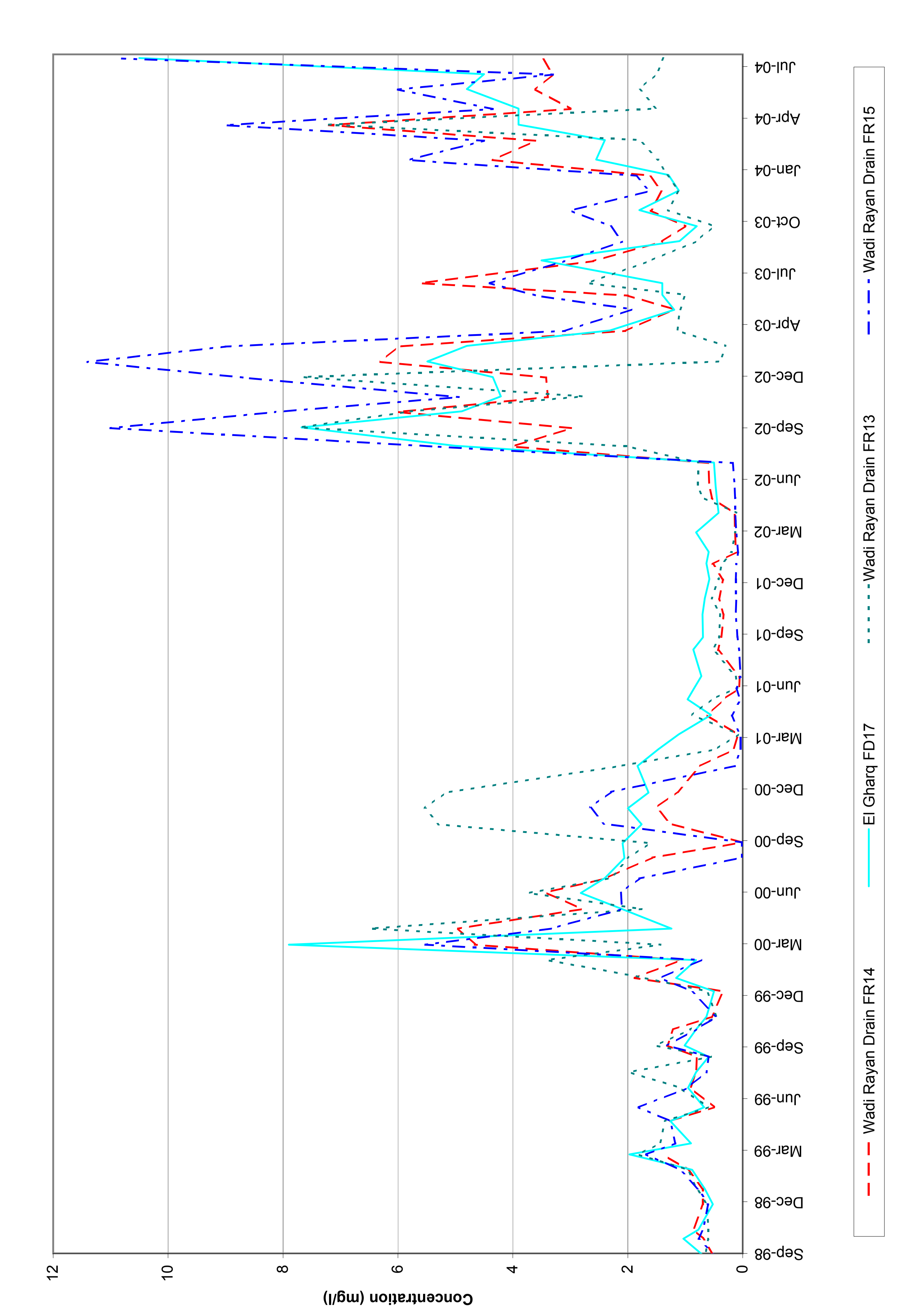
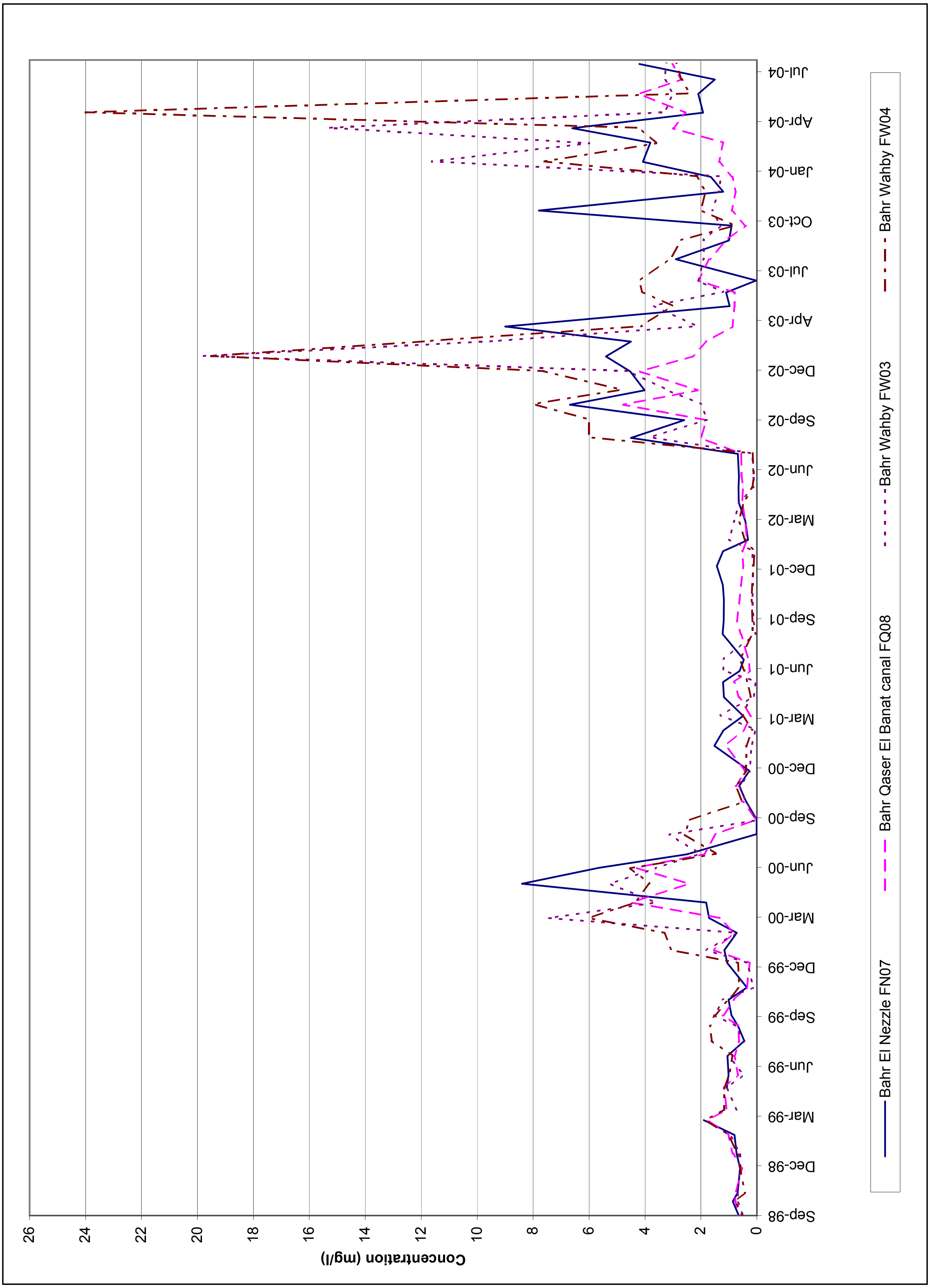
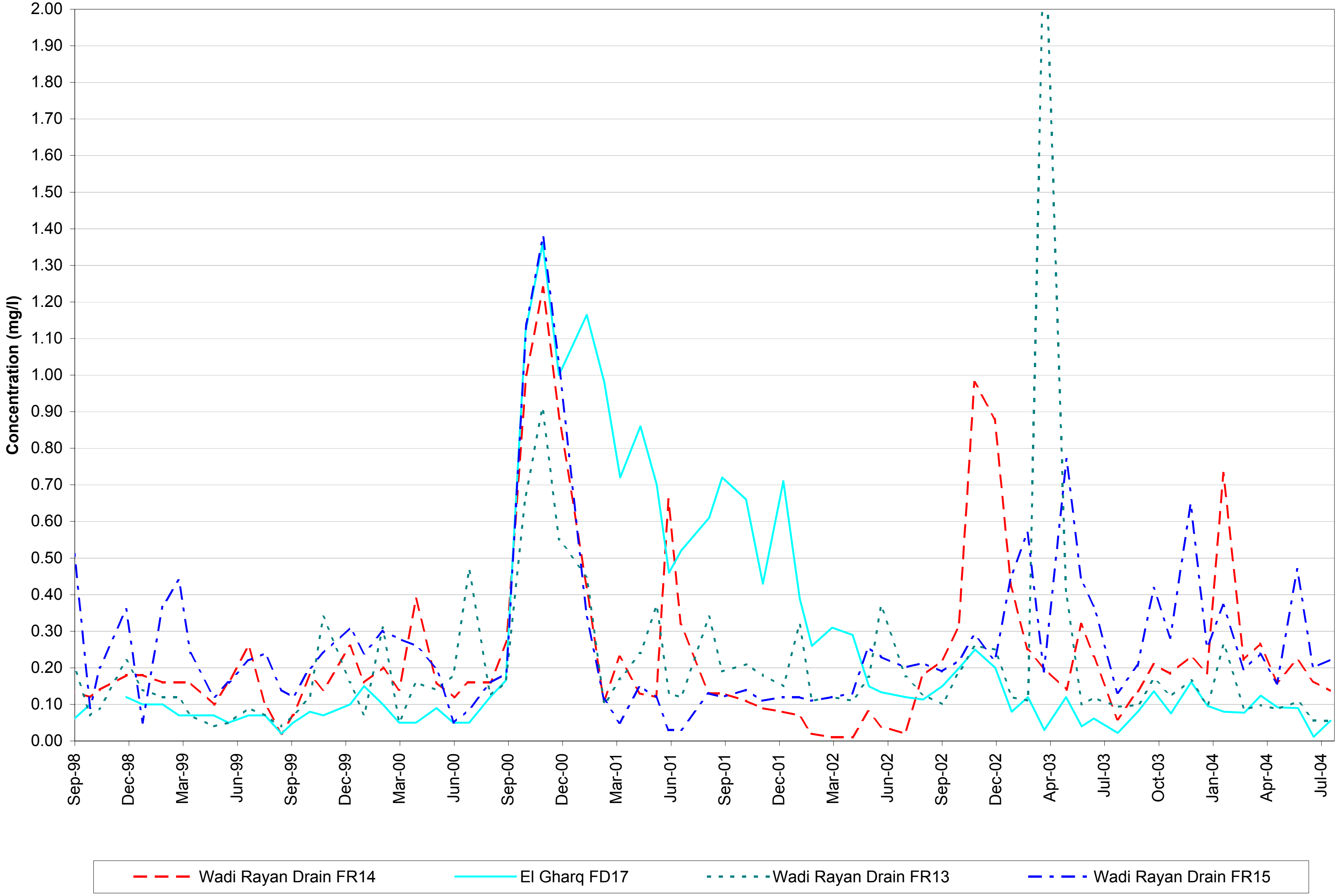
Ammonium Seasonal Variations in Drains (NAWQAM data)



Ammonium Seasonal Variations in Canals (NAWQAM data)



Total Phosphate Seasonal Variations in Drains (NAWQAM data)



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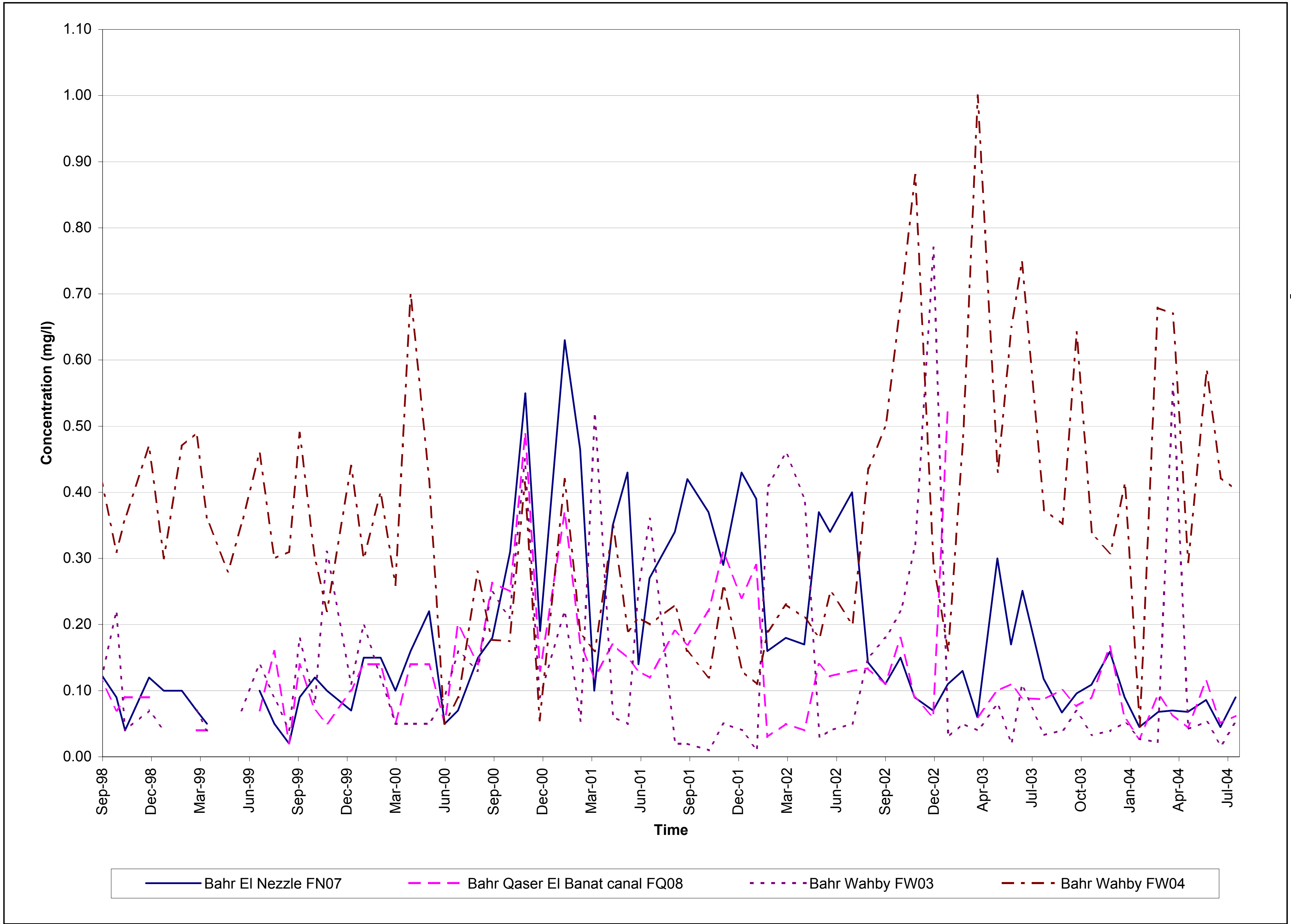
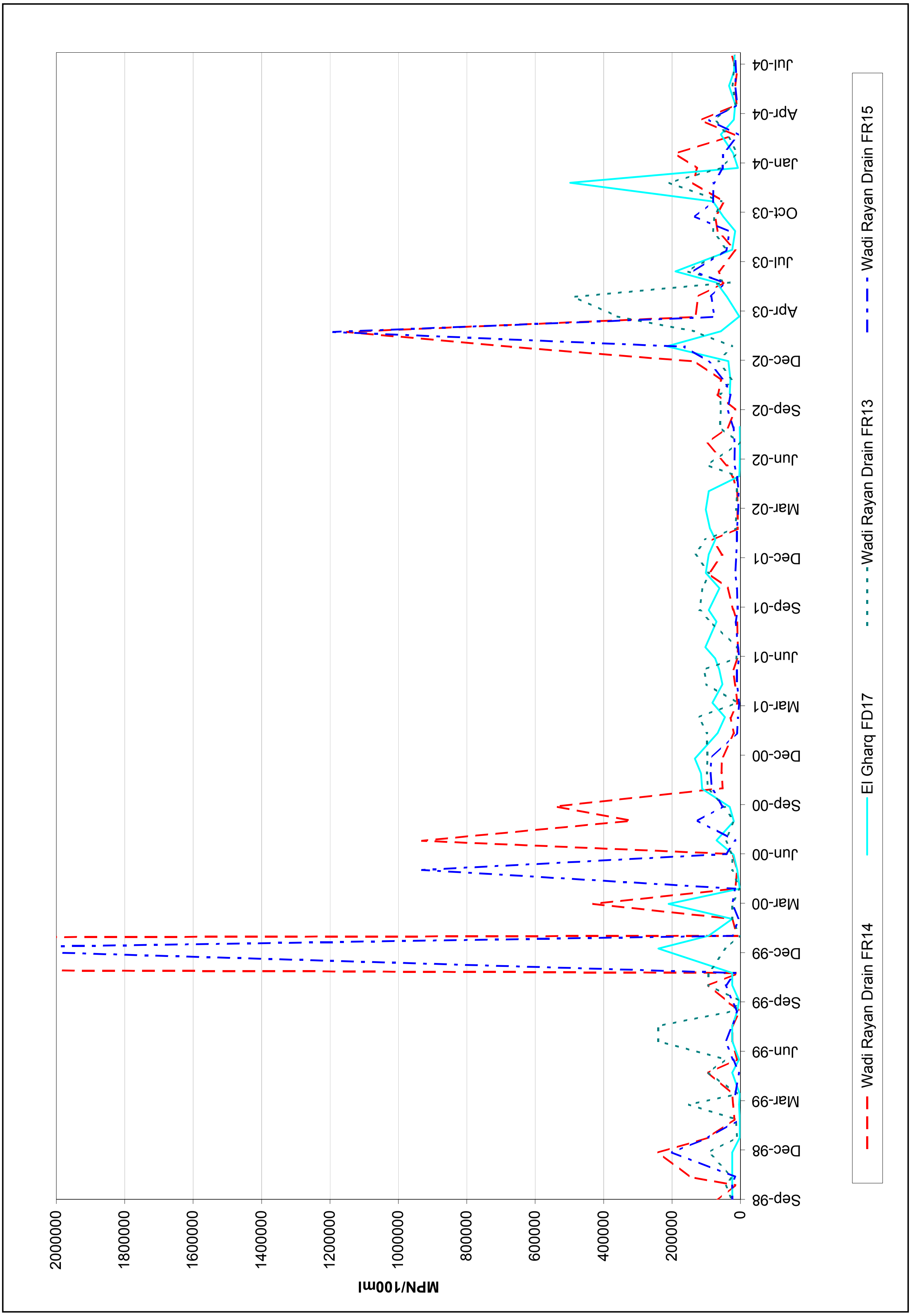
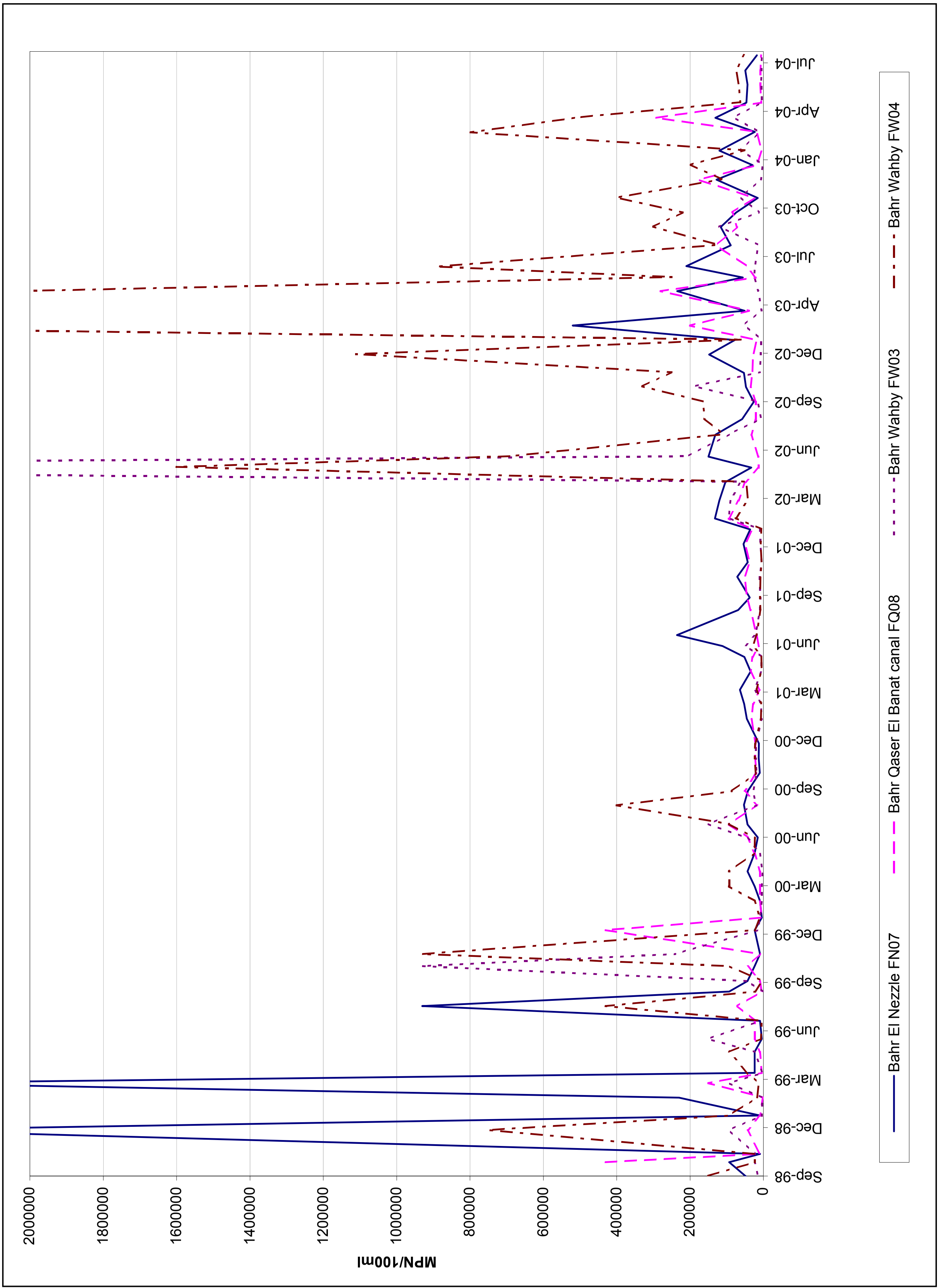
Total Phosphate Seasonal Variations in Canals (NAWQAM data)



Total Coliforms Seasonal Variations in Drains (NAWQAM data)



Total Coliforms Seasonal Variations in Canals (NAWQAM data)



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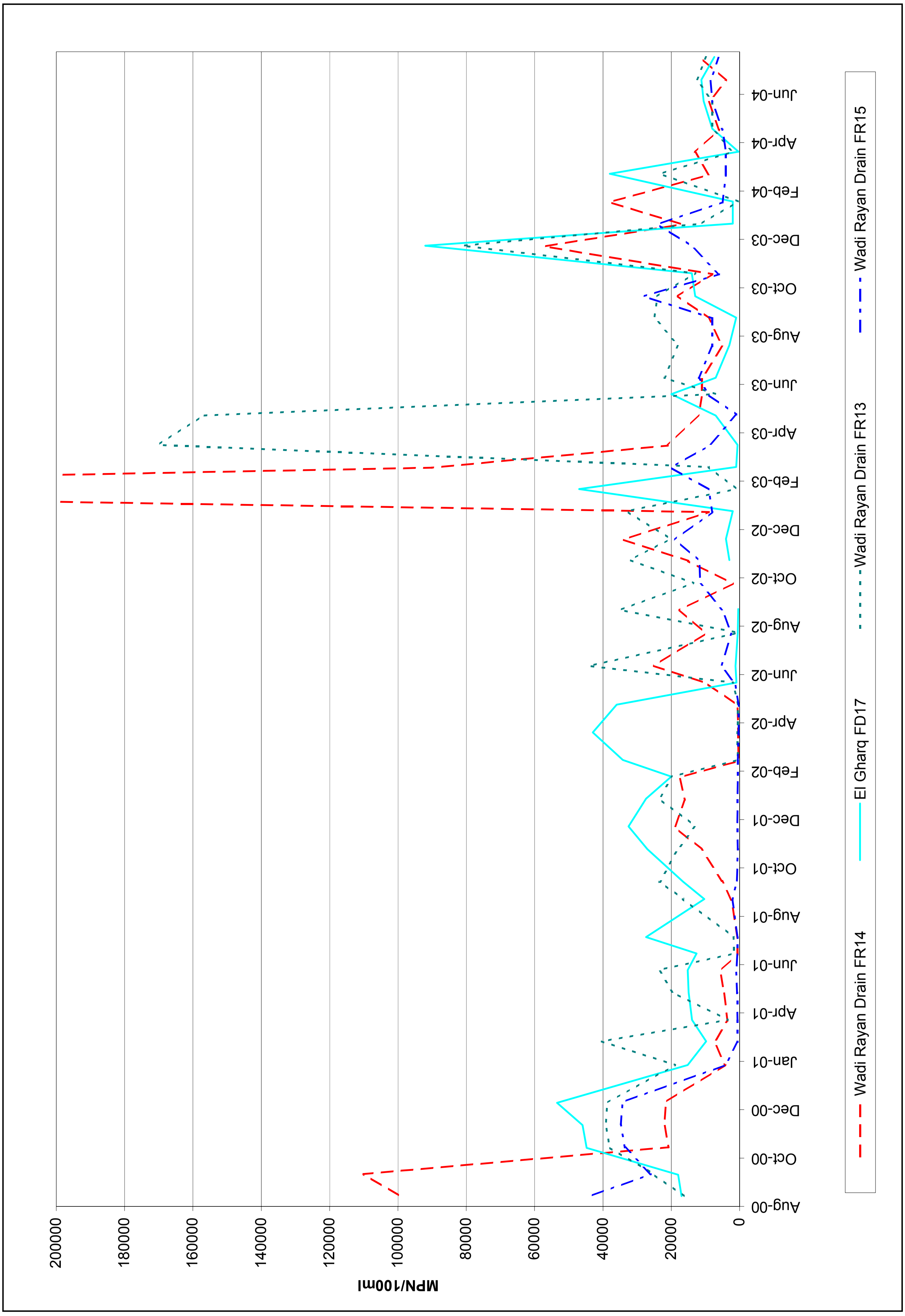
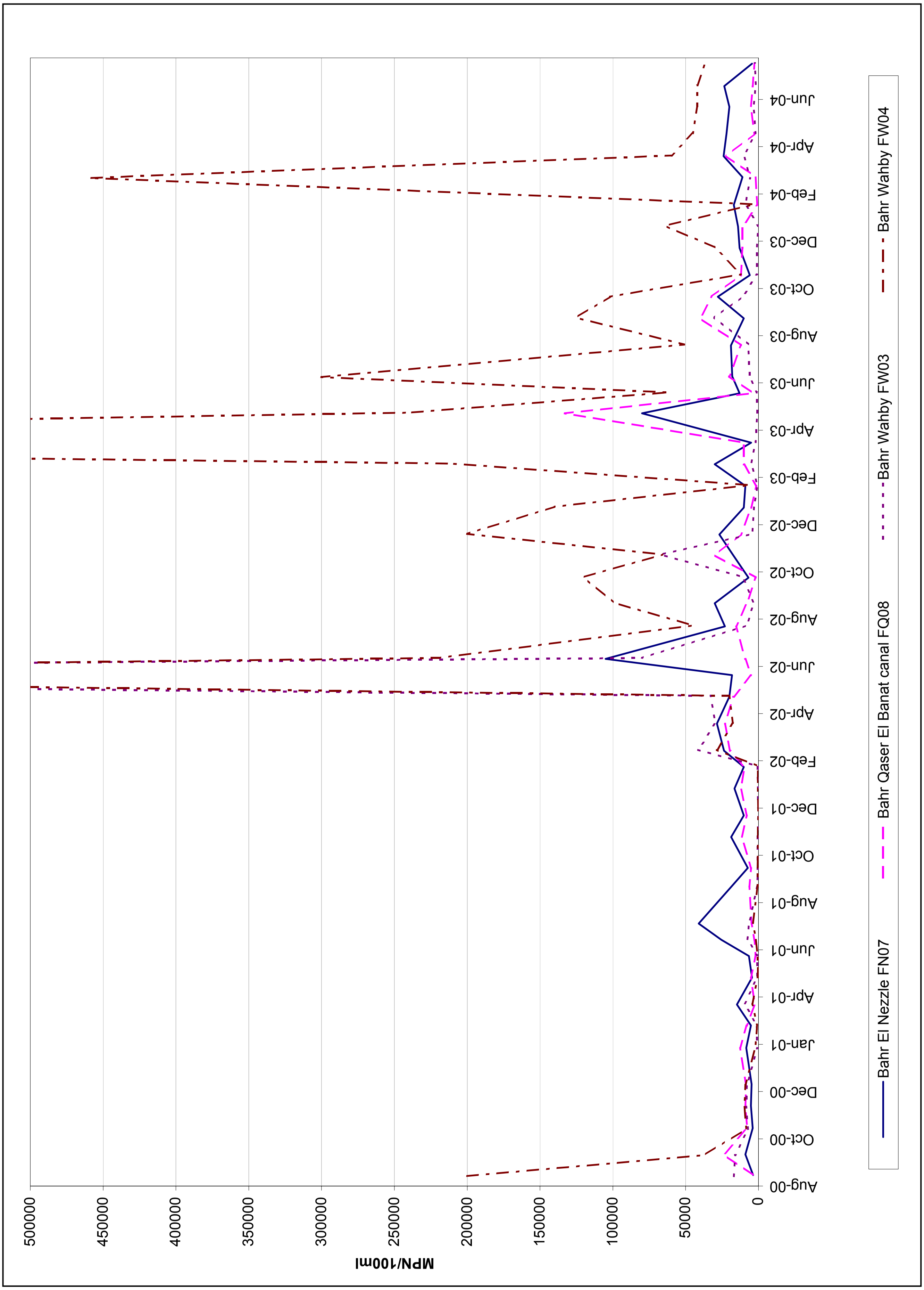
Faecal Coliforms Seasonal Variations in Drains (NAWQAM data)



Faecal Coliforms Seasonal Variations in Canals (NAWQAM data)



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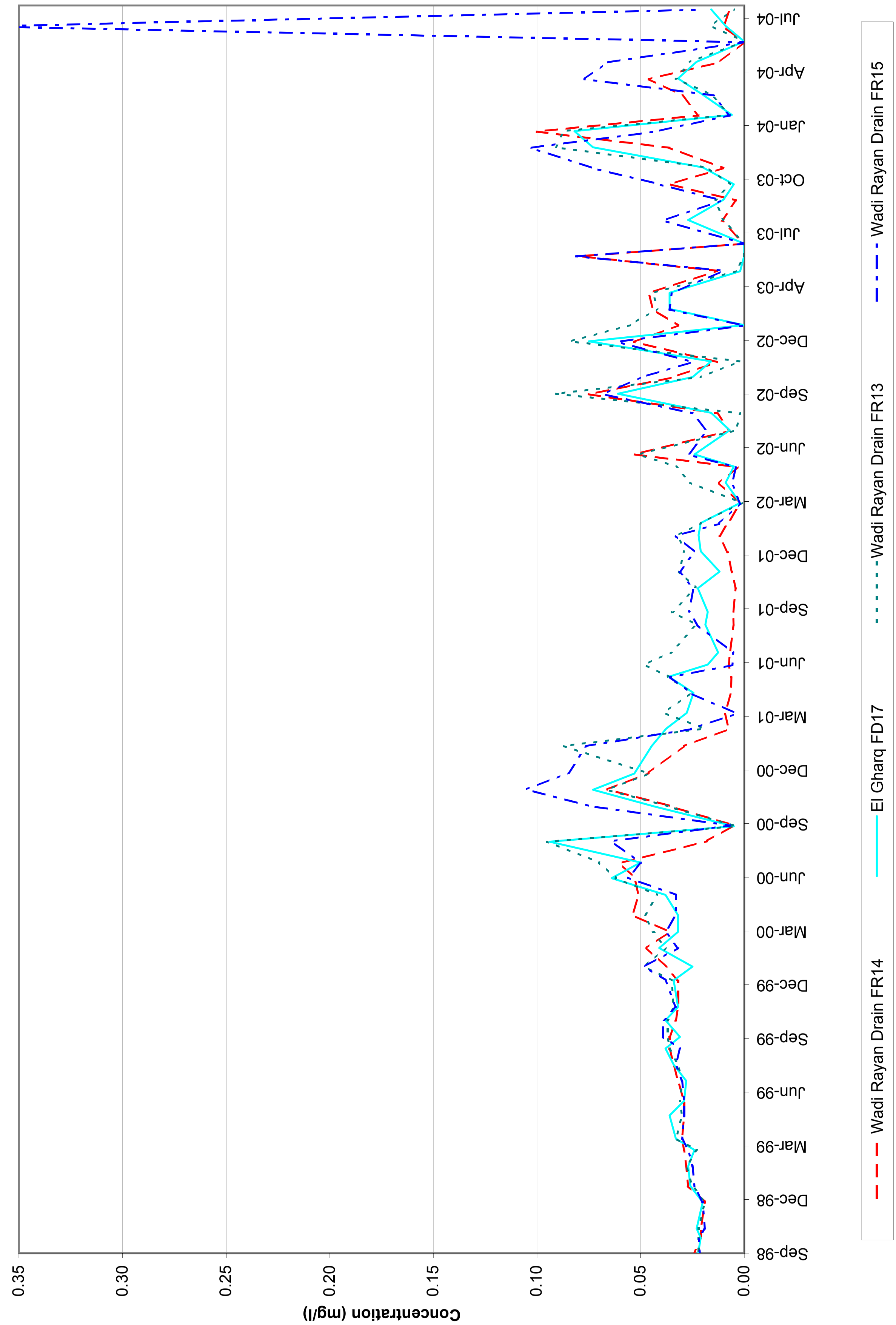
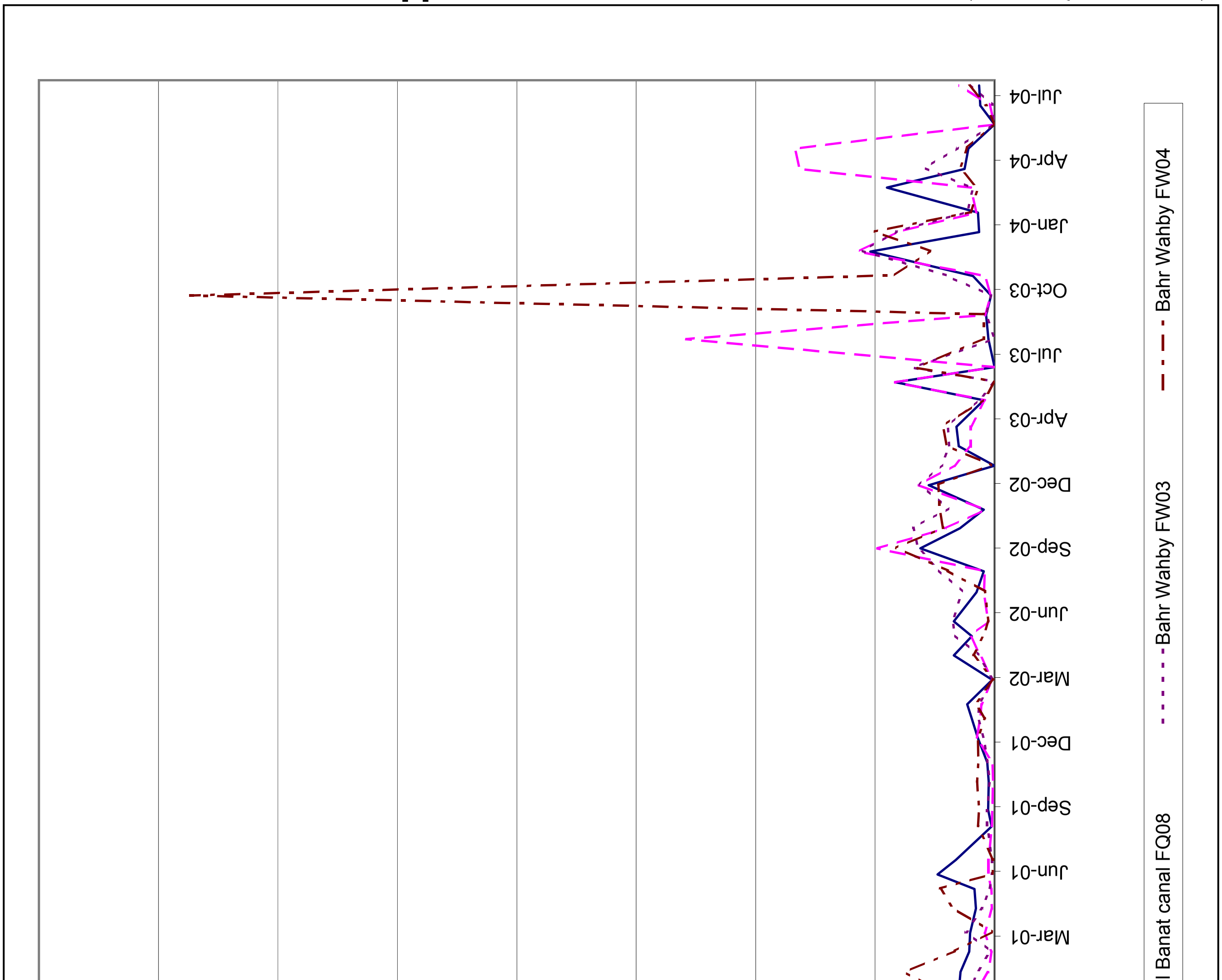
Copper Seasonal Variations in Drains (NAWQAM data)



Copper Seasonal Variations in Canals (NAWQAM data)



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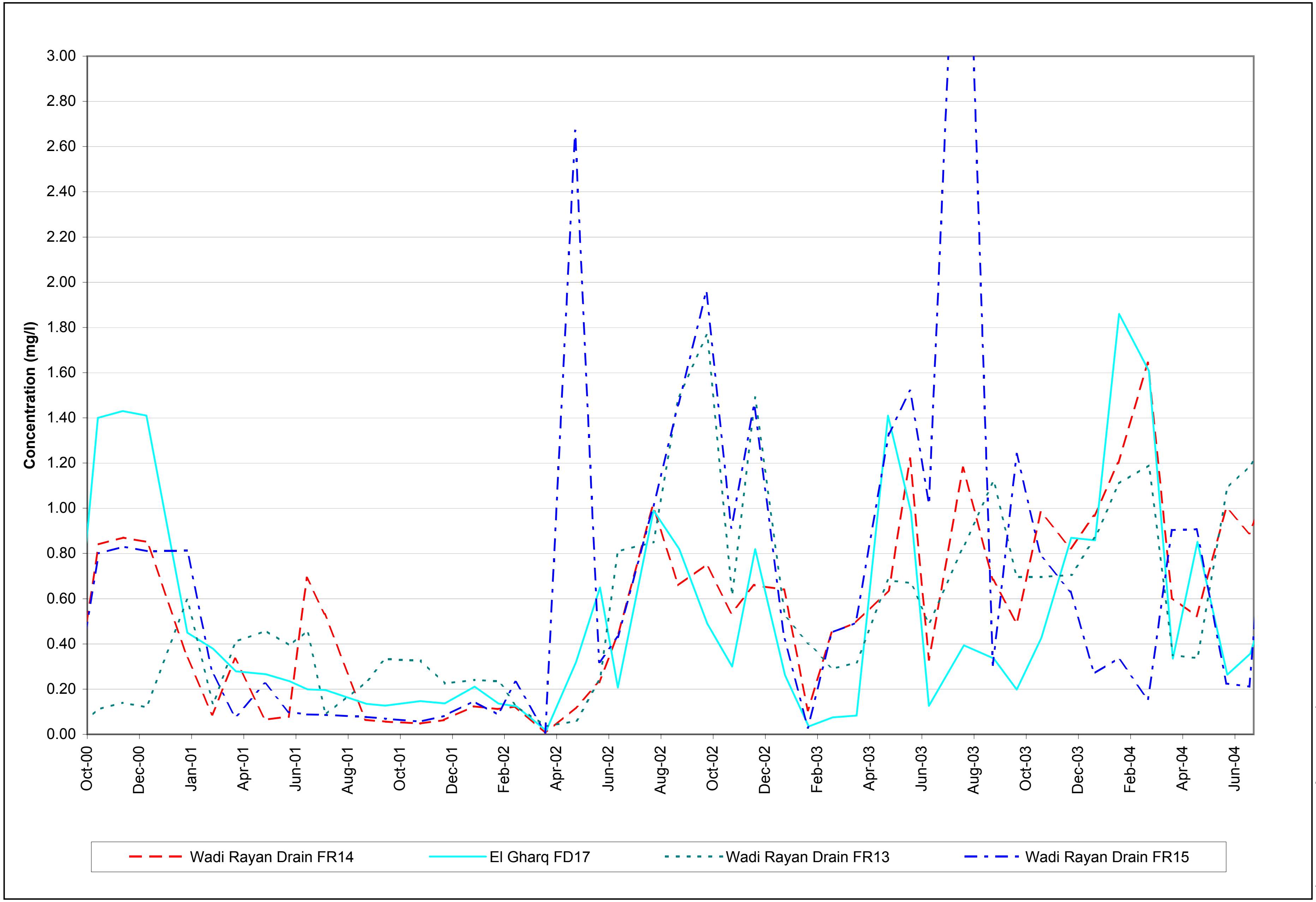
Iron Seasonal Variations in Drains (NAWQAM data)



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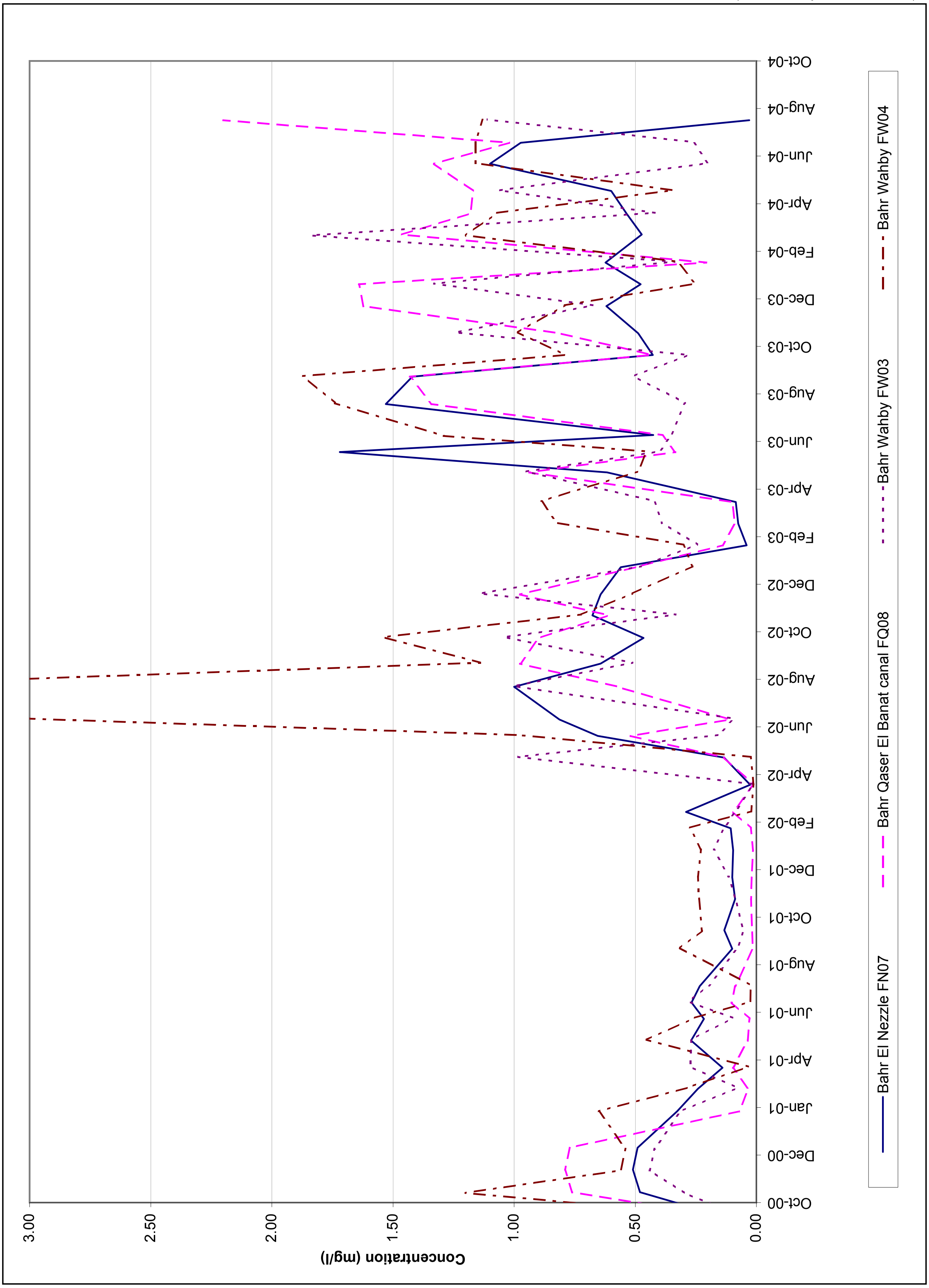
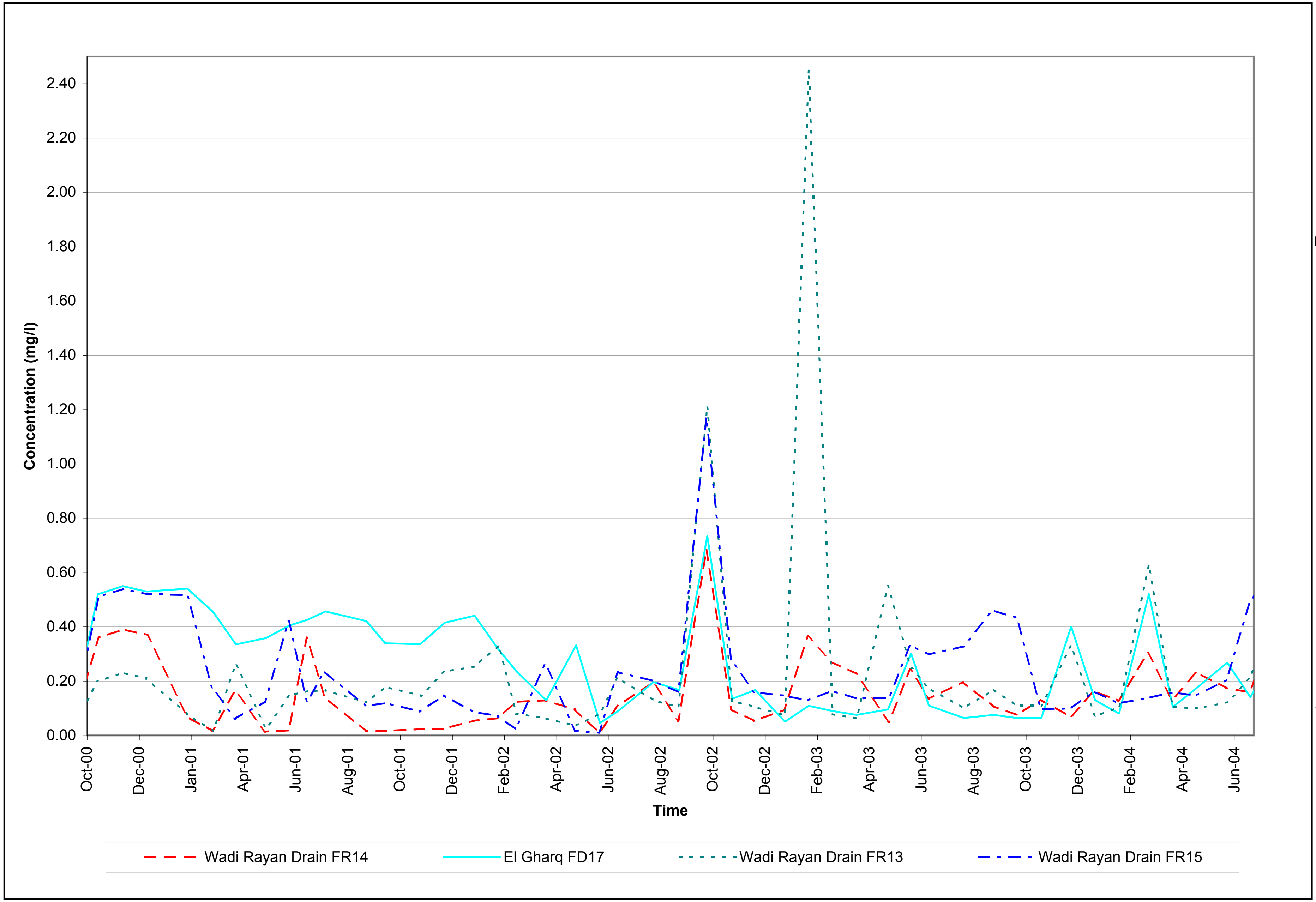
Iron Seasonal Variations in Canals (NAWQAM data)



Manganese Seasonal Variations in Drains (NAWQAM data)



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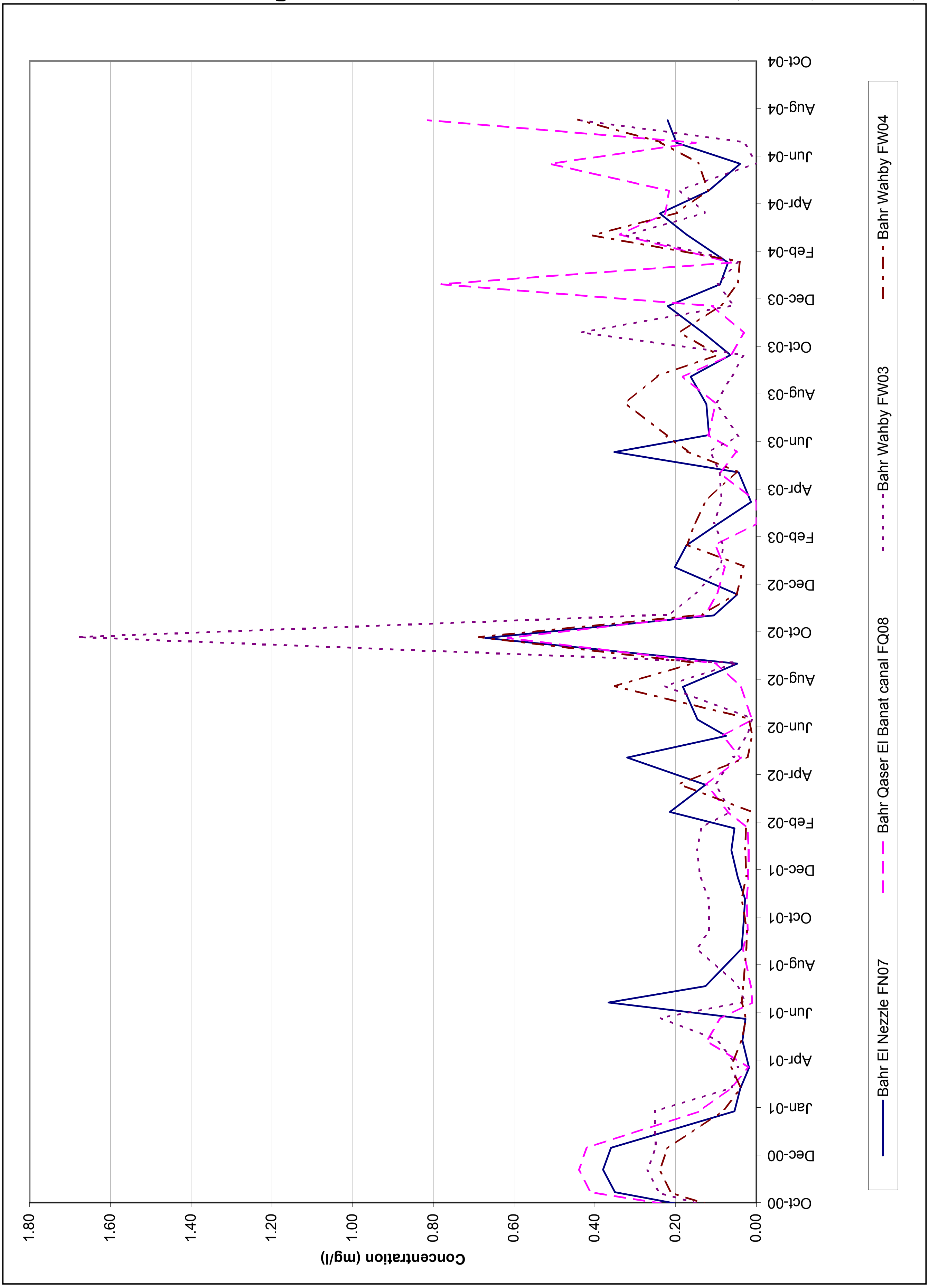
Maganese Seasonal Variations in Canals (NAWQAM data)



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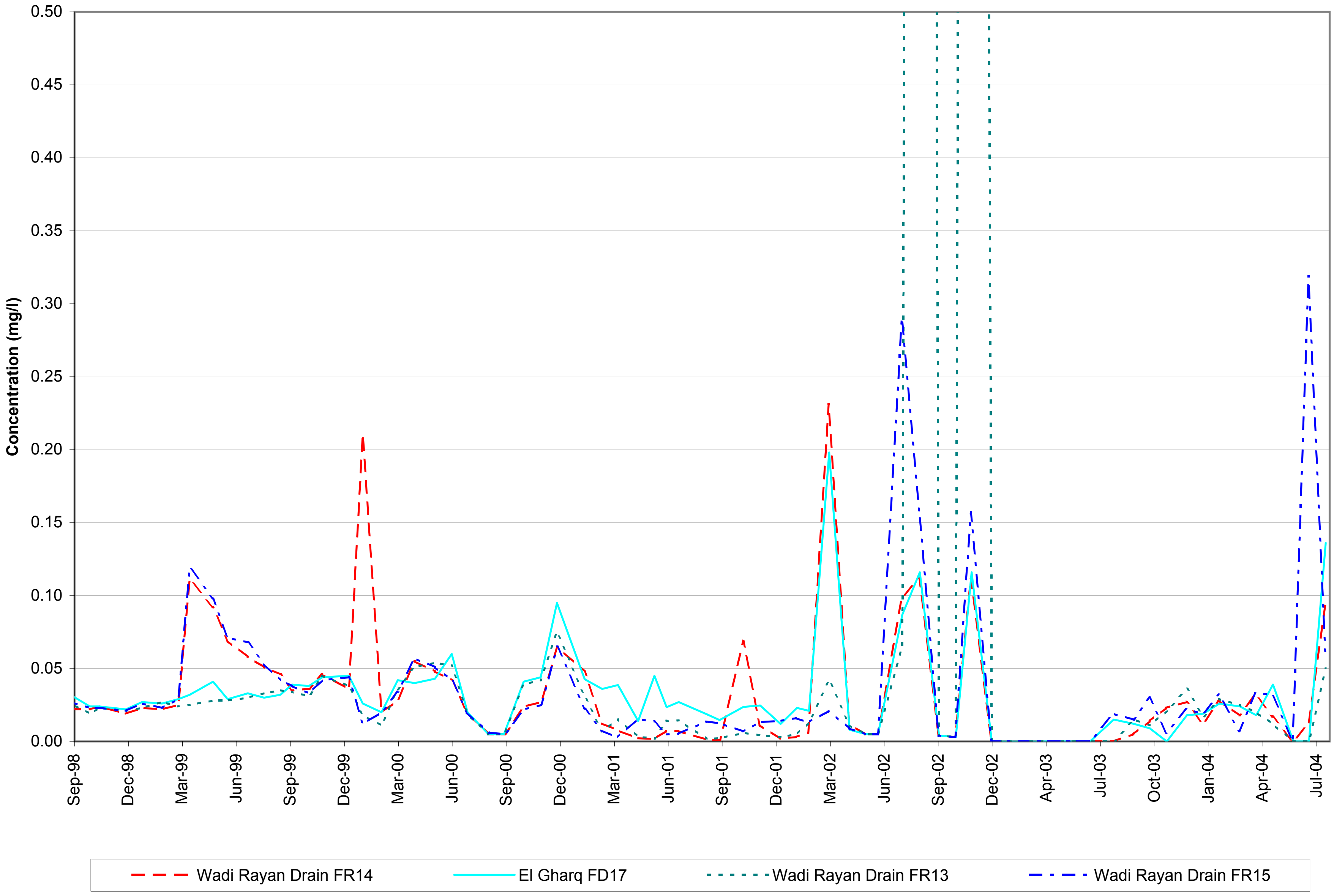
Zinc Seasonal Variations in Drains (NAWQAM data)



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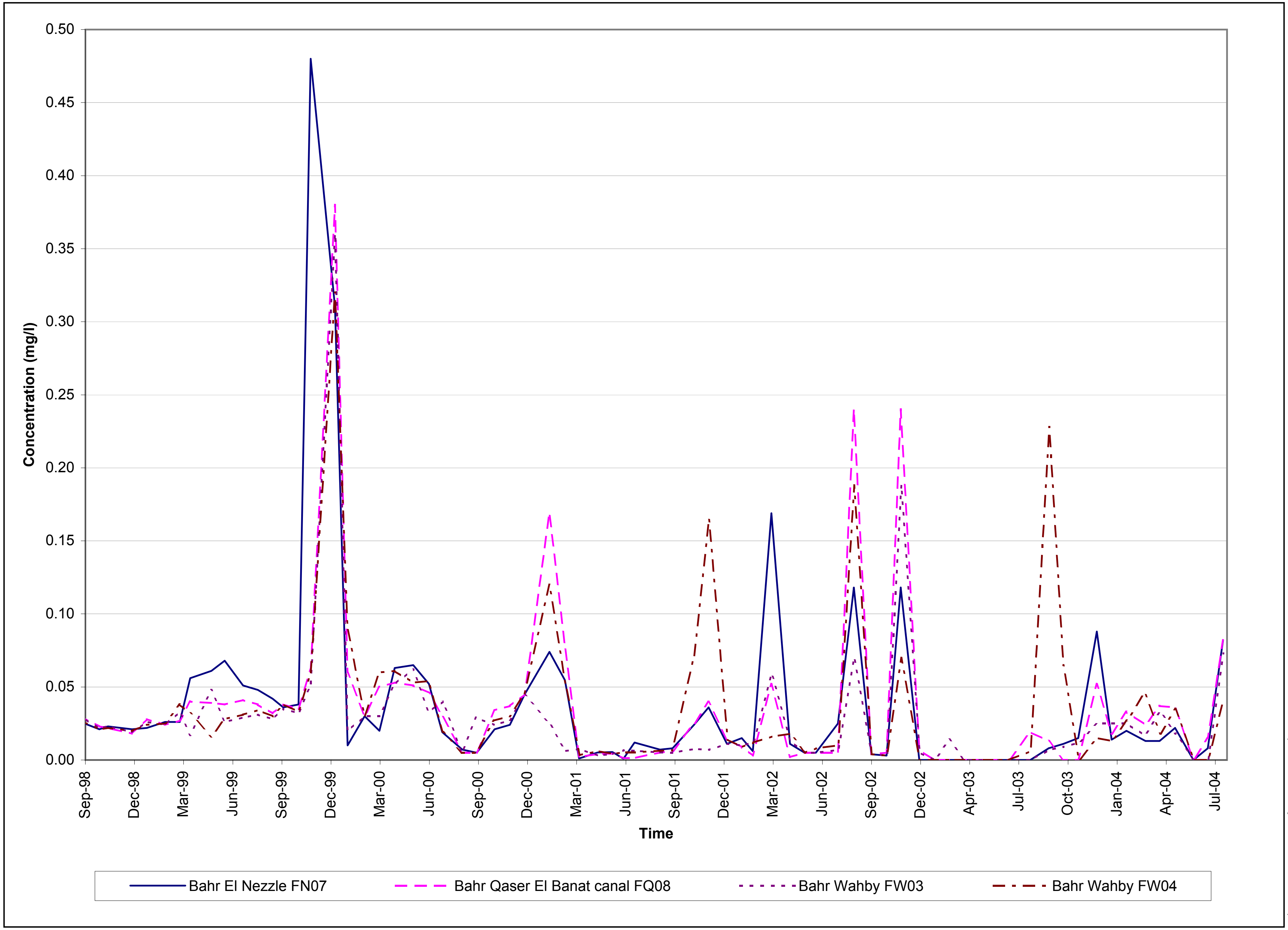
Zinc Seasonal Variations in Canals (NAWQAM data)



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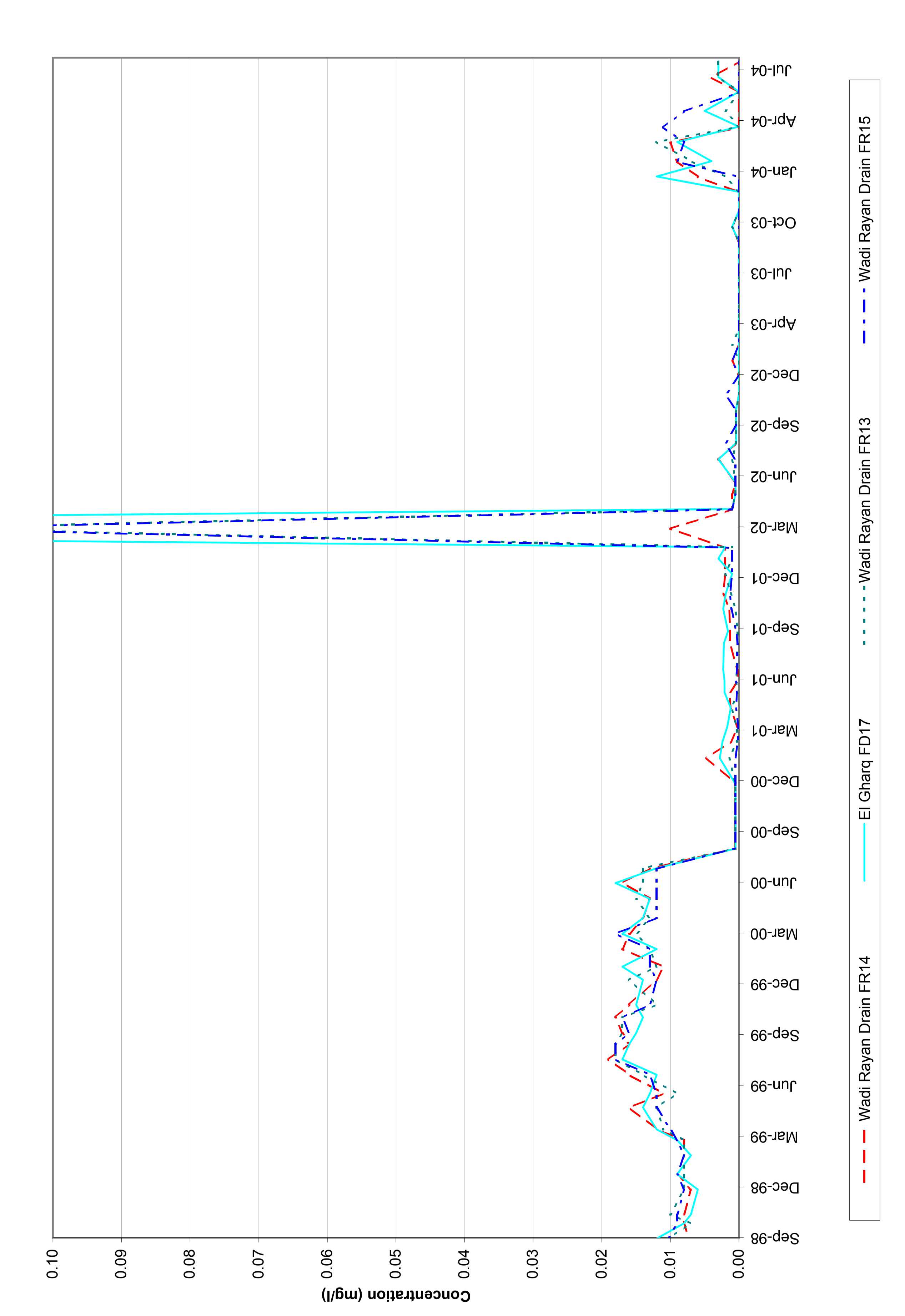
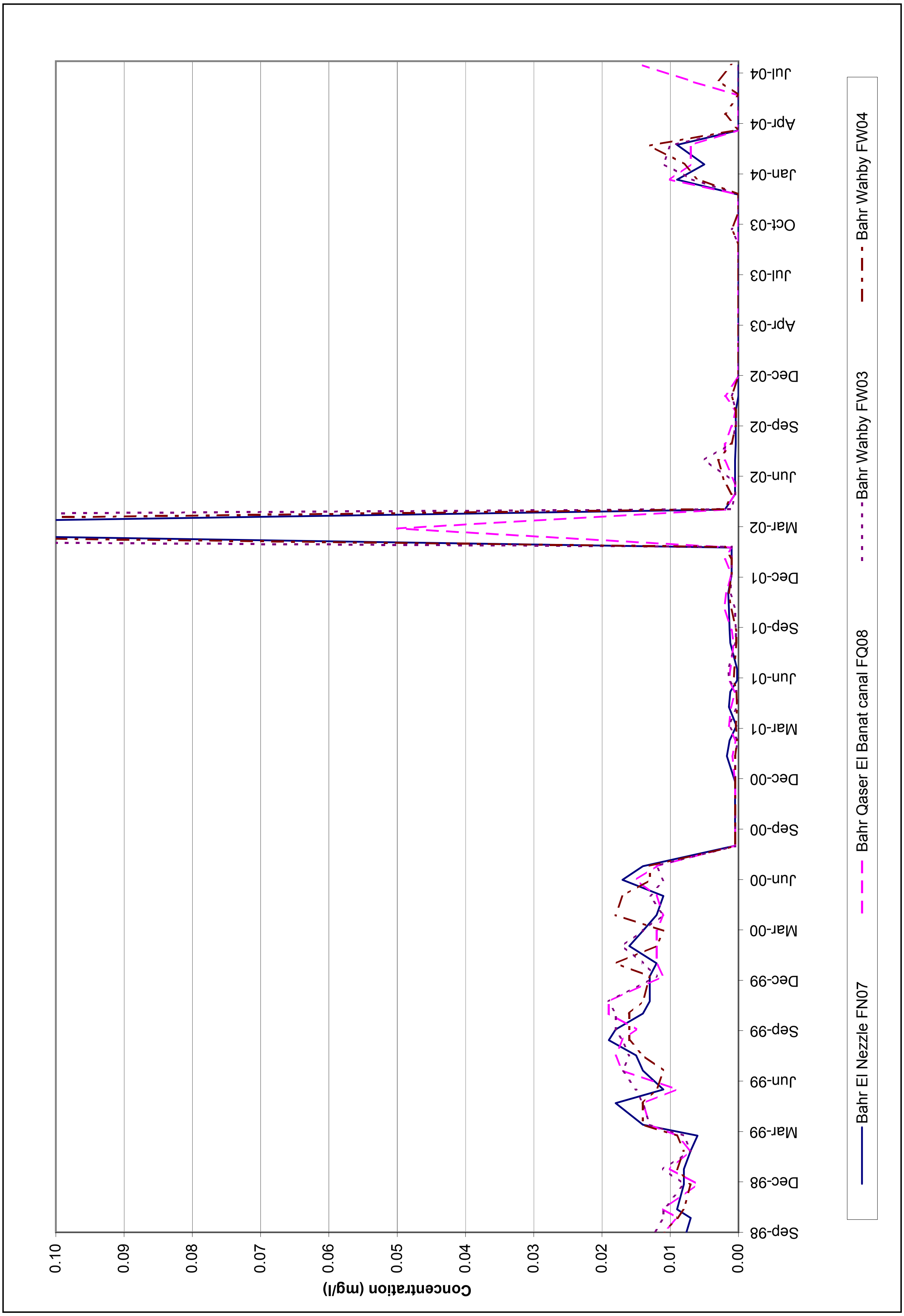
Cadmium Seasonal Variations in Drains (NAWQAM data)



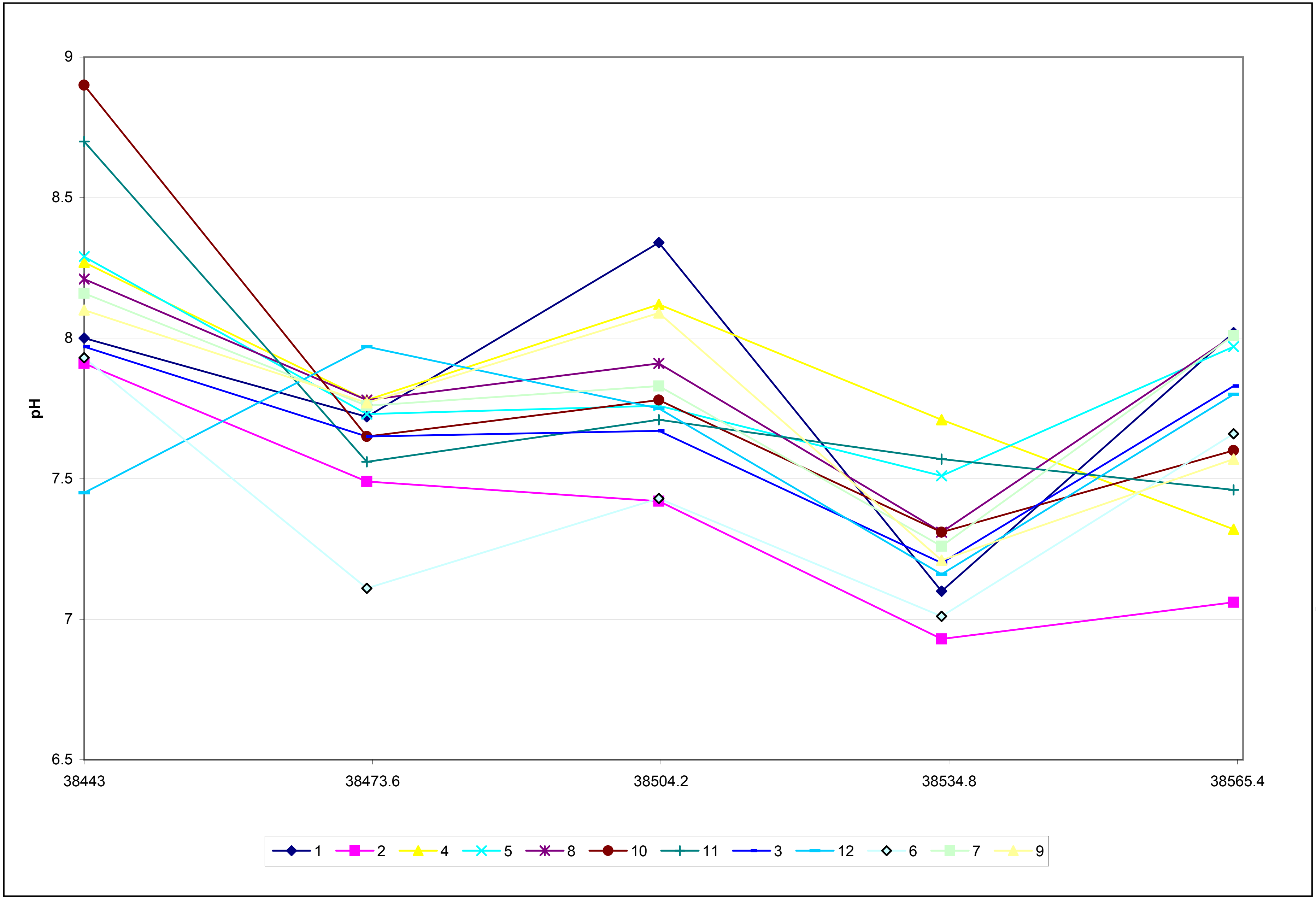
Cadmium Seasonal Variations in Canals (NAWQAM data)



Appendix F: Sri Lanka – Water Quality Monitoring Data

F.1 Seasonal Variation

pH - Seasonal Variation



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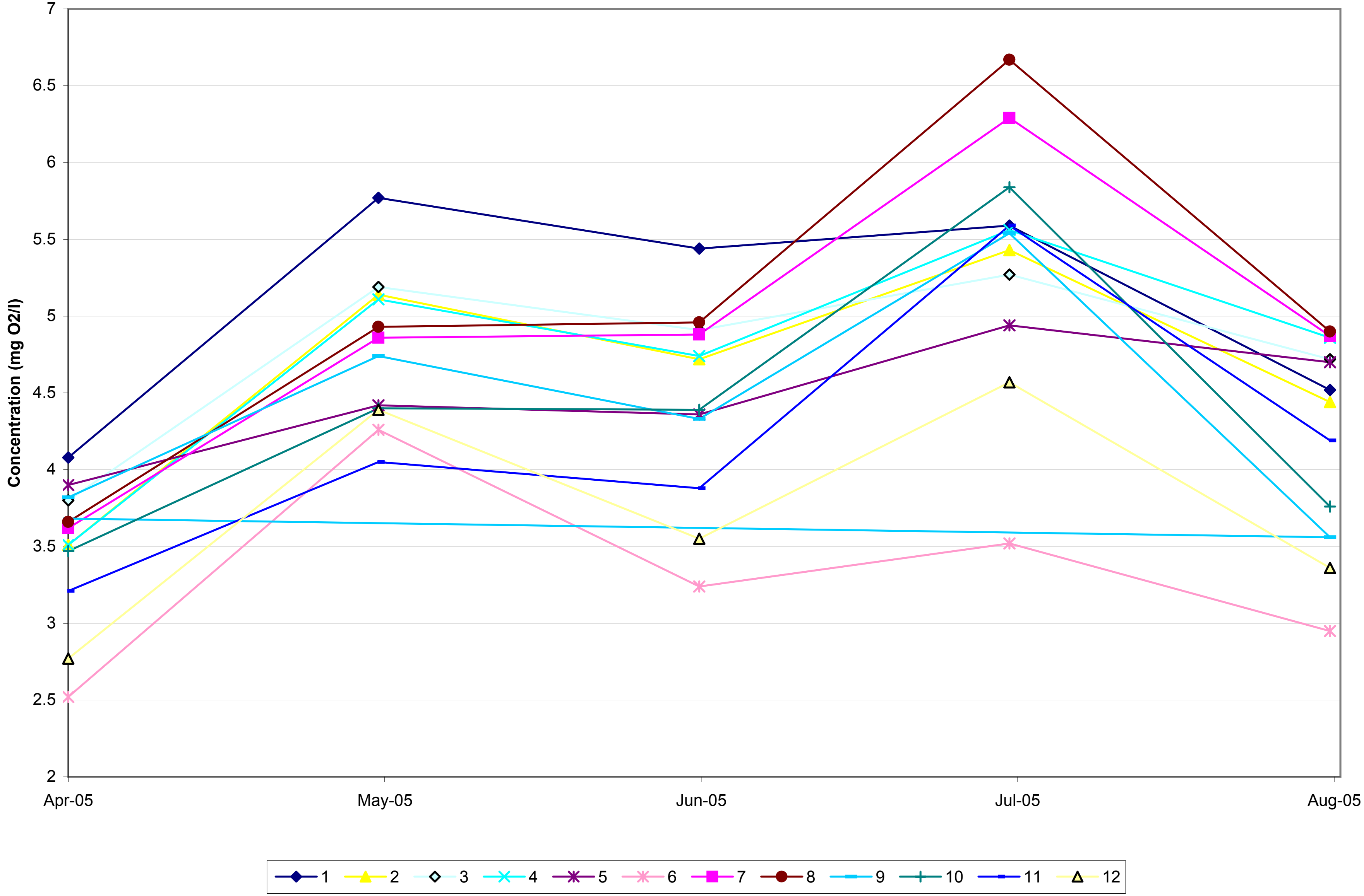
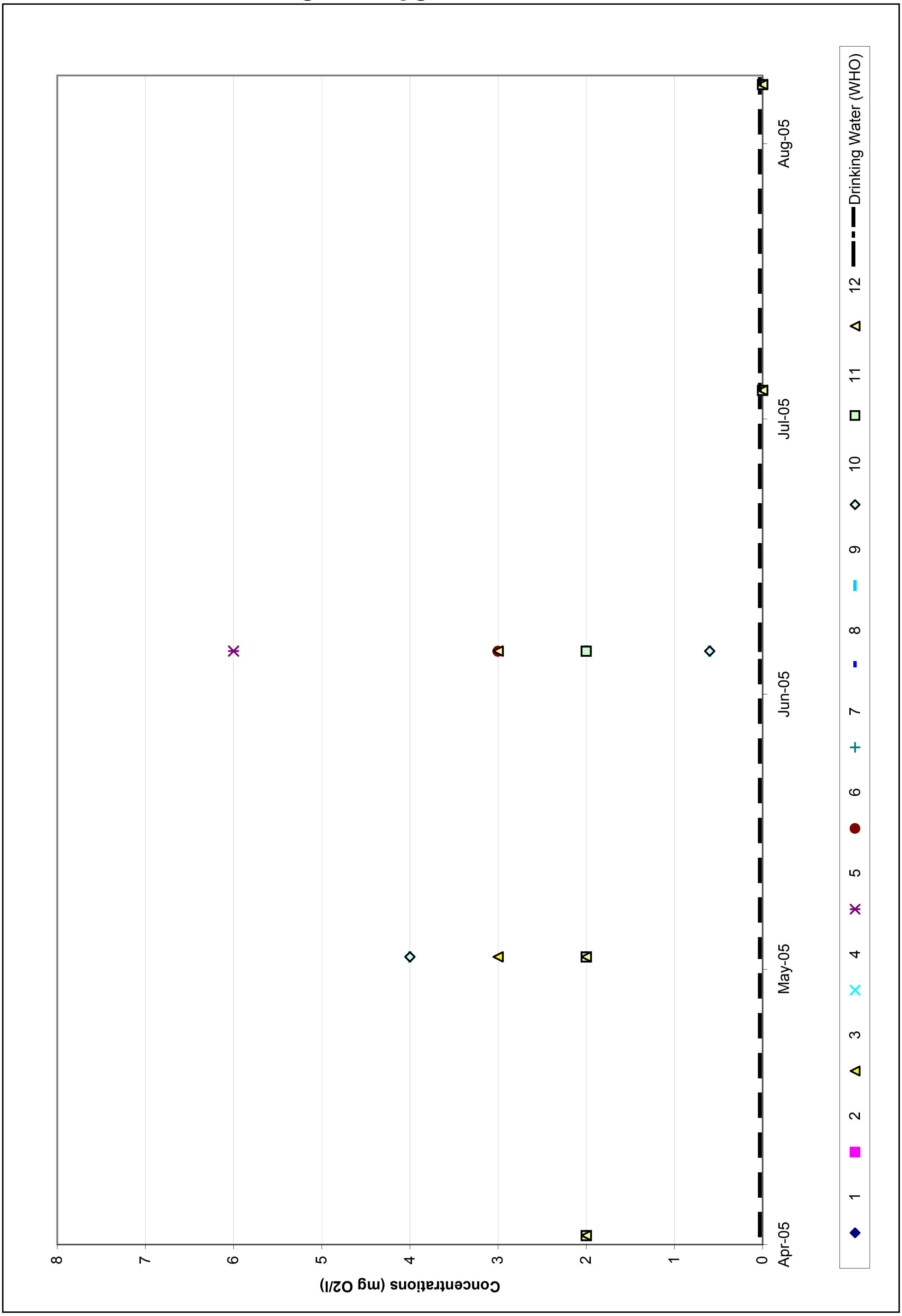
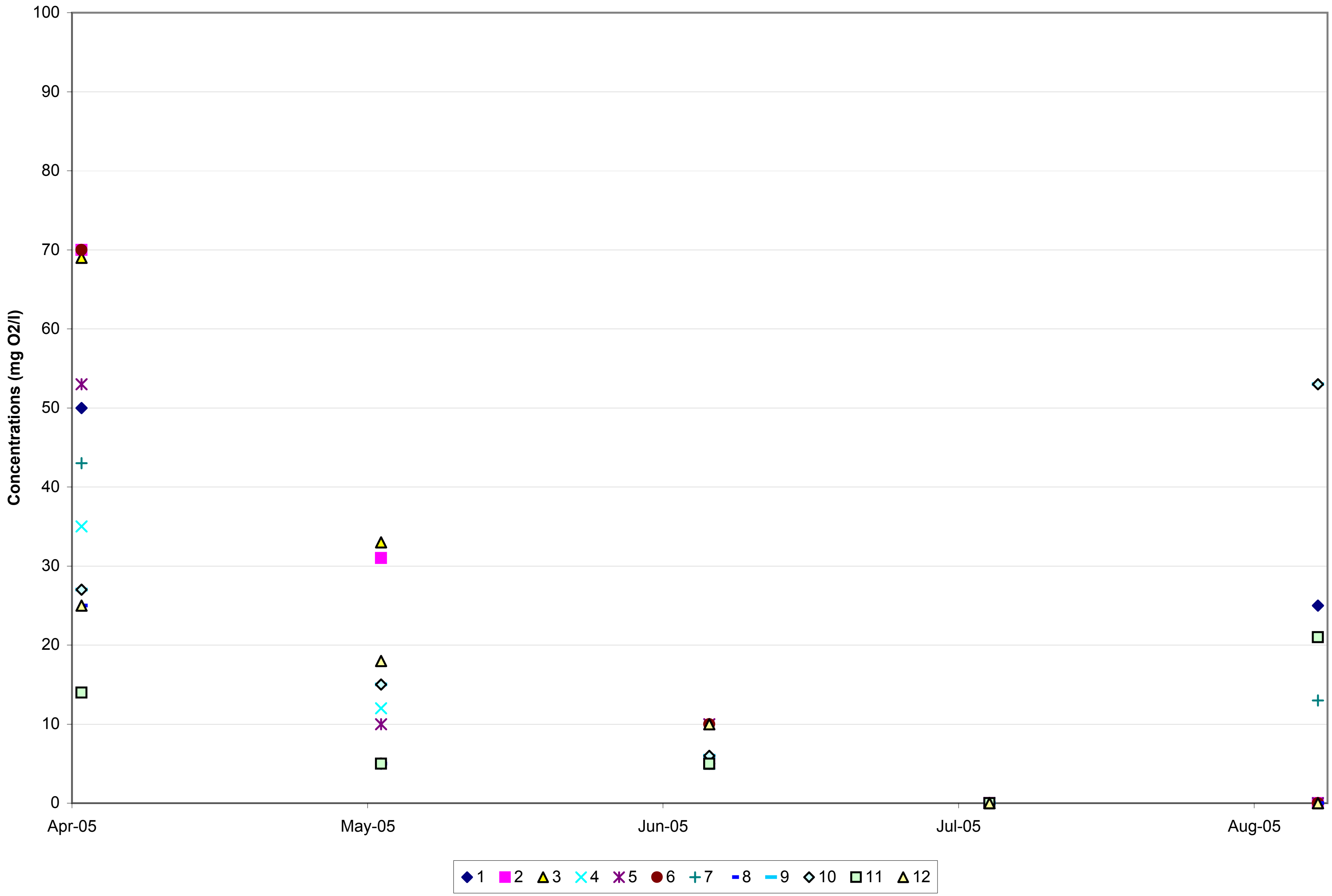
Dissolved Oxygen - DO -Seasonal Variation



Biological Oxygen Demand - BOD - Seasonal Variation



Chemical Oxygen Demand - COD - Seasonal Variation



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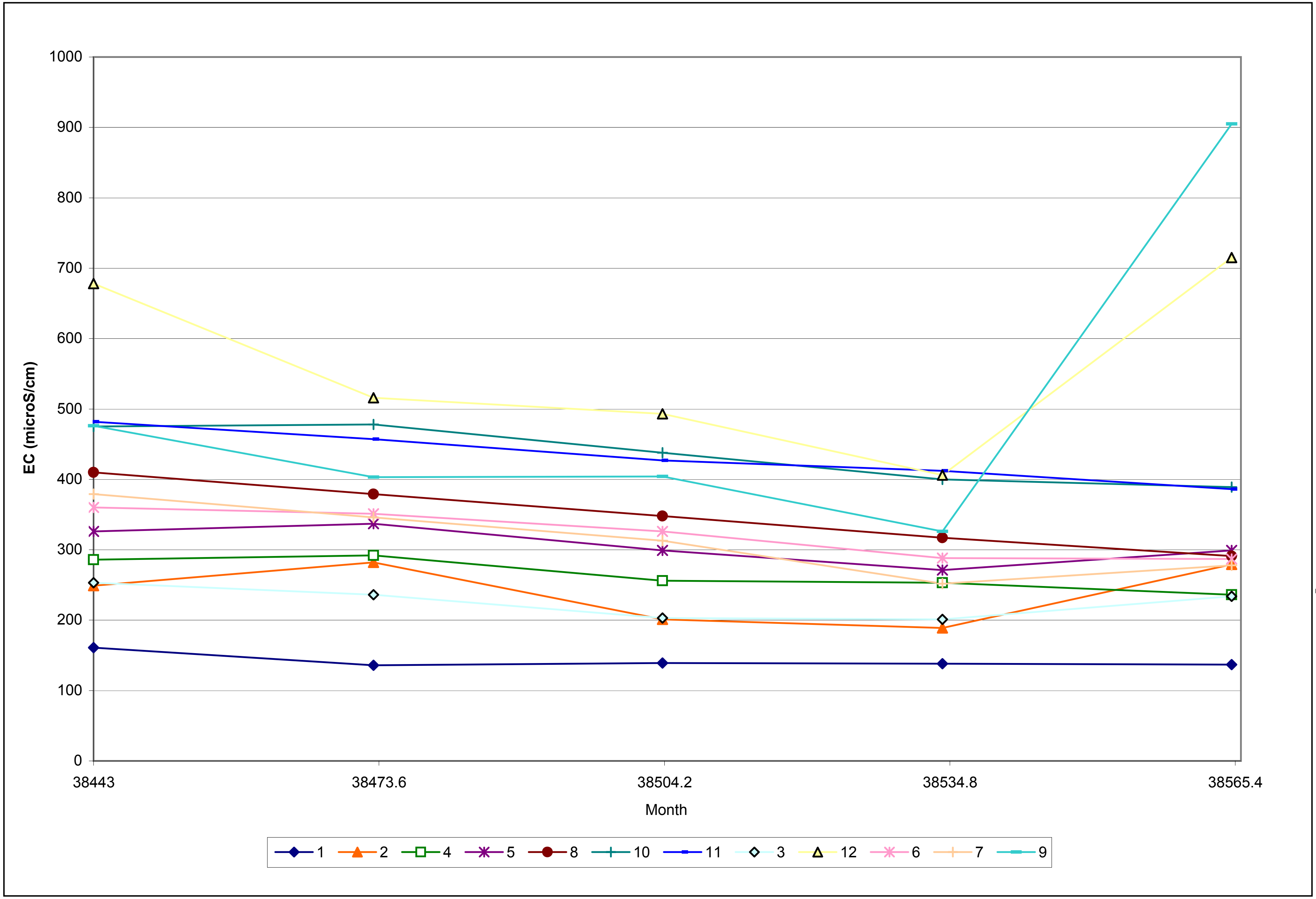
Electric Conductivity - EC - Seasoal Variation



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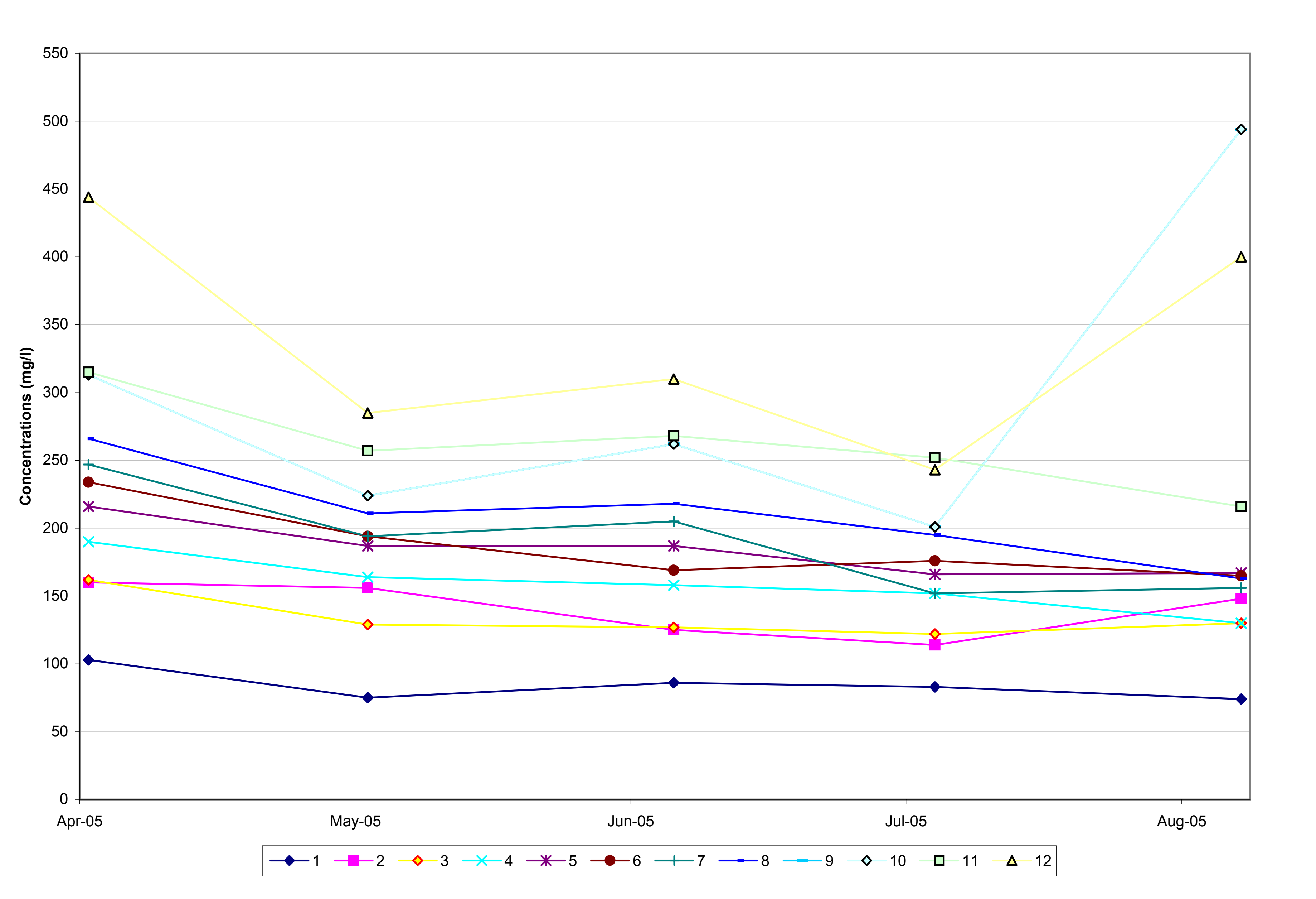
Total Dissolved Solids - TDS - Seasonal Variation



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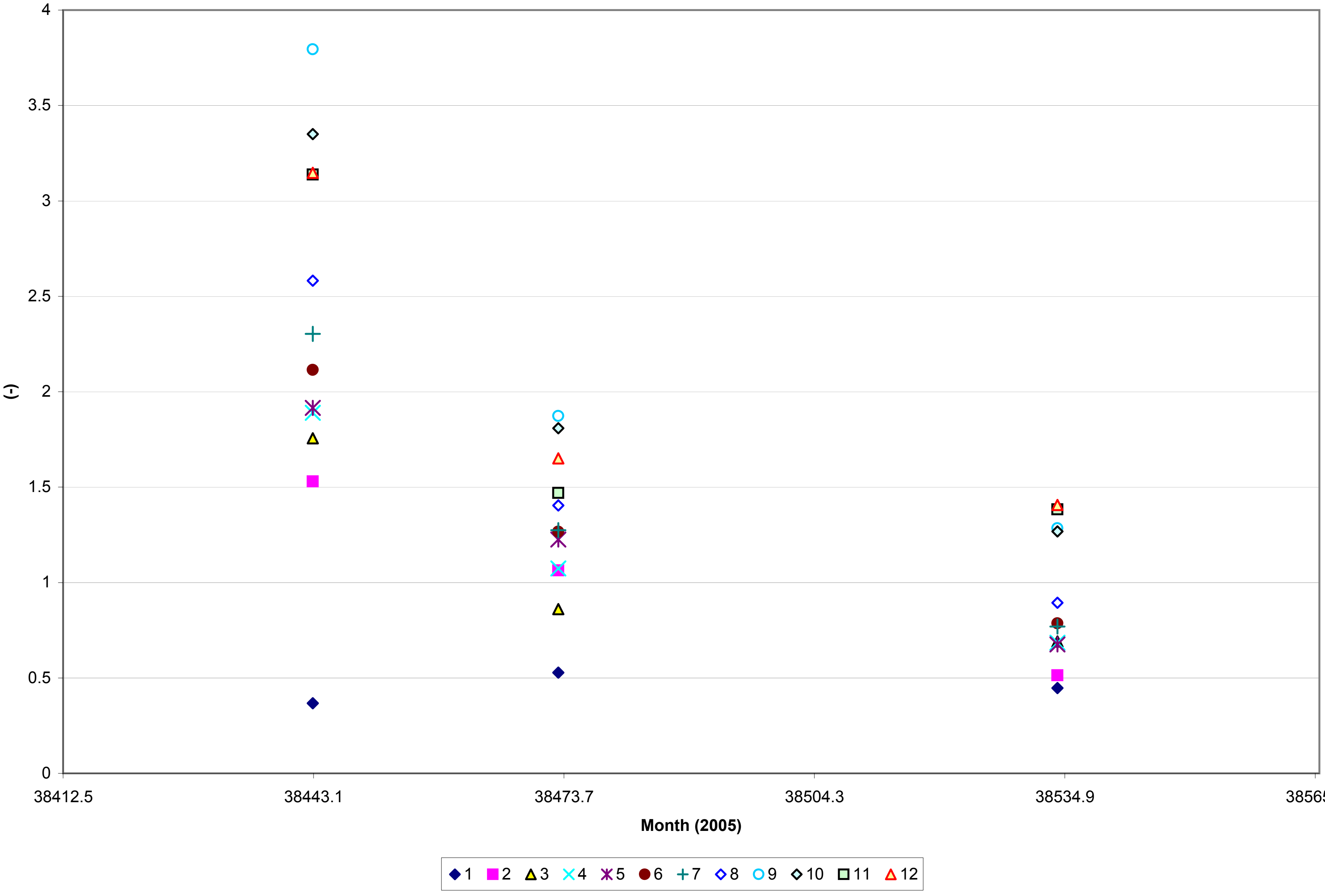
Sodium Absoprtium Ratio - SAR - Seasonal Variation



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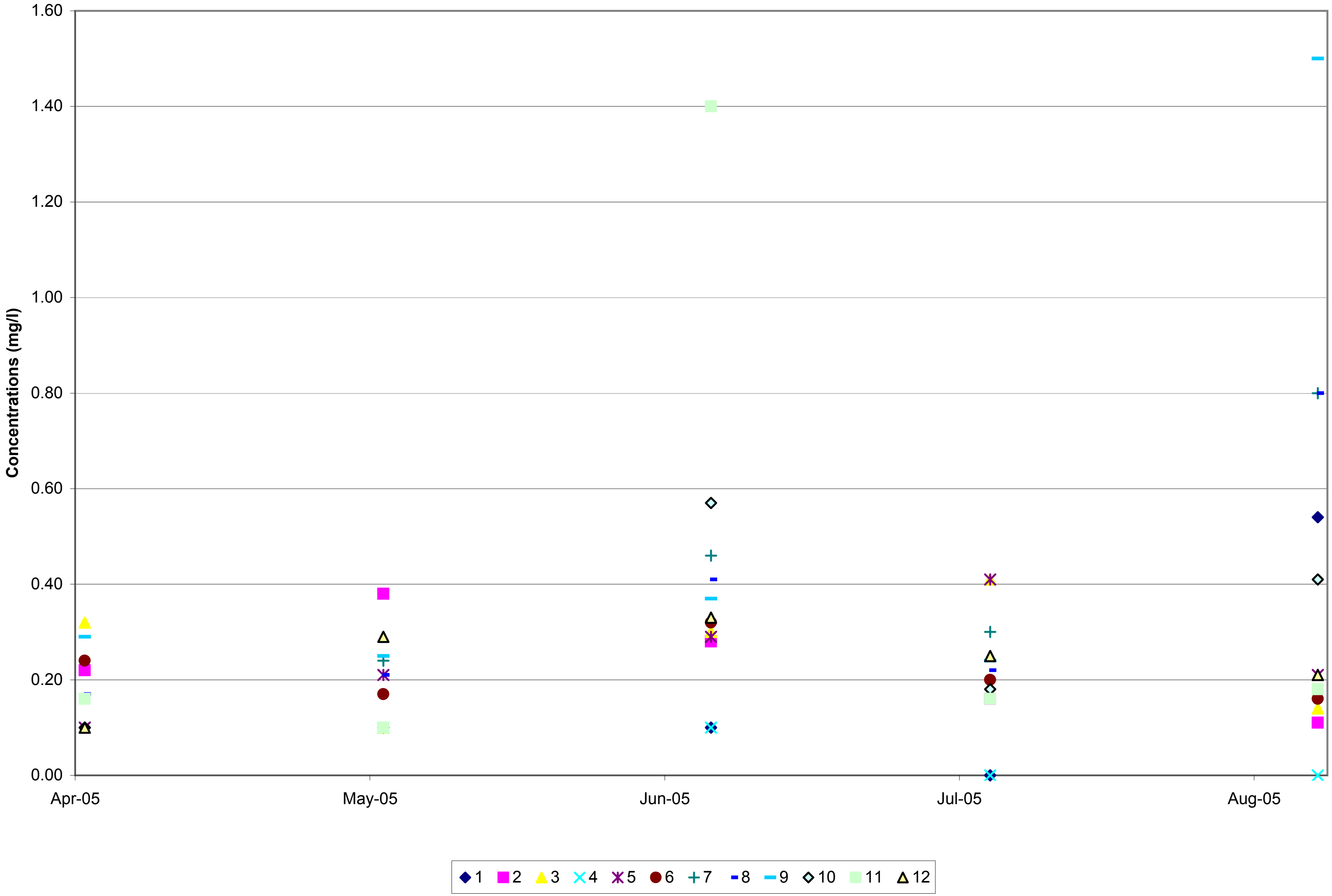
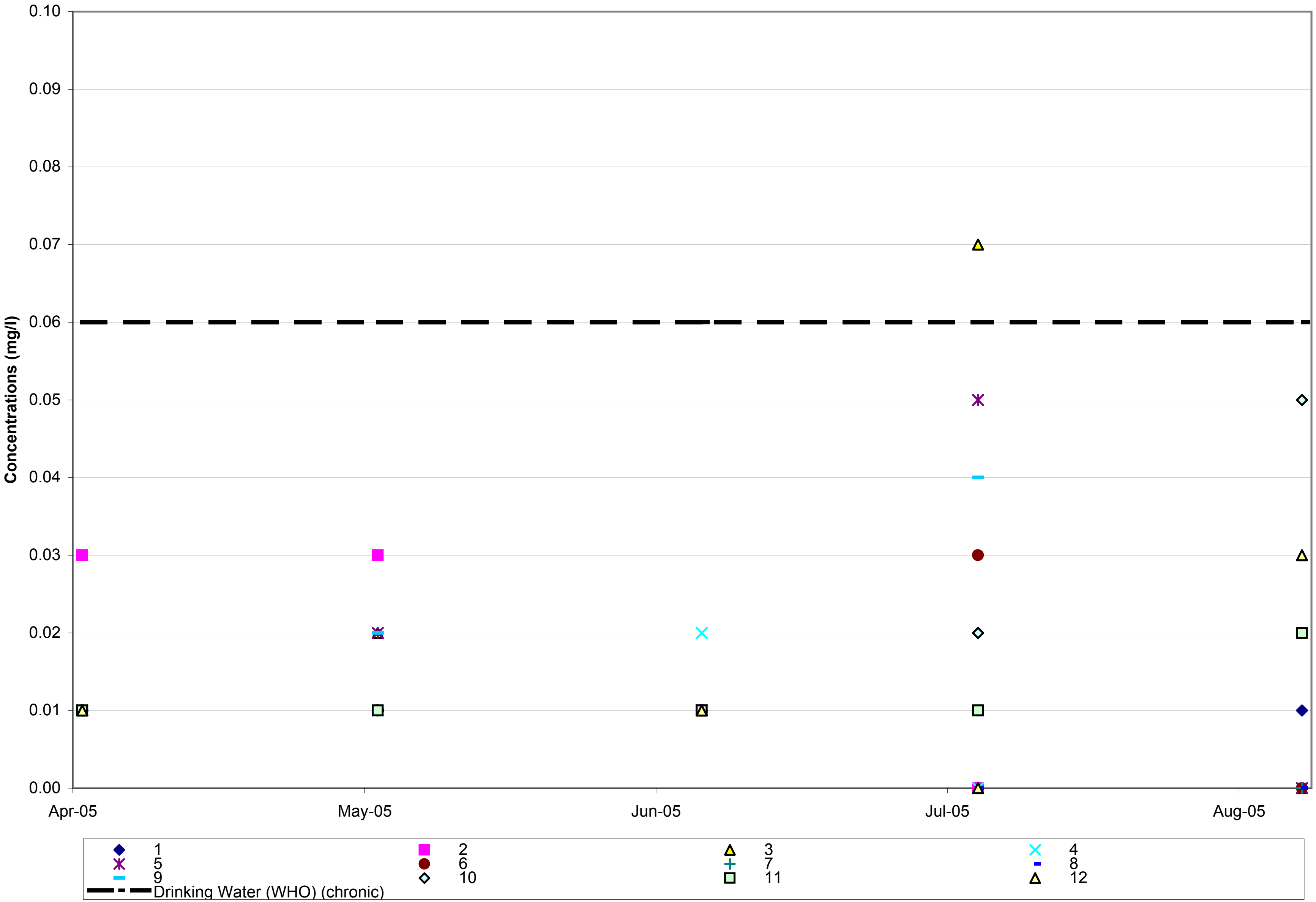
Nitrate - NO3-N - Seasonal Variation



Nitrite - NO2-N - Seasonal Variation



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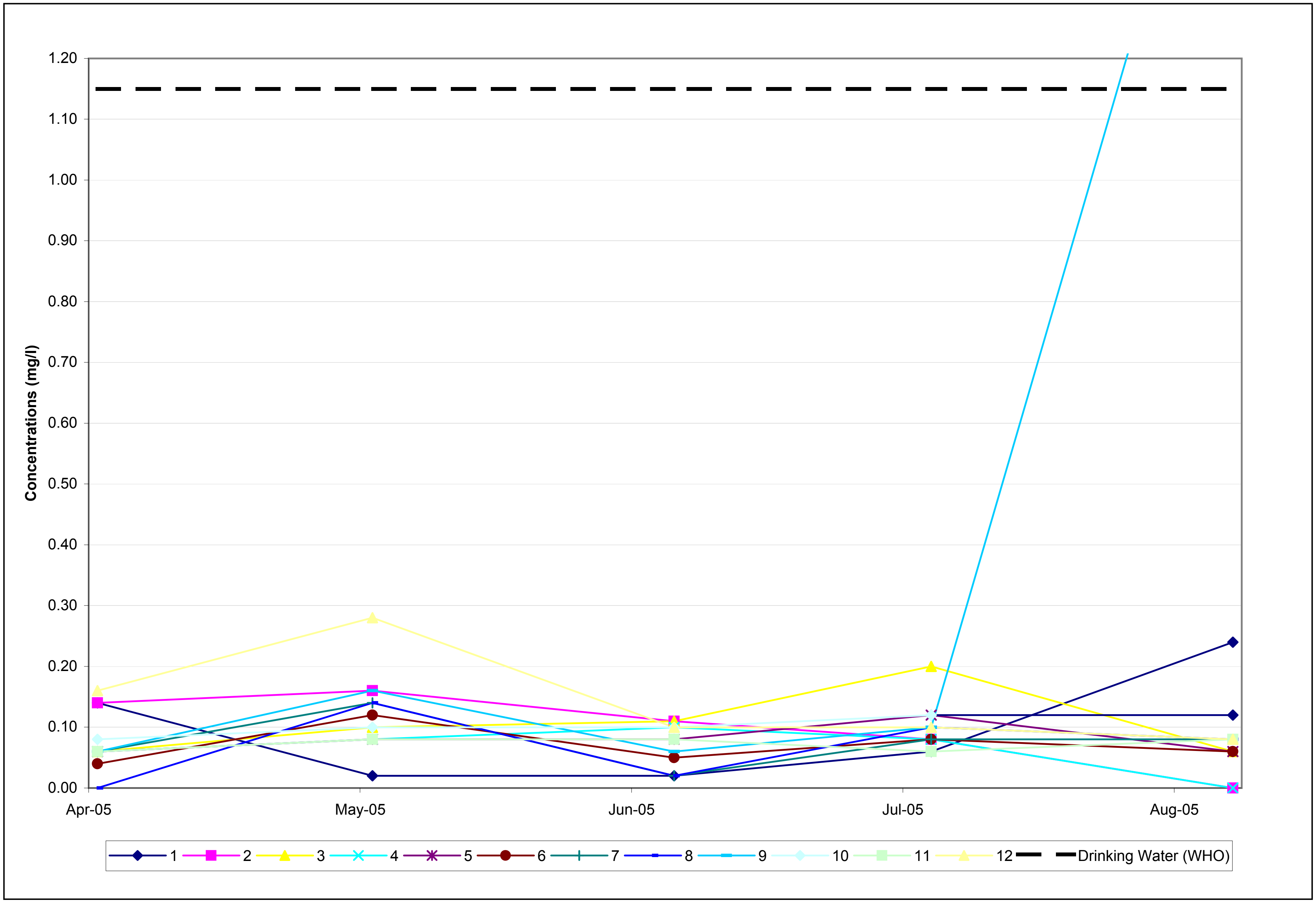
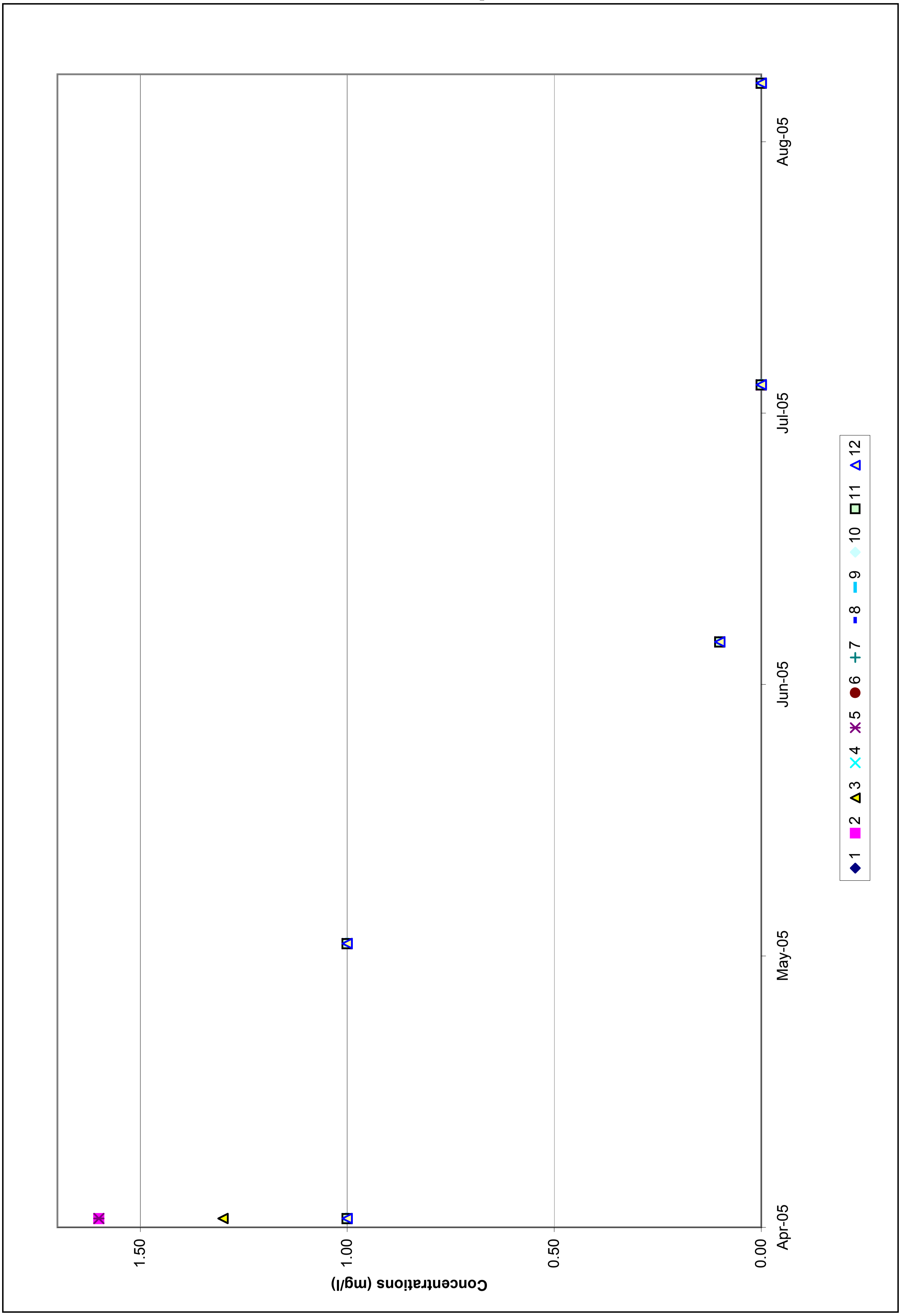
Ammonium - NH4-N - Seasonal Variation



Phosphate - PO4-P - Seasonal Variation



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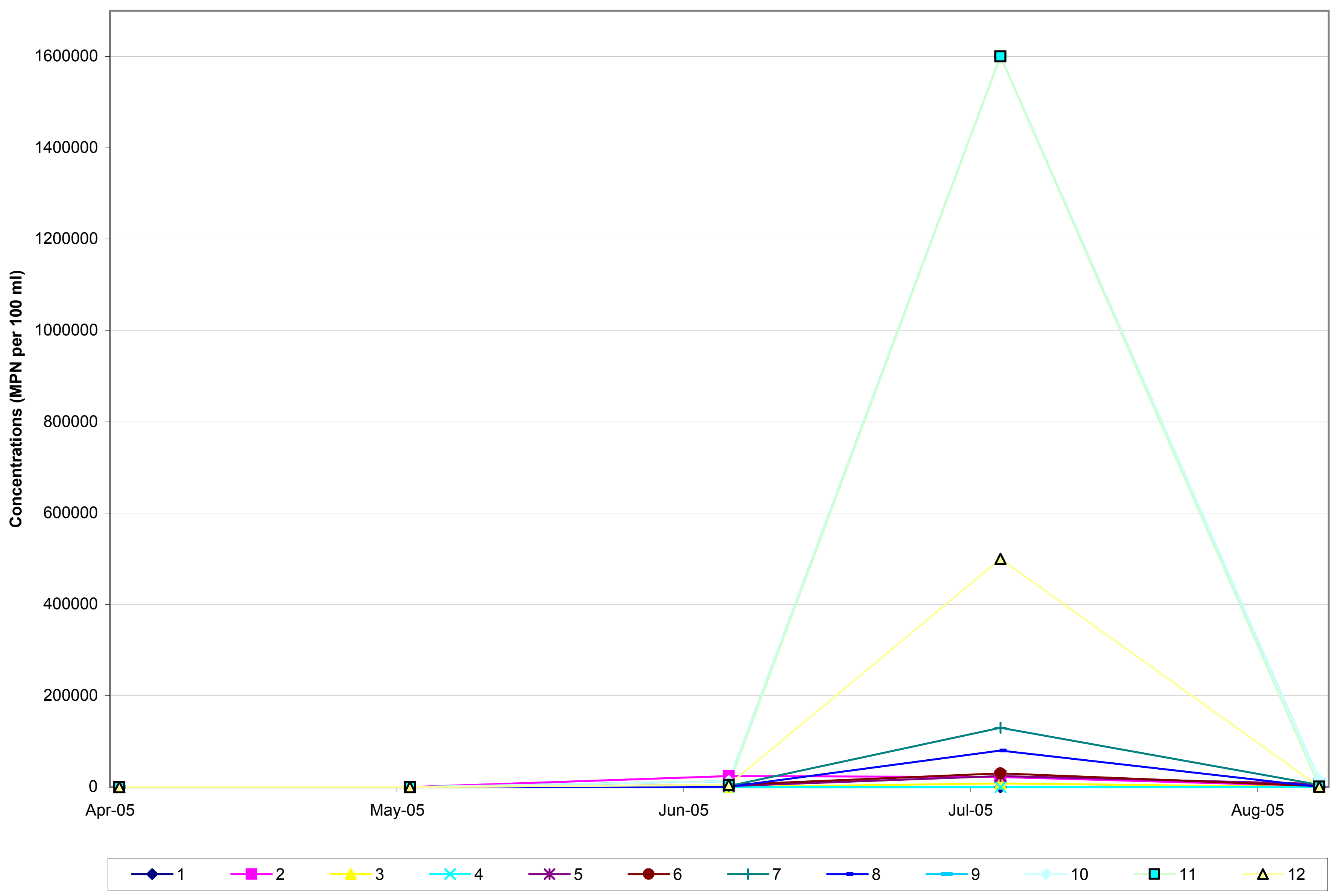
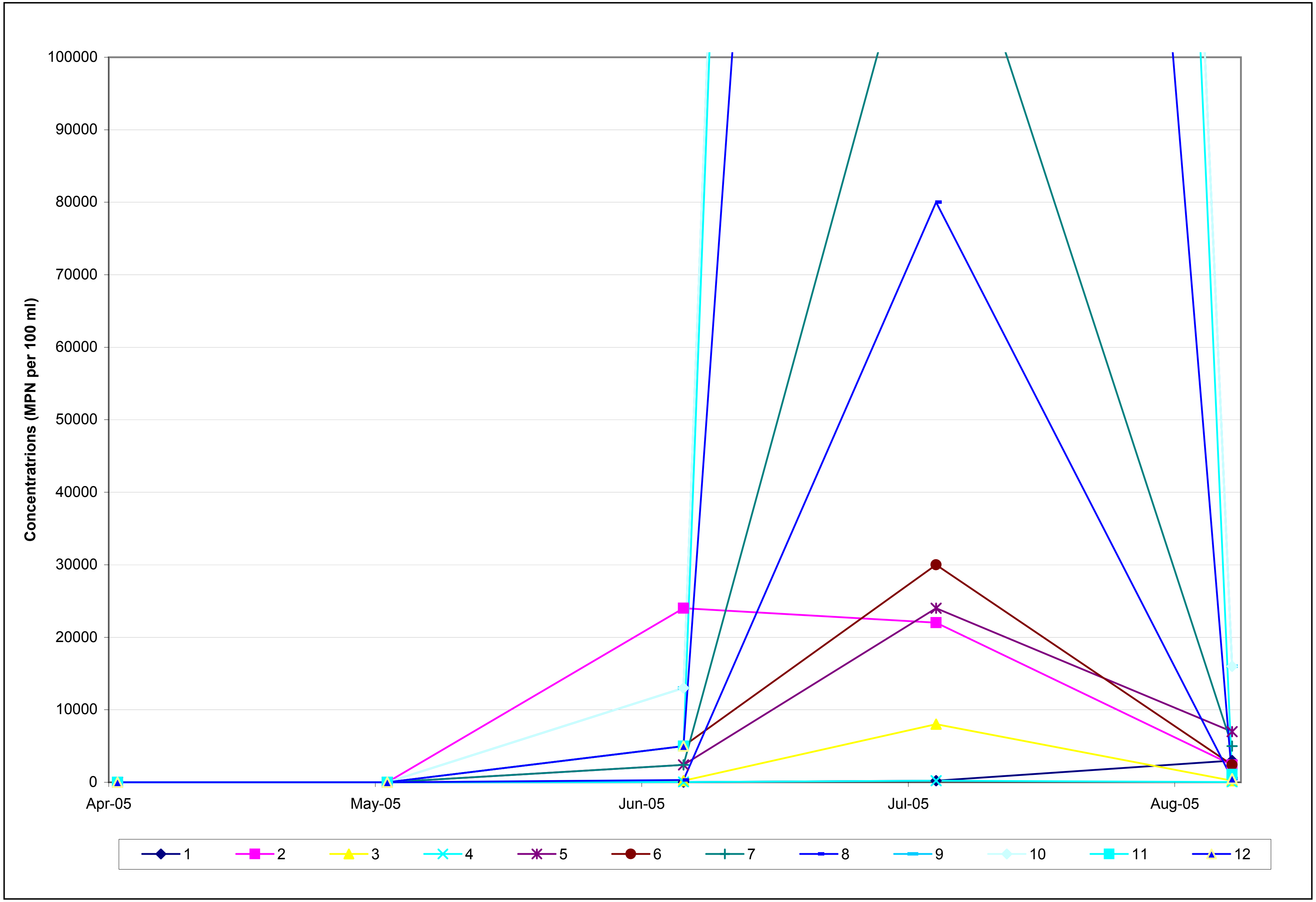
Faecal Coliforms - Seasonal Variation



Faecal Coliforms (rescalled) - Seasonal Variation



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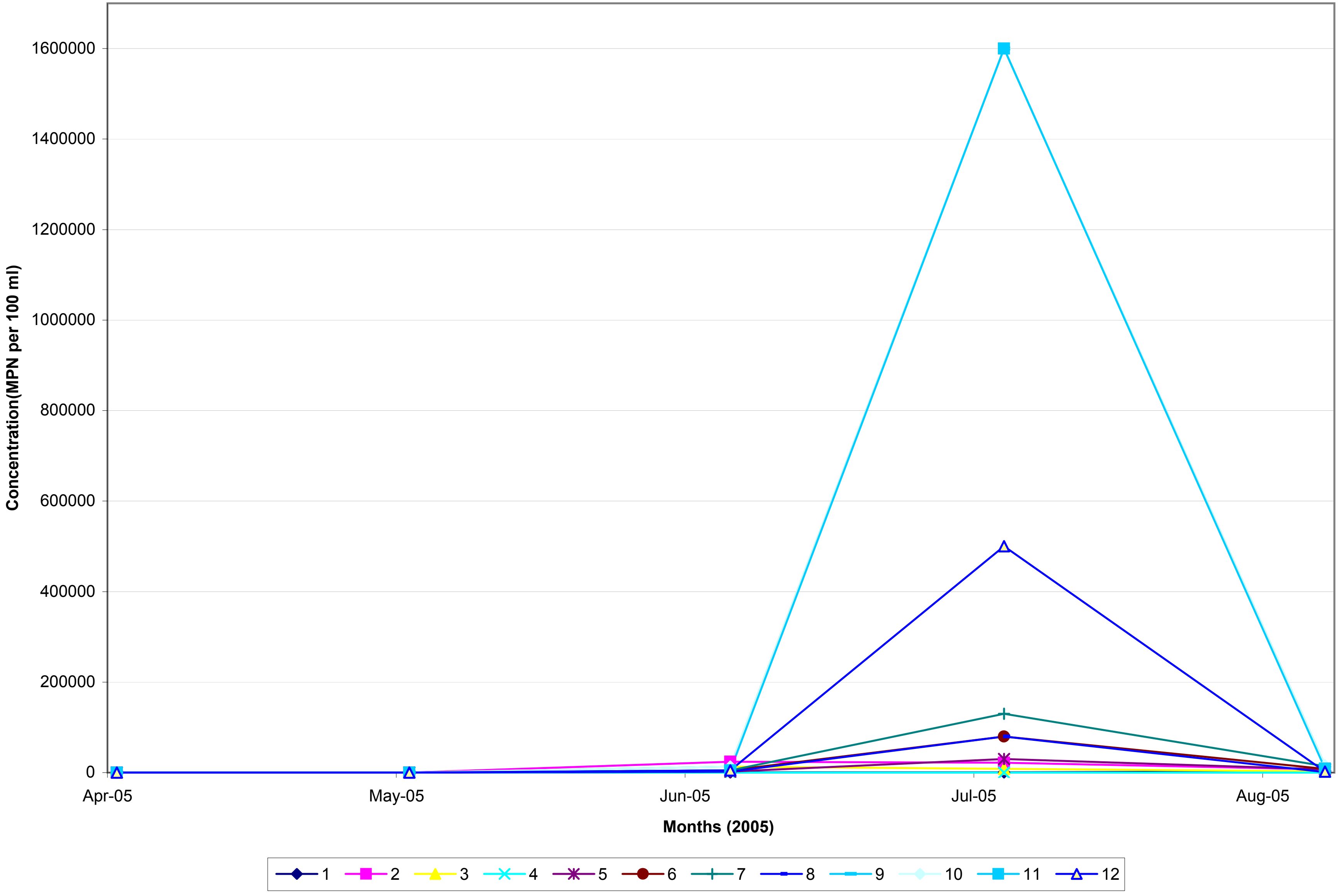
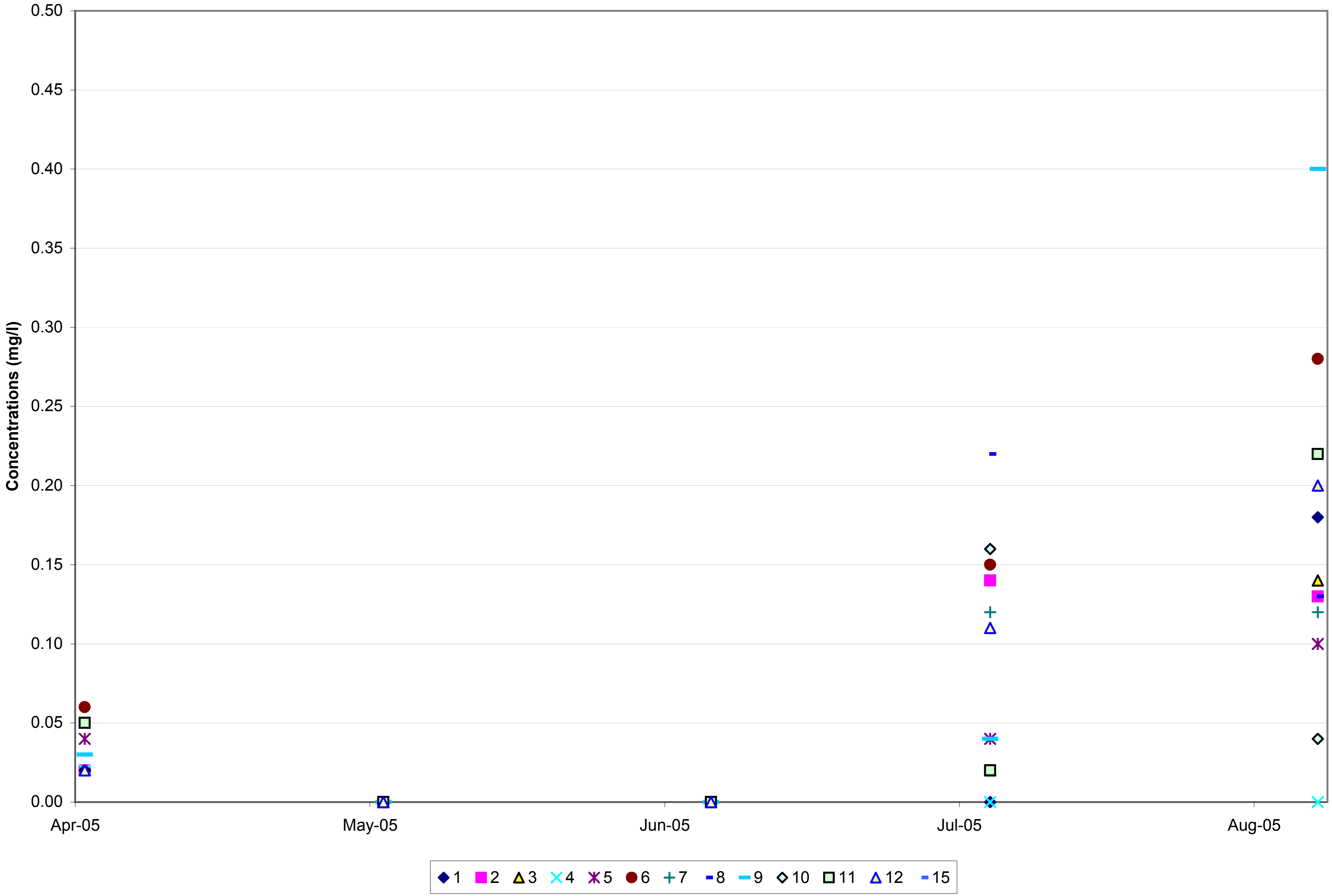
Total Coliforms - Seasonal Variation



Manganese - Mn - Seasonal Variation



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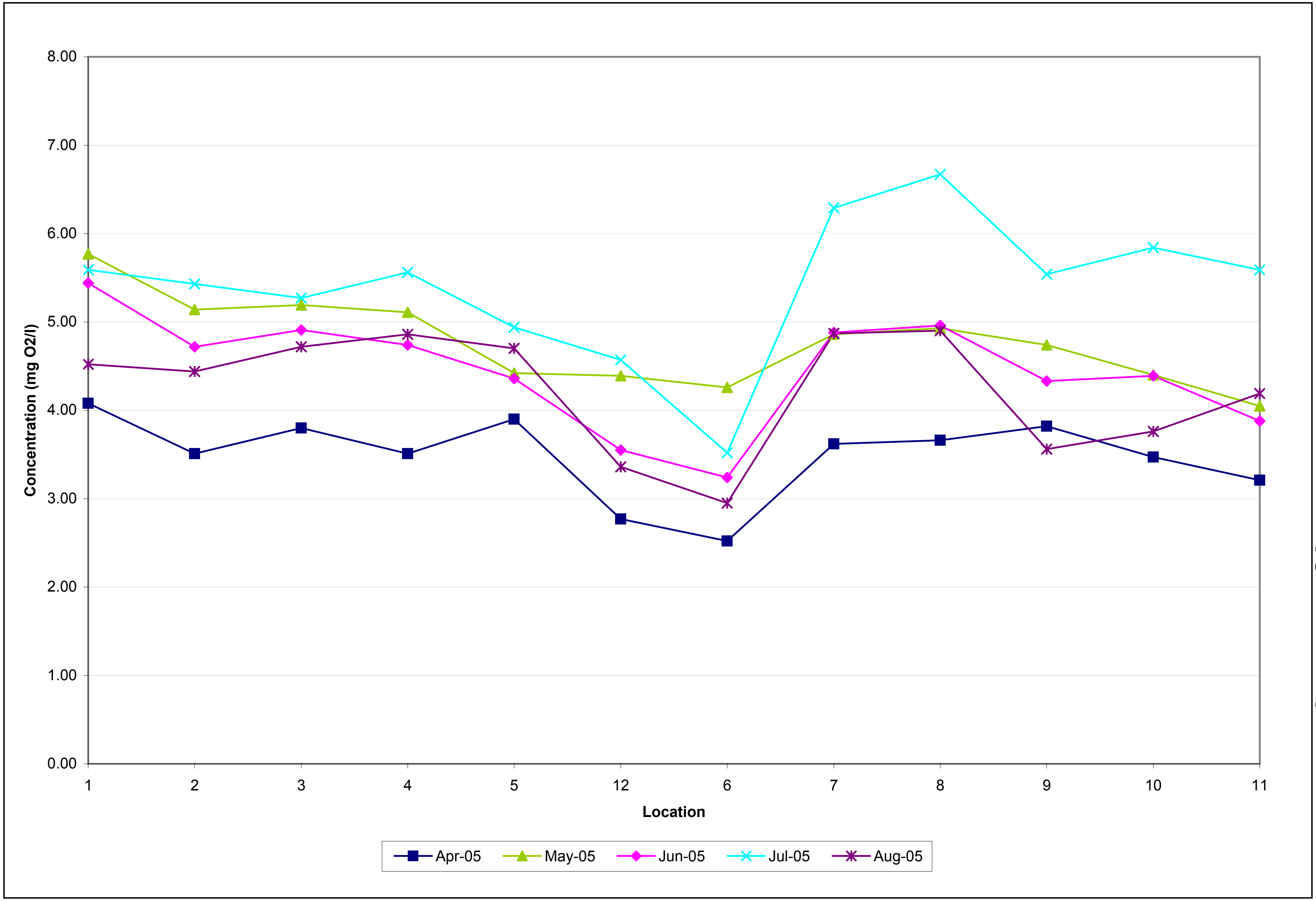
F.2 Spatial variation

Dissolved Oxygen - DO - Spatial Variation



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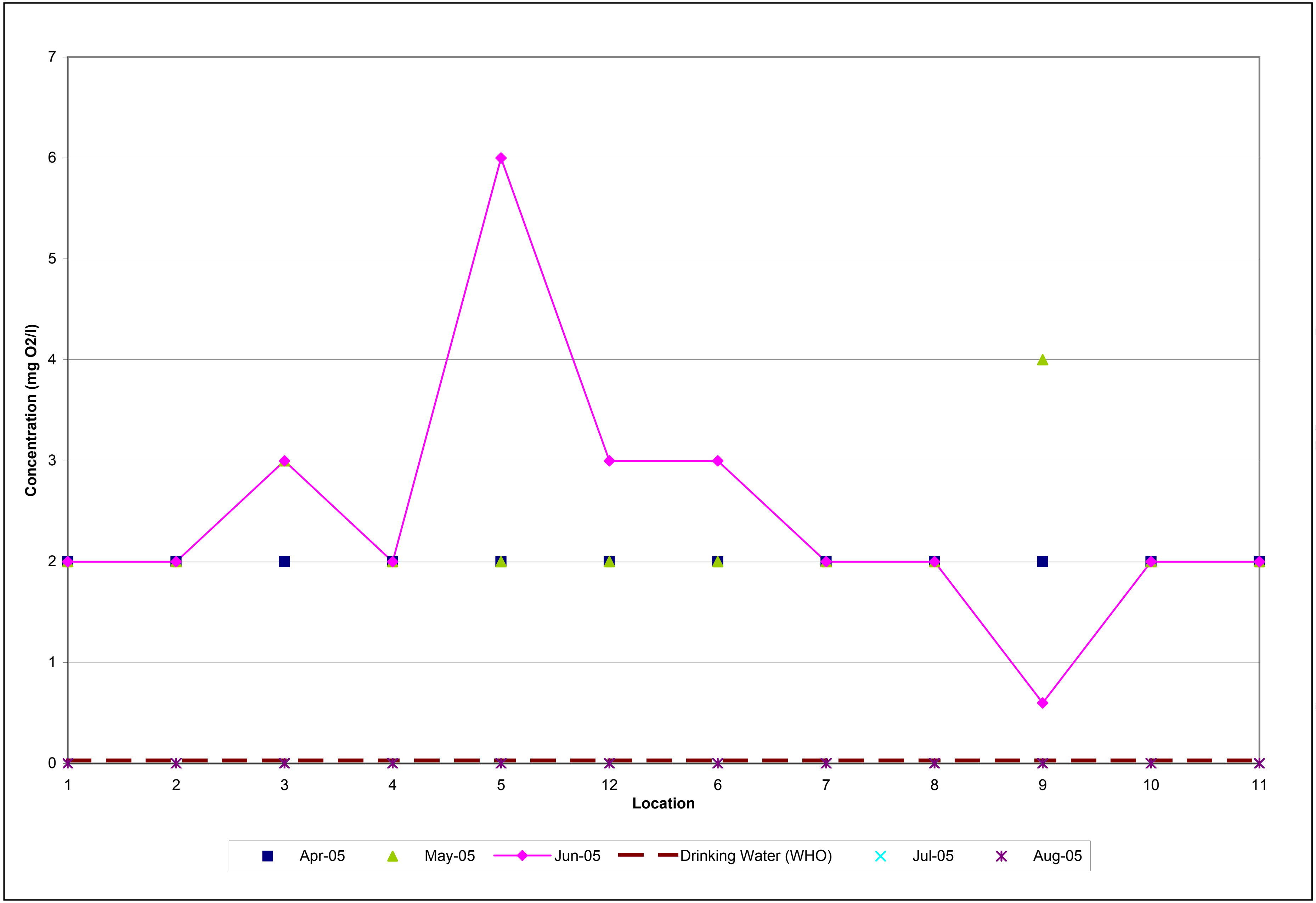
Biological Oxygen Demand - BOD - Spatial Variation



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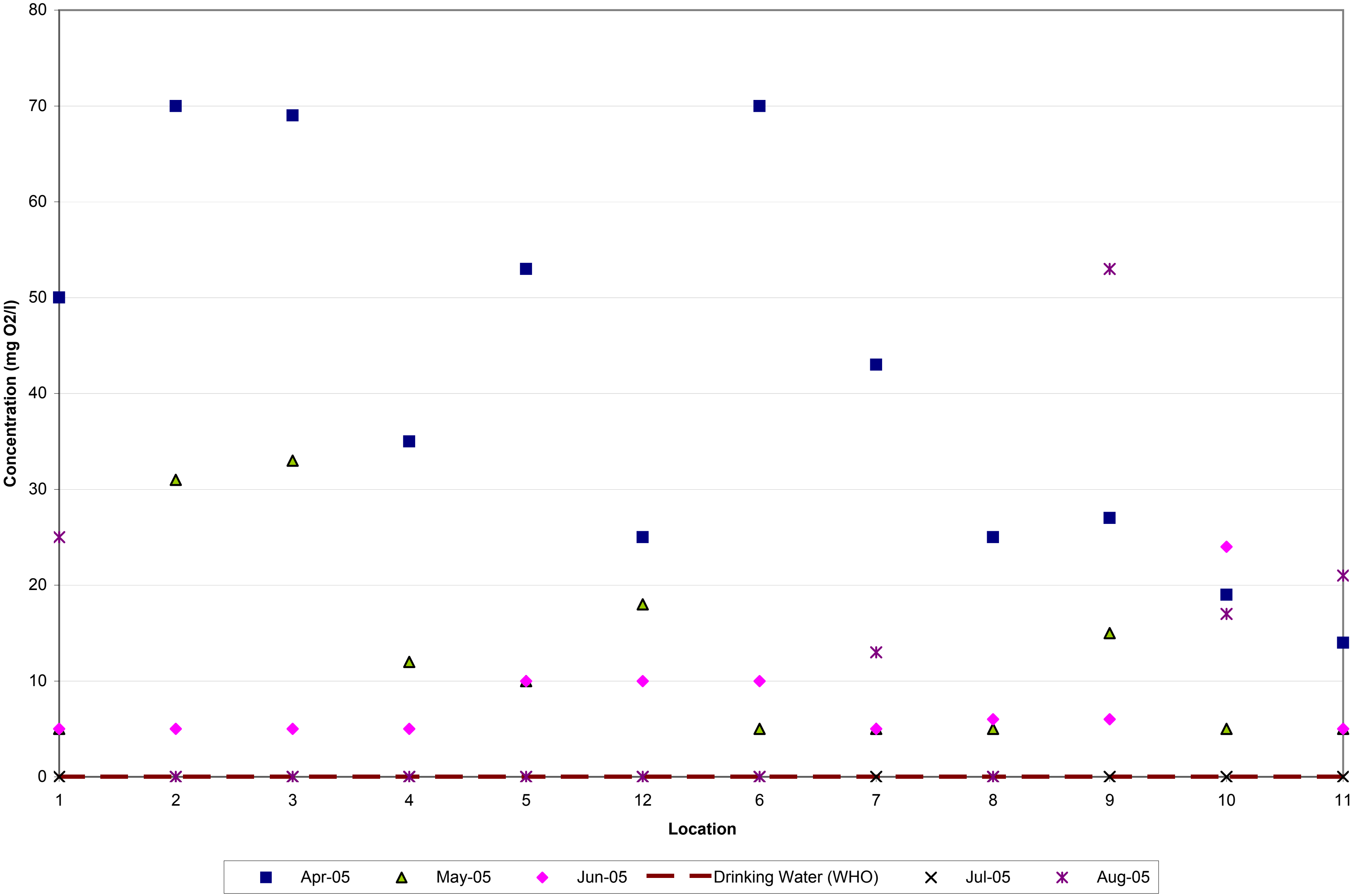
Chemical Oxygen Demand - COD - Spatial Variation



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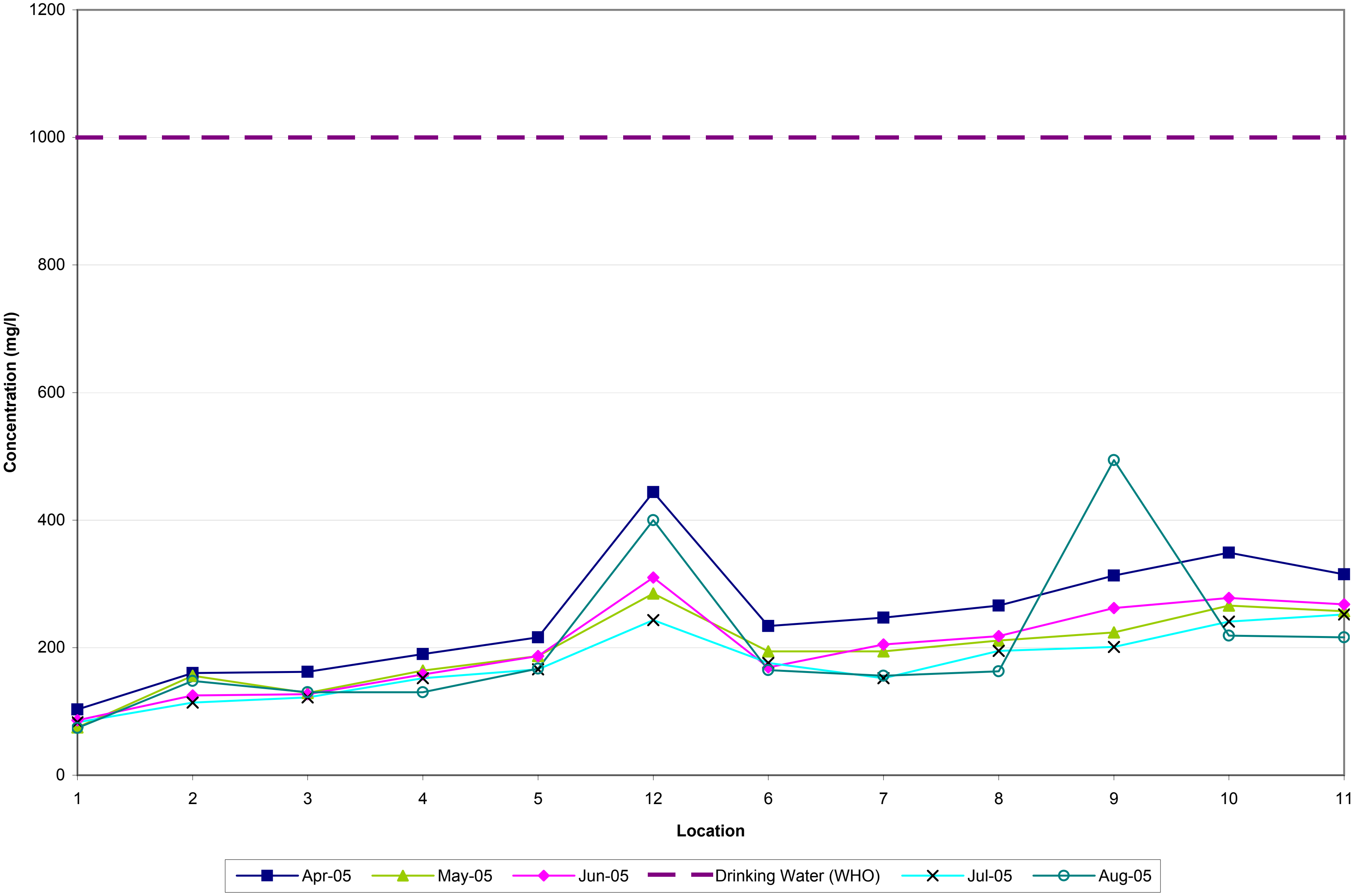
Total Dissolved Solids - TDS - Spatial Variation



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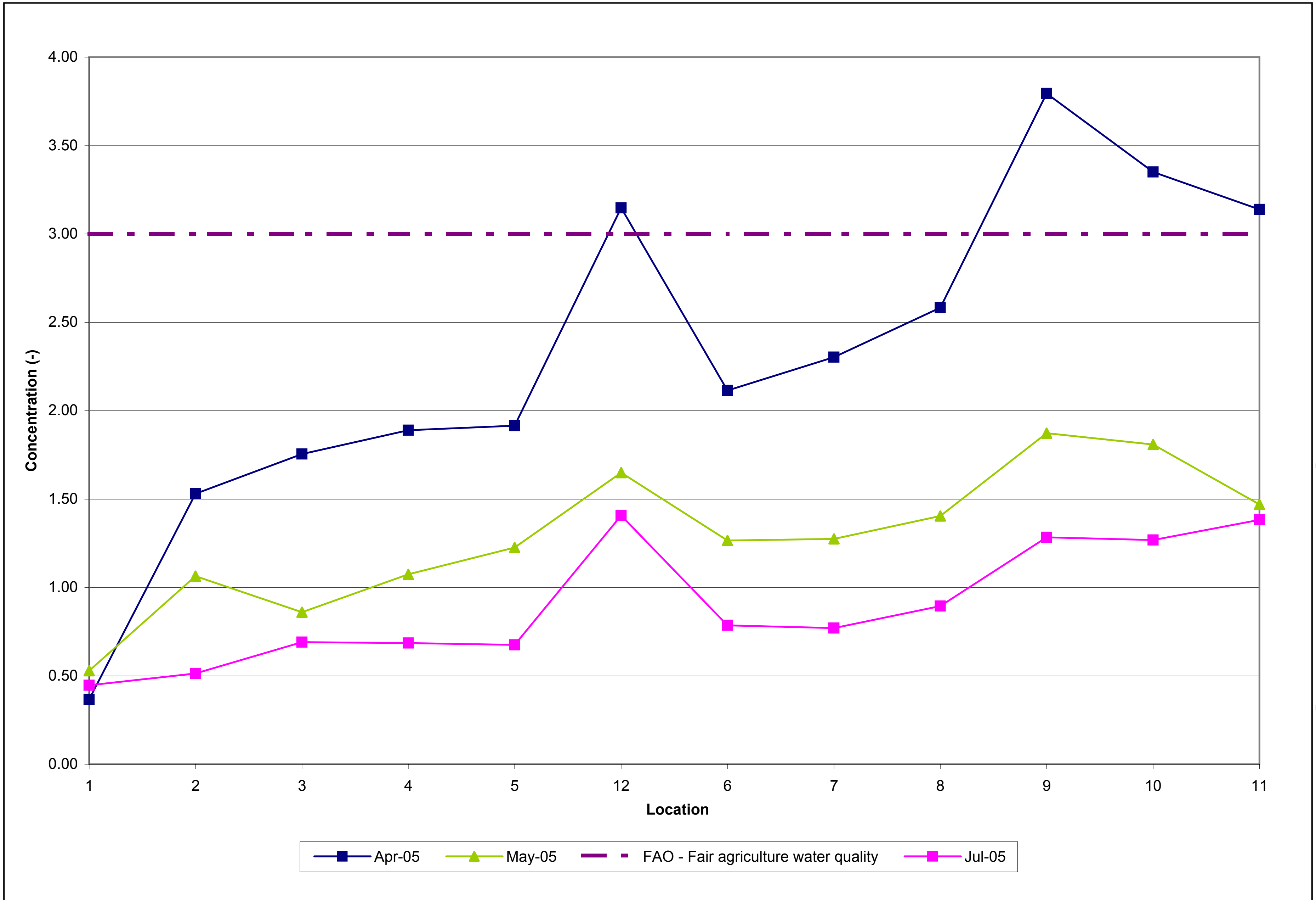
Sodium Absorption Ratio - SAR - Spatial Variation



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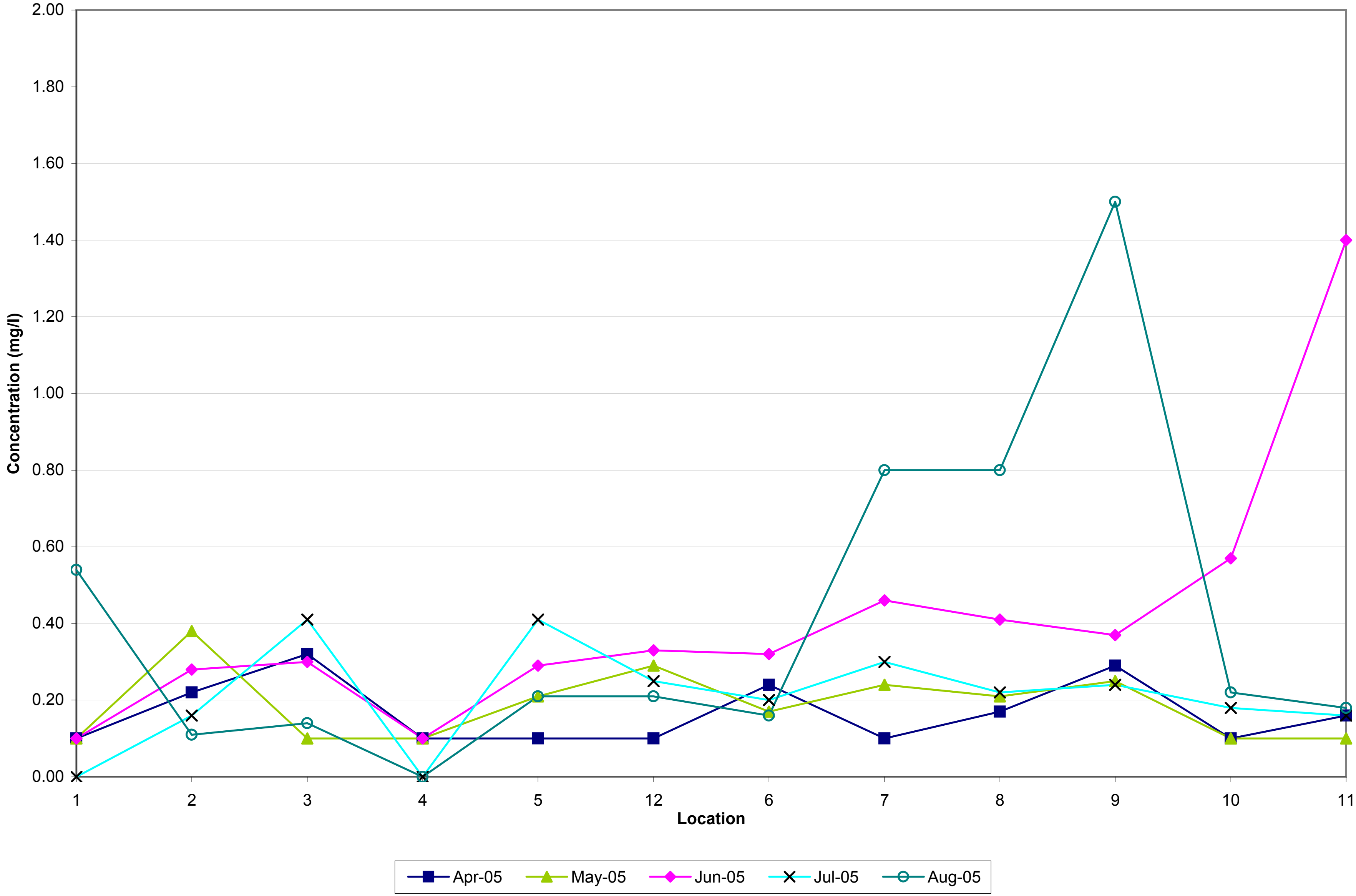
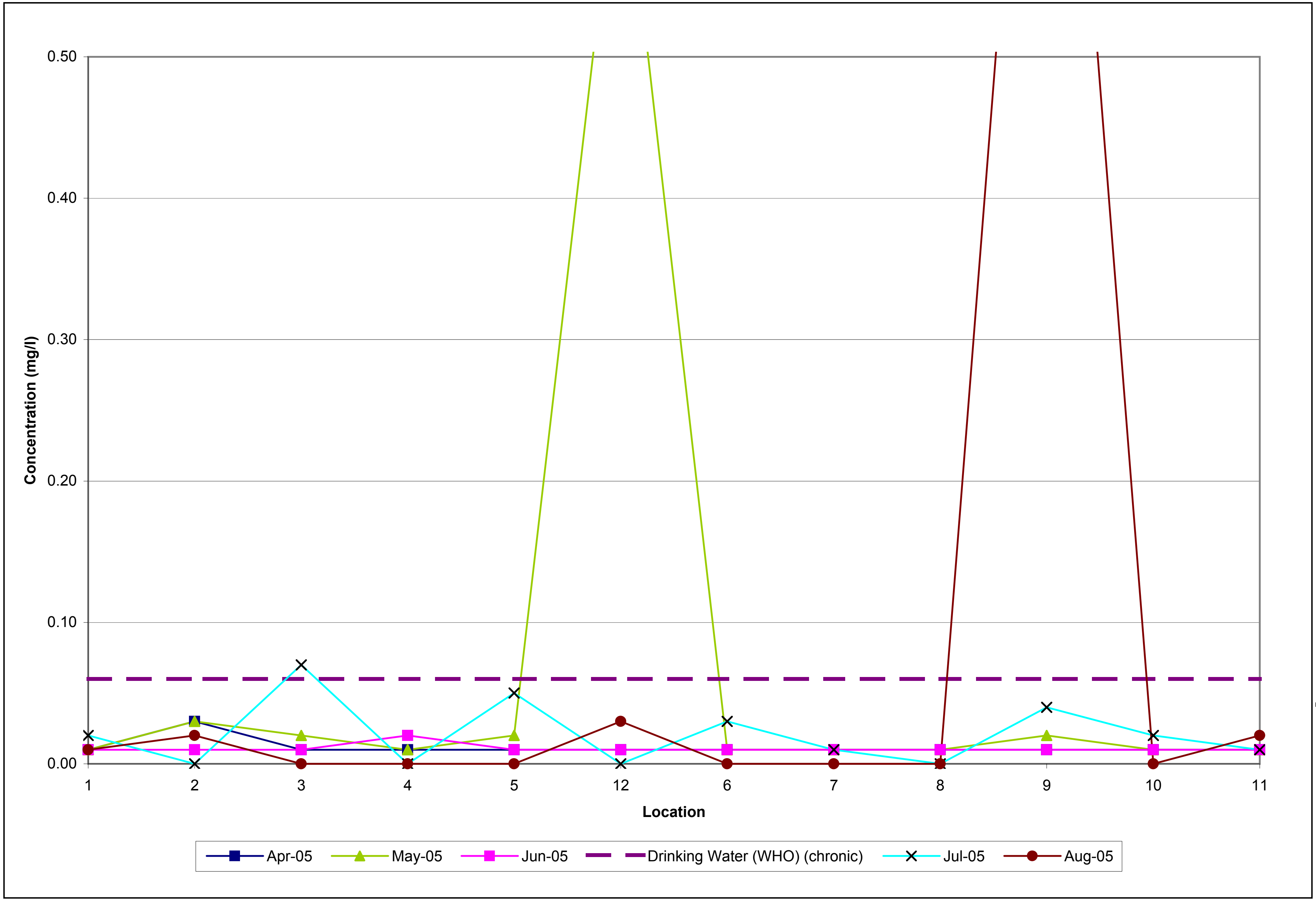
Nitrate - NO3-N - Spatial Variation



Nitrite - NO2-N - Spatial Variation



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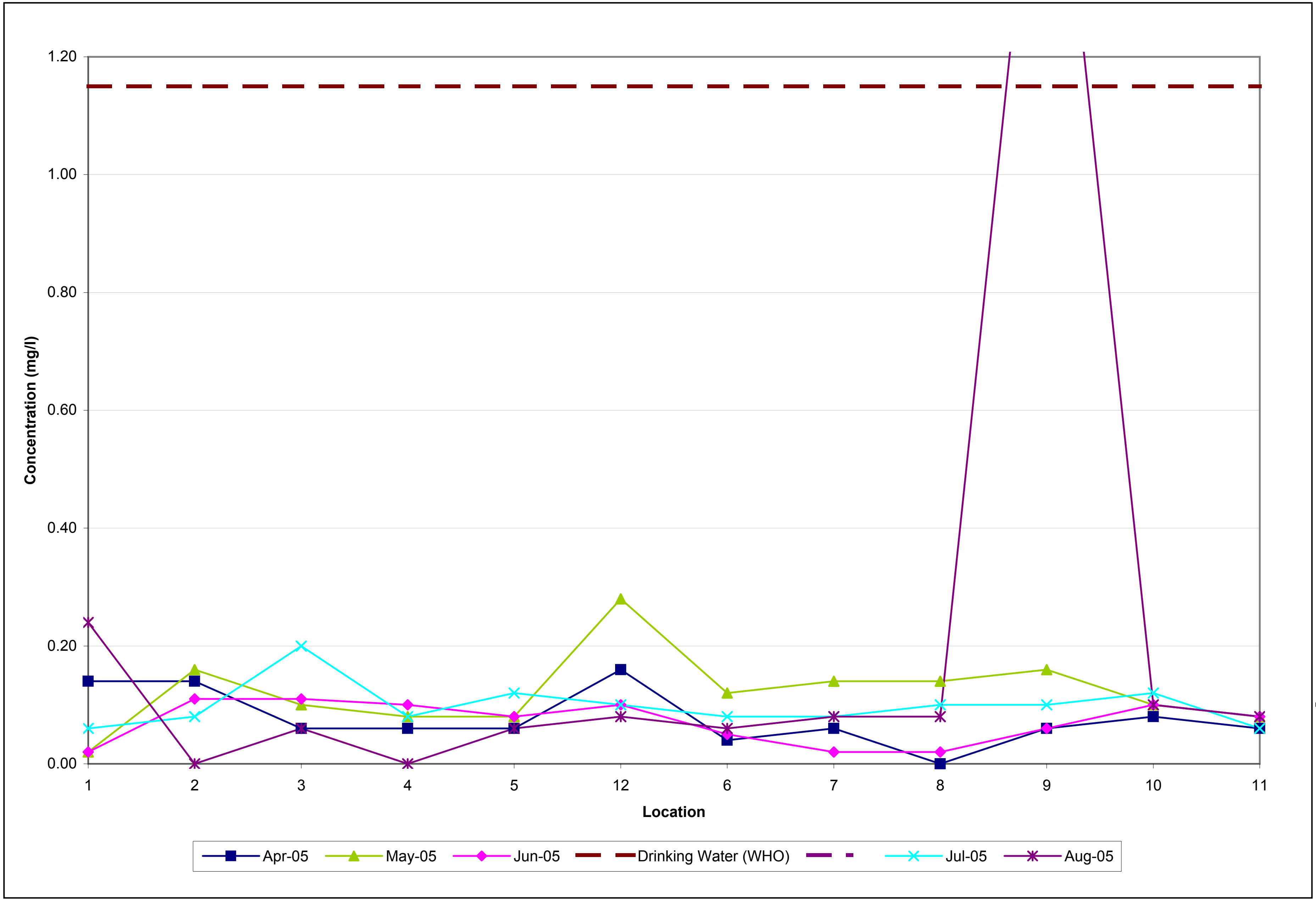
Ammonium - NH4-N - Spatial Variation



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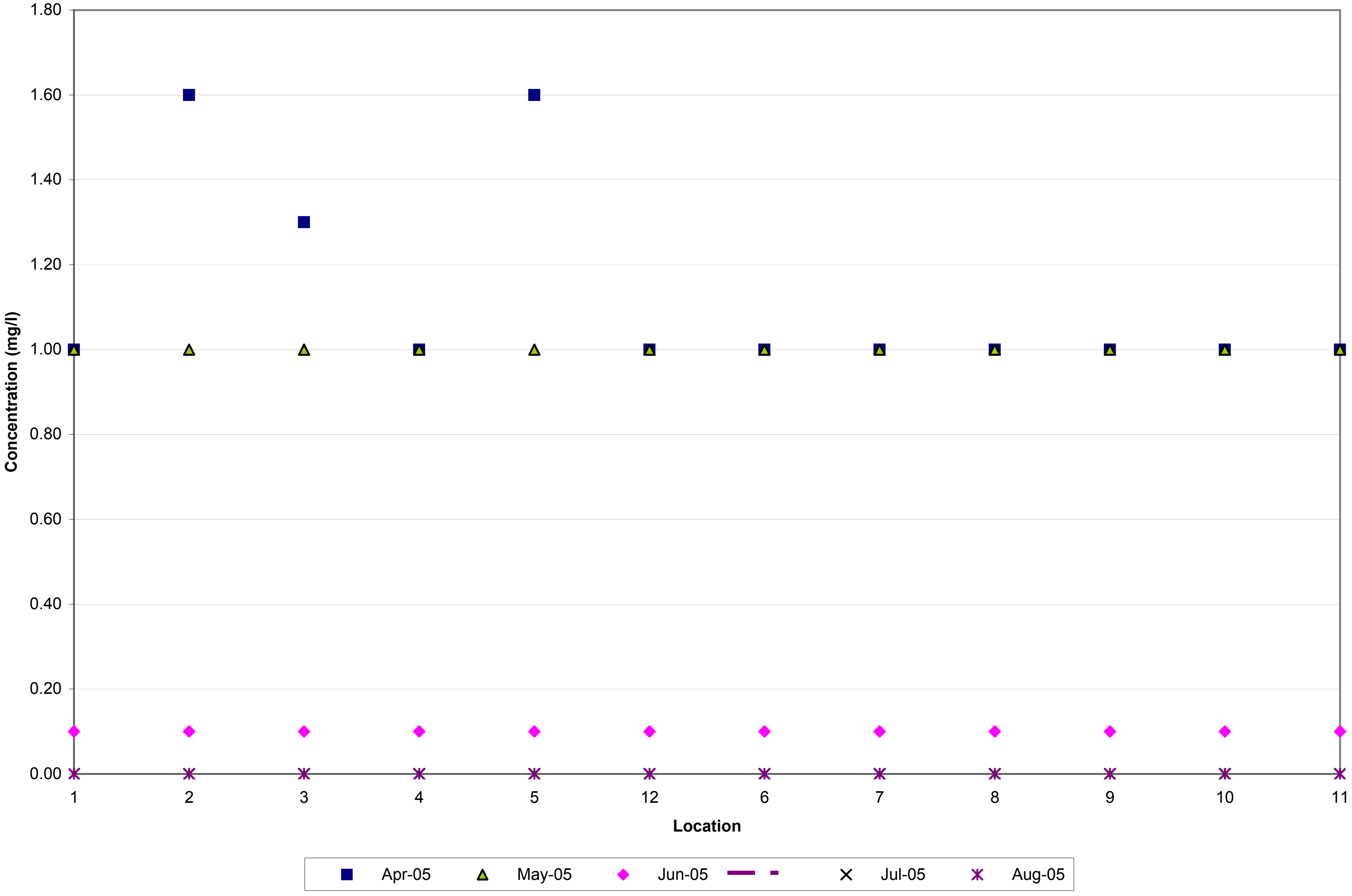
Phosphate - PO4-P - Spatial Variation



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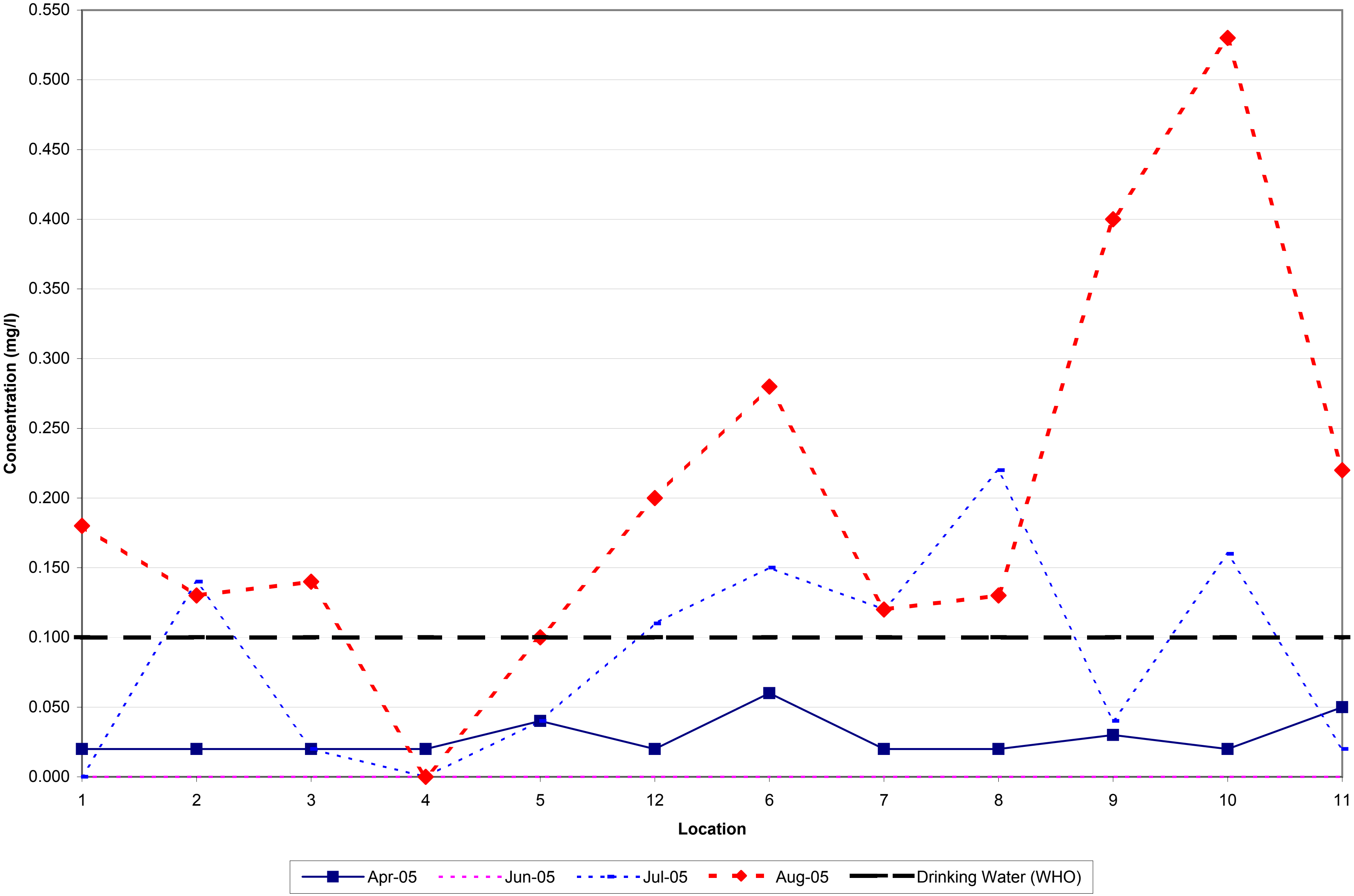
Manganese - Mn - Spatial Variation



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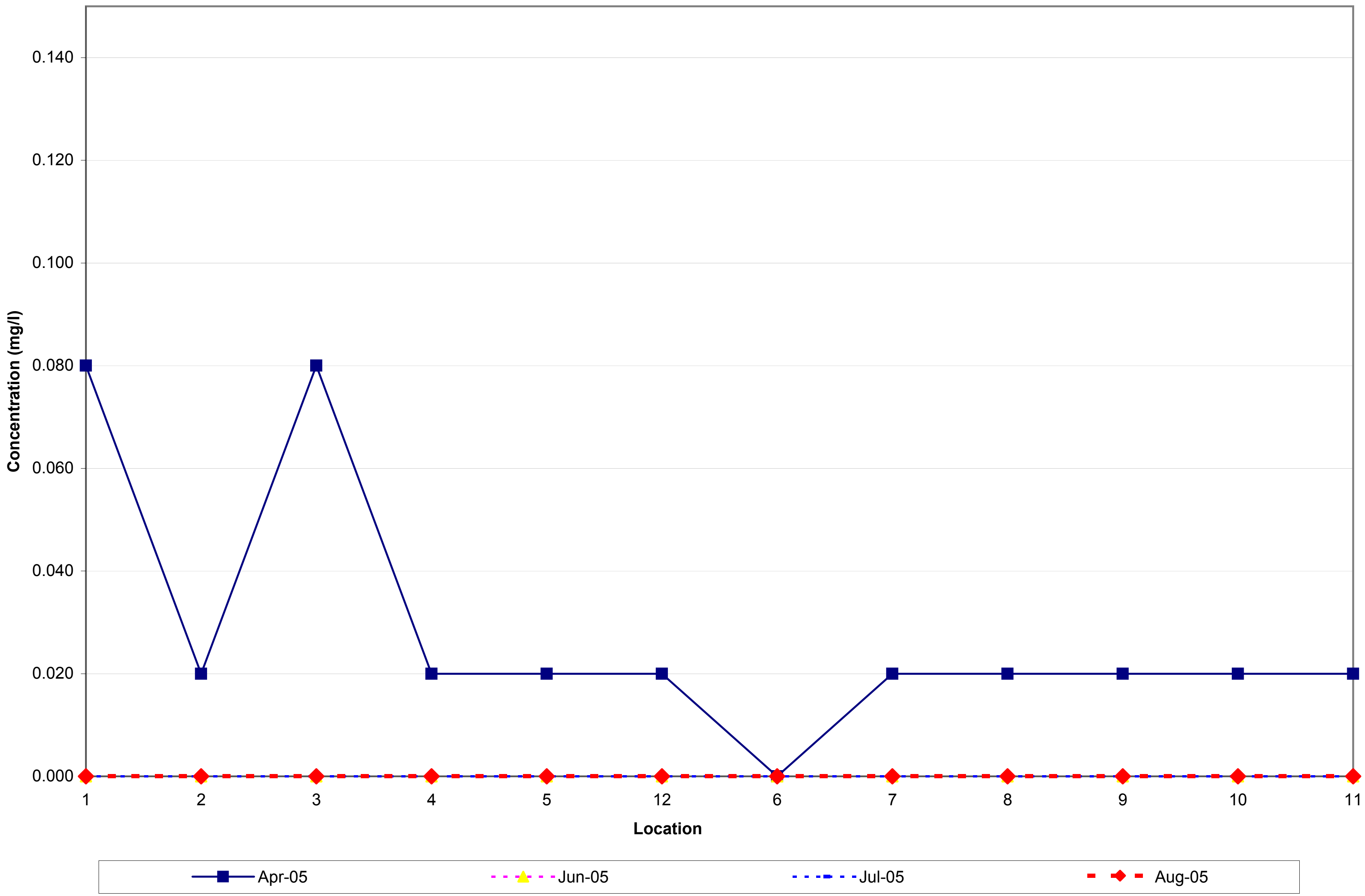
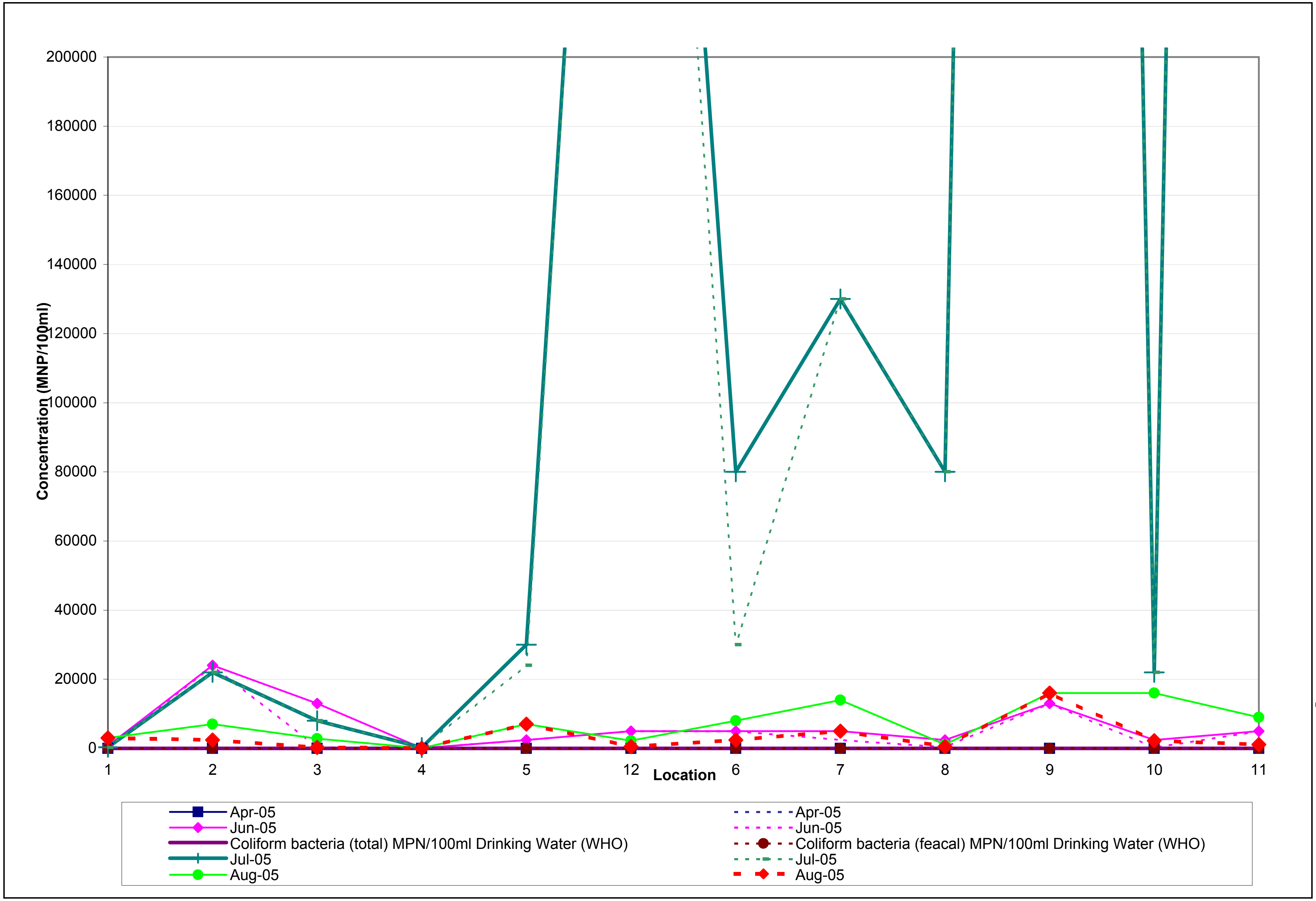
Zinc - Zn - Spatial Variation



Coliforms (Total and Faecal) - Spatial Variation



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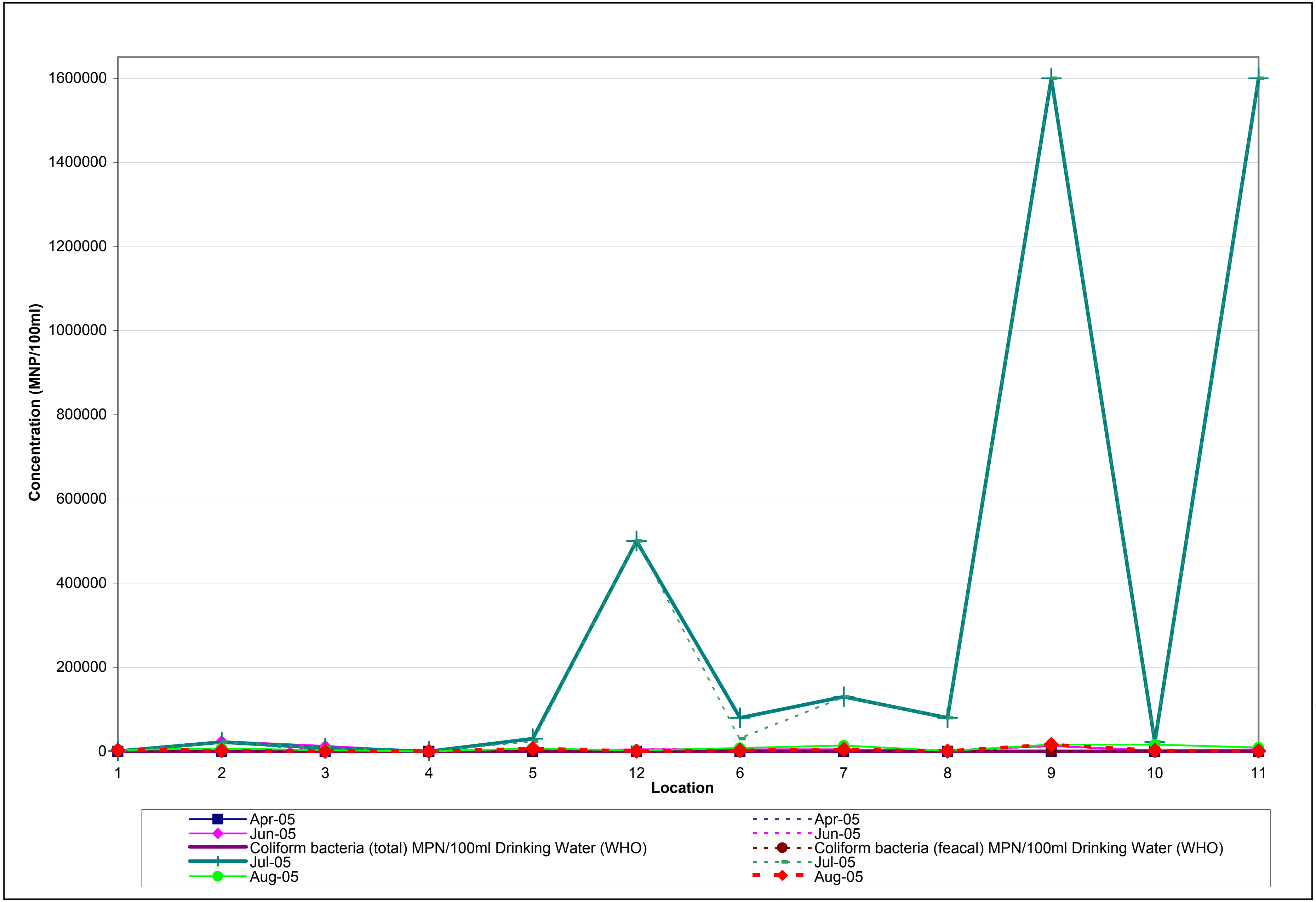
Coliforms (Total and Faecal) - Spatial Variation



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