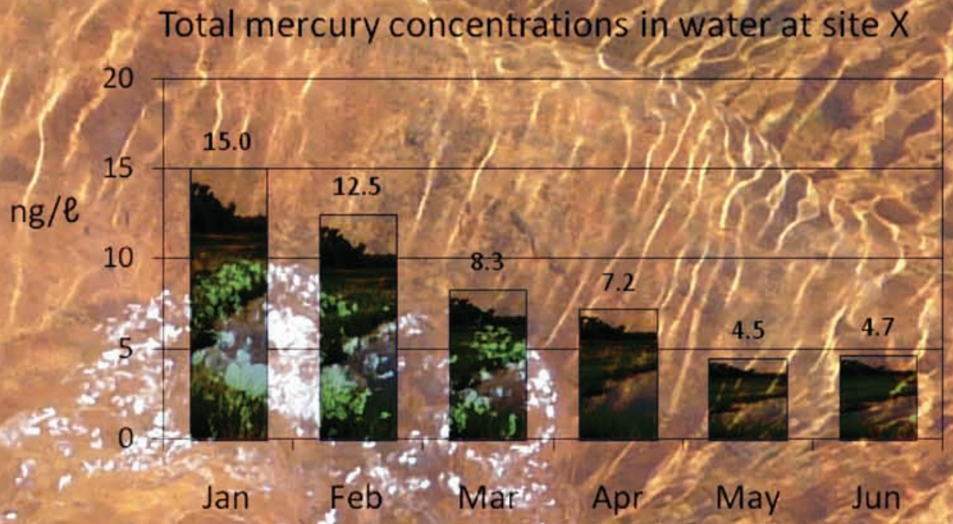
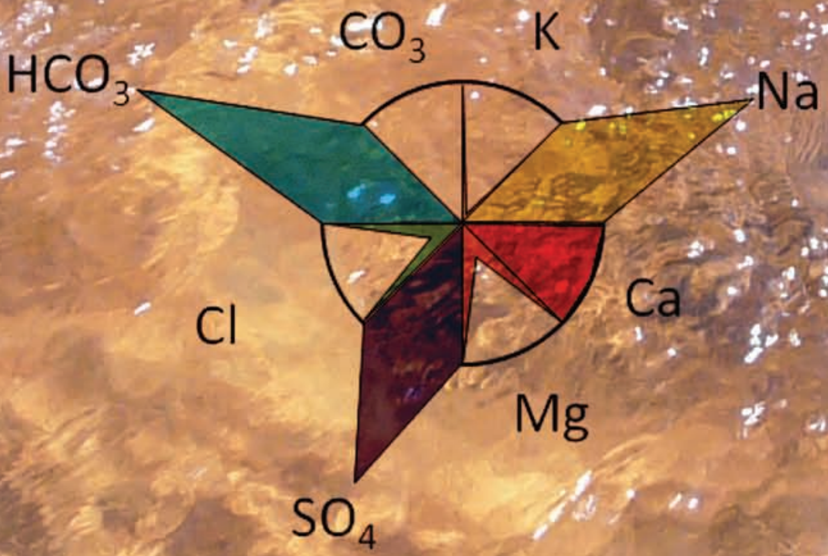
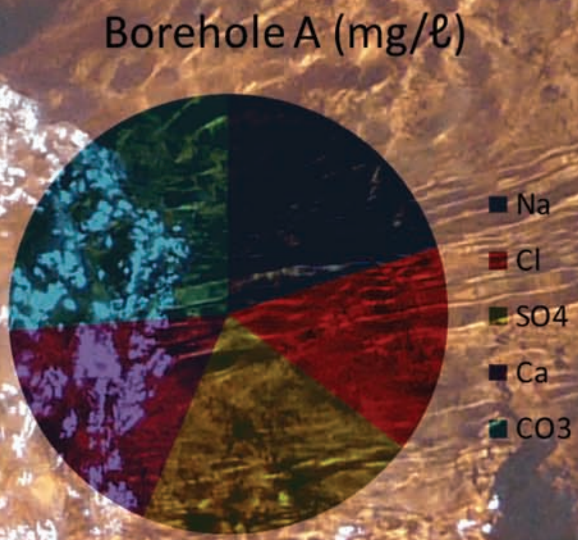
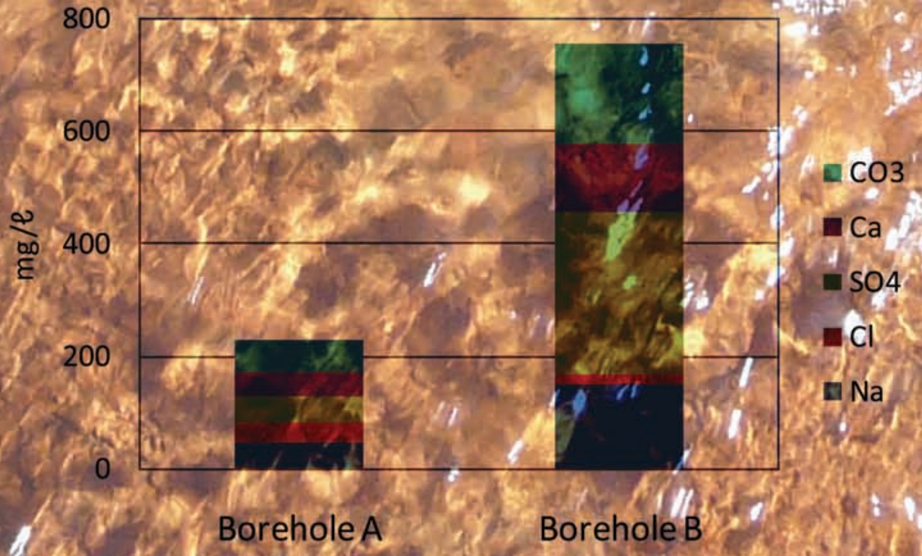
Water Quality Data and Information: A Communicator's Manual

K Murray, J Dabrowski, L Hill,
M du Preez, M Kadiaka & W Strydom









WATER RESEARCH COMMISSION
TT 394/10

WATER QUALITY DATA AND INFORMATION: A Communicator's Manual

Report to the
Water Research Commission

by

K Murray[1], J Dabrowski[2], L Hill[2],
M du Preez[2], M Kadiaka[3], and W Strydom[2]

[1] Insight Modelling Services,
[2] Natural Resources and the Environment, CSIR
[3] Department of Water Affairs and Forestry

WRC Report No. TT 394/10

March 2010

Obtainable from:

Water Research Commission
Private Bag X03
Gezina, 0031

The publication of this report emanates from a project entitled: *Water Quality Monitoring Data and Target Users: Maximising Value* (WRC Project No. K5/1755).

ISBN: 978-1-77005-837-8

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

This manual arose out of a perceived need to provide recommendations for the way in which data and information relating to water quality can best be communicated to various target audiences. Improving this communication allows the full value to be realised of the generally considerable investment in data acquisition. This manual is aimed primarily at people responsible for such communication in both the public and private sectors. The manual is introductory, not exhaustive.

It is inevitable that a degree of subjectivity exists in some aspects of a manual such as this. Nevertheless, applying the recommendations will improve standardisation and hence the general effectiveness of communication nationally. On the other hand, when the recommendations are obviously inappropriate in special circumstances, alternative approaches should of course be used.

A wide variety of situations are covered in this manual. Accordingly, a number of mechanisms are provided for finding information in the manual. Besides the usual contents page and lists of tables and figures, a one page "Manual Roadmap" is also given. Chapter 2 (How to Use this Manual) presents a series of specific questions and references to associated chapters. It also presents two tables that can be used to identify appropriate communication media (billboards, brochures, etc.) and tools (charts, graphs, etc.). These tables are also the basis of a simple spreadsheet facility that allows the media and tools to be established interactively.

Chapter 3 (General Recommendations) provides suggestions that apply to many media and tools. Appropriate communication principles (such as keeping it simple, keeping it standard, etc.) are presented. Because such a wide variety of languages exist in South Africa, some basic recommendations are given for good English writing style. This is augmented with a series of formatting recommendations relating to such issues as use of acronyms, expressing units and writing numbers. The important concepts of accuracy and precision are also presented with advice on when and how to round numbers sensibly. Finally some suggestions are made regarding importing images into documents.

Chapter 4 (Data categories) describes three fundamentally different categories of data. Each represents a different degree of value addition to the primary data. The categories are:

1. **Minimal integrative processing**. This essentially amounts to presenting the primary ("raw") data of any number of water quality variables.
2. **Intermediate integrative processing**. This typically involves presenting basic summary statistics of the primary data for individual water quality variables.
3. **Highly integrative processing**. This involves calculating aggregated values from the primary data of many water quality variables, often called indices (or indicators).

Examples, characteristics, advantages and disadvantages, and dos and don'ts are presented for each.

Chapter 5 (Communication Tools) describes a series of tools (charts, diagrams, graphs, icons, maps, photographs, short stories and tables). Examples, characteristics, advantages and disadvantages, and practical and aesthetic dos and don'ts are presented for each.

Chapter 6 (Communication Media) describes a series of media (billboards, brochures, emails, exhibitions, newspapers, popular articles, posters, radio, technical reports, television, verbal presentations, water accounts, and web sites). Advantages and disadvantages, dos and don'ts, and references to further information are presented.

Chapter 7 (Scenario-specific Recommendations) provides suggestions on what data categories and communication media and tools are best used for a variety of well-defined water quality data

communication scenarios. These include catchment assessment, national state of water resources, state of drinking water, performance monitoring of resource quality objectives, and compliance monitoring. In each case the context, target users and general communication message are defined.

Chapter 8 (Understanding a water quality communication) acknowledges (a) that there are many scientific disciplines required for effective communication of water quality data and information and (b) that those receiving such communications do not always possess such multi-disciplinary expertise. Accordingly, this chapter captures information that can be provided to those receiving such communications to help them understand basic concepts so that they can better understand the communication they receive. Basics are provided on water quality guidelines, chemistry, biotoxicology, microbiology, statistics and graph interpretation.

ACKNOWLEDGEMENTS

The authors wish to thank the following people for their contributions during the project.

Reference Group

Mr Meiring du Plessis	Water Research Commission (Research Manager)
Mr Morteza Fayazi	Department of Water Affairs & Forestry
Dr Anneli Kühn	Department of Water Affairs & Forestry
Ms Tandi Zokufa	Department of Water Affairs & Forestry
Dr Martin van Veelen	ILISO Consulting Environmental Management Division
Mr Nico Rossouw	Ninham Shand

TABLE OF CONTENTS

EXECUTIVE SUMMARY i
ACKNOWLEDGEMENTS iii
CONTENTS v
LIST OF FIGURES viii
LIST OF TABLES ix
WATER QUALITY ACRONYMS x

CHAPTER 1: BACKGROUND 3

CHAPTER 2: HOW TO USE THIS MANUAL 4

2.1 FINDING INFORMATION 4
2.2 IDENTIFYING SUITABLE MEDIA 5
2.3 IDENTIFYING SUITABLE TOOLS 7

CHAPTER 3: GENERAL RECOMMENDATIONS 9

3.1 COMMUNICATION PRINCIPLES 9
3.2 BASIC WRITING STANDARDS 9
3.3 ACCURACY AND PRECISION 11
3.4 ROUNDING 12
3.5 IMPORTING IMAGES 13

CHAPTER 4: DATA CATEGORIES 14

4.1 INTRODUCTION 14
4.2 GLOSSARY 14
4.3 PRIMARY DATA 15
4.4 SINGLE-VARIABLE SUMMARY STATISTICS 17
4.5 MULTIPLE-VARIABLE INDICES 19

CHAPTER 5: COMMUNICATION TOOLS 21

5.1 INTRODUCTION 21
5.2 GLOSSARY 22
5.3 CHARTS 23
5.3.1 Bar charts 24
5.3.2 Pie charts 28
5.4 DIAGRAMS 29
5.4.1 Maucha diagrams 29
5.4.2 Piper and Expanded Durov diagrams 31
5.5 GRAPHS 34
5.6 ICONS 39
5.7 MAPS 41
5.8 PHOTOGRAPHS 46
5.9 SHORT STORIES 48
5.10 TABLES 49

CHAPTER 6: COMMUNICATION MEDIA 51

6.1 INTRODUCTION 51
6.2 BILLBOARDS 52

6.3 BROCHURES 53
6.4 EMAILS 54
6.5 EXHIBITIONS....55
6.6 NEWSPAPERS 56
6.7 POPULAR ARTICLES....57
6.8 POSTERS 58
6.9 RADIO....59
6.10 TECHNICAL REPORTS....60
6.11 TELEVISION 61
6.12 VERBAL PRESENTATIONS....62
6.13 WATER ACCOUNTS 63
6.14 WEB SITES....64

CHAPTER 7: SCENARIO-SPECIFIC RECOMMENDATIONS 65

7.1 GLOSSARY....65
7.2 CATCHMENT ASSESSMENT 66
7.3 ANNUAL NATIONAL STATE OF WATER RESOURCES 68
7.4 STATE OF DRINKING WATER 71
7.5 PERFORMANCE MONITORING OF RQOS 73
7.6 COMPLIANCE MONITORING 74

CHAPTER 8: UNDERSTANDING A WATER QUALITY COMMUNICATION 76

8.1 INTRODUCTION....76
8.2 WATER QUALITY GUIDELINES 77
8.2.1 Glossary....77
8.2.2 How to use them....77
8.3 BASIC CHEMISTRY 79
8.3.1 Glossary....79
8.3.2 The elements....79
8.3.3 Anions and cations 80
8.3.4 Concentration units....80
8.3.5 Organic compounds....80
8.3.6 Chemical speciation....81
8.3.7 pH 81
8.4 BASIC BIOTOXICOLOGY....82
8.4.1 Glossary....82
8.4.2 The nature of toxicity 83
8.4.3 Factors affecting the degree of toxicity 83
8.4.4 Measuring toxicity....84
8.4.5 The nature of toxicants 84
8.4.6 Factors affecting toxicant concentrations 84
8.4.7 Measuring toxicant concentrations 85
8.5 BASIC MICROBIOLOGY 86
8.5.1 Glossary....86
8.5.2 Importance....86
8.5.3 Size of microorganisms 86
8.5.4 Viruses and bacteria....87
8.5.5 Indicator organisms 87
8.6 BASIC STATISTICS....89
8.6.1 Glossary....89
8.6.2 Measures of central tendency....89
8.6.3 Measures of variability....90
8.6.4 Frequency distributions....90
8.7 BASIC GRAPH INTERPRETATION 92
8.7.1 Independent and dependent variables 92

8.7.2 The slope 93
8.7.3 Log scales..94

CHAPTER 9: REFERENCES & FURTHER READING..95

CONTENTS OF ATTACHED CD:

1. Research report (WRC Report No. 1755/1/09);

2. This manual; and

3. An excel spreadsheet for determining recommended communication media and tools.

LIST OF FIGURES

Figure 1: The difference between accuracy and precision. 11
Figure 2: Summary statistics example. Pie chart indicating comparison with "Very Good" water quality. 18
Figure 3: Summary statistics example. Pie charts on a map with numbers identifying the monitoring site. 18
Figure 4: Indicator example: Overall water quality status on a map with numbers indicating concentrations. 20
Figure 5: Stacked column example. Comparing absolute concentrations. 24
Figure 6: 100% stacked column example. Comparing relative constituent concentrations. 25
Figure 7: Horizontal bar charts example. Comparing absolute concentrations. 25
Figure 8: Reflected horizontal bar charts example. Comparing absolute concentrations. 26
Figure 9: Sorted horizontal bar charts example. Emphasising the highest concentrations. 26
Figure 10: Clustered horizontal bar chart example. Direct comparisons of concentrations. 27
Figure 11: Image bar chart example. Eye-catching reinforcement of message. 27
Figure 12: Image bar chart example. Aesthetically pleasing bars. 28
Figure 13: Paired pie charts. Comparing relative concentrations. 28
Figure 14: The basic structure of a Maucha diagram. 29
Figure 15: Maucha diagram example. Comparison between two waters. 30
Figure 16: Piper diagram example. Relative concentrations in meq/ℓ of major ions. 32
Figure 17: Piper diagram example. Classification of major ion types. 32
Figure 18: Expanded Durov diagram. 33
Figure 19: Time series graph example. Concentrations at site X. 35
Figure 20: Exceedence diagram example: Concentration. 36
Figure 21: Box-and-Whisker graph example: Concentration percentiles at site X over time. 36
Figure 22: Box-and-Whisker graph example: Concentration percentiles along river X in 2005. 37
Figure 23: Flow-concentration graph example. Concentration versus flow at site X in 2005. 37
Figure 24: Vertical profile graph example. Temperature profile as a function of depth. 38
Figure 25: Map example. Coloured symbols showing water quality status at single locations. 43
Figure 26: Map example. Coloured river reaches showing water quality status. 43
Figure 27: Map example. Coloured river reaches showing changes in concentrations over time. 44
Figure 28: Map example. Google Earth used to present chemical data. 45
Figure 29: The metal elements (bold) and non-metal elements (not bold). 79
Figure 30: The relative size ranges of microorganisms. 87
Figure 31: Mode, median and mean of symmetrical and skewed distributions. 90
Figure 32: Example frequency distribution for TDS (mg/ℓ) data. 91
Figure 33: Example cumulative frequency distribution for TDS (mg/ℓ) data. 91

Figure 34: Independent and dependent variables in a graph. 92
Figure 35: How to interpret the steepness of a graph. 93
Figure 36: How to interpret a positive and negative slope in a graph. 93
Figure 37: Comparison of normal and logarithm axes. 94

LIST OF TABLES

Table 1: The suitability (Hi=high or Lo=low) of various media for specified attributes. 6
Table 2: The suitability (Hi=high or Lo=low) of various tools for specified media and attributes...... 8
Table 3: Primary data example. pH and concentrations (mg/ℓ) at site X for 2005. 16
Table 4: Indicator example. Chemical quality as percentage of the total length of rivers. 20
Table 5: Constituent concentration dataset for chart examples. 24
Table 6: Icons example. SASS (macroinvertebrates), water quality status and fish. 40
Table 7: Recommended minimum widths for legibility of point symbols on maps. 42
Table 8: Table example. Total dissolved solids and hardness on 12-Dec-2006 at site X. 50
Table 9: Some common elements and their names. 79
Table 10: Some common cations and their names. 80
Table 11: Some common anions and their names. 80
Table 12: Recommended general assessments of microbial analyses. 88
Table 13: TDS data used for graphs of frequency distributions. 90

WATER QUALITY ACRONYMS

Use acronyms sparingly. When you do, ensure they are defined in your communication.

ADI	Acceptable Daily Intake
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
ED	Electrodialysis
EDC	Endocrine Disrupting Compound
EDTA	Ethylenediamine Tetra-acetic Acid
HPLC	High Performance Liquid Chromatography
ISO	International Standards Organisation
LC	Lethal Concentration
MFC	Membrane: Faecal Coliforms
MS	Mass spectrometer
NOAEL	No Observed Adverse Effect Level
NTU	Nephelometric Turbidity Unit
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutant
QA	Quality Assurance
QC	Quality Control
RQO	Resource Quality Objective
RWQO	Resource Water Quality Objective
SABS	South African Bureau of Standards
SANS	South African National Standard
SD	Secchi Disk (depth in metres)
SOB	Sulphate Oxidising Bacteria
SRB	Sulphate Reducing Bacteria
TAL	Total Alkalinity
TDS	Total Dissolved Salts
THM	Trihalomethane
TOC	Total Organic Carbon
TWQR	Target Water Quality Range

Manual Roadmap

Chapter 2: How to use this manual	*This chapter describes where to find information in this manual.*
Chapter 3: General recommendations	*This chapter provides recommendations that apply to all communication media and tools.*
Chapter 4: Data categories (primary data, summary stats, indices)	*This chapter describes the characteristics of three kinds of data you can communicate*
Chapter 5: Communication tools (graphs, maps, etc.)	*This chapter describes the tools that can be used to present the data (dos and don'ts, etc.)*
Chapter 6: Communication media (web sites, radio ads, etc.)	*This chapter describes the communication media that can be used (pros and cons, etc.)*
Chapter 7: Scenario-specific recommendations	*This chapter makes recommendations for some specific kinds of reporting*
Chapter 8: Understanding a water quality communication (guidelines, chemistry, biotoxicology, microbiology, statistics, graphs)	*This chapter provides some basics to help readers understand what is being communicated*

CHAPTER 1: BACKGROUND

In the context of water quality monitoring it is the users of the data that determine the actual value of the data. However, this value can also be limited by the technical capabilities of those who produce it. In practice, the actual value is therefore determined by three distinct stages (although they do not necessarily occur consecutively):

1. The **design** of the monitoring programme (*i.e.* the decisions made on what to monitor, where, when, how and by whom),
2. The **implementation** of the programme to the point of producing the primary data, and
3. The **reporting**, namely the exposure of the user to the data, or an assessment of the data, and the application of that data.

Stages 1 and 2 only provide potential value, not actual value, since no value can be realised without the user. This manual does not address stages 1 and 2 directly. It is concerned with stage 3. It is the effectiveness of stage 3 that determines the degree to which the potential value (established by stages 1 and 2) is actually achieved. Actual value, as perceived by the users, attains the potential value if and only if stage 3 is totally effective.

Accordingly, this introductory (not exhaustive) manual provides recommendations for optimum transfer of water quality data (the series of observations or measurements) and information (the meaning given to data by the way it is interpreted) to targeted users. It is aimed at all those who supply water quality data and information to others and at those who may receive such communications. This may be at a local level or a national strategic level. Educators and trainers in the water field are also possible users. The following are typical target readers:

- Department of Water Affairs and Forestry (DWAF);
- Water Management Institutions (WMIs) like Catchment Management Agencies (CMAs);
- Department of Health (DoH);
- Water Services Authorities (WSAs);
- Provincial and local government authorities;
- Parliamentarians;
- Non-Government Organisations (NGOs);
- All industrial sectors;
- Educators and trainers; and
- Water users.

The manual suggests what media (web sites, hard-copy reports, etc.) can be used and what tools (graphs, maps, tables, etc.) are most appropriate. The manual does not assume much technical expertise in the reader. However, it deliberately assumes a very wide range of competence in the possible target audience of transferred water quality data and information.

Reference is made to national and international recommendations whenever appropriate. However, it is acknowledged that a degree of subjectivity is involved in some of the recommendations. Nevertheless, the reader is encouraged to adhere to the recommendations for purposes of standardisation. There may be some circumstances in which it may be inappropriate to do so. If good reasons exist (that are not purely subjective), then other approaches should be used.

For more background information on the research performed that culminated in this manual see the associated research report (Communicating water quality data and information: Research Report. Murray K, Dabrowski J, Hill L, Du Preez M, Kadiaka M, Strydom W (2009). Water Research Commission).

CHAPTER 2: HOW TO USE THIS MANUAL

This chapter describes where to find information in this manual.

2.1 FINDING INFORMATION

This manual is designed to:

- Cater for a number of specific reporting situations in some depth, and
- Cater for a very wide variety of other situations.

The following sequence of questions and instructions will help you decide where you will find information:

1. Do you want initial recommendations on the best communication media to use?

If so, first use **Table 1** in this chapter and then answer the questions from no. 3 onwards.

2. Do you want initial recommendations on the best communication tools for specified media?

If so, first use **Table 2** in this chapter and then answer the questions from no. 3 onwards.

3. Do you want any of the following general recommendations?

- Guiding principles of good communication.
- An outline of basic technical writing standards.
- How to handle accuracy and precision.
- How to round numbers correctly.

If so, go to **CHAPTER 3: GENERAL RECOMMENDTIONS**

4. Do you want to better understand the types of data that can be communicated, like the following?

- Primary data.
- Summary statistics.
- Indices.

If so, go to **CHAPTER 4: DATA CATEGORIES**.

5. Do you want information on individual communication tools, like the following?

- Charts.
- Diagrams.
- Graphs.
- Icons.
- Maps.
- Photographs.
- Short stories.
- Tables.

If so, go to **CHAPTER 5: COMMUNICATION TOOLS**.

6. Do you want information on communication media, like the following?

- Billboards.
- Brochures.
- Emails.
- Exhibitions.
- Newspapers.
- Popular articles.
- Posters.
- Radio.
- Technical reports.
- Television.
- Verbal presentations.
- Water accounts.
- Web sites.

If so, go to **CHAPTER 6: COMMUNICATION MEDIA**.

7. Is your situation one of the following?

- Catchment assessment.
- State of aquatic environment.
- State of drinking water.
- National monitoring programmes.
- Performance monitoring of RQOs.
- Compliance monitoring.

If so, go to **CHAPTER 7: SCENARIO-SPECIFIC RECOMMENDATIONS**.

8. Do you want to communicate basic concepts that may help less-technical readers better understand your message, like the following?

- Water quality guidelines
- Basic chemistry.
- Basic biotoxicology.
- Basic microbiology.
- Basic statistics.
- Basic graph interpretation.

If so, go to **CHAPTER 8: UNDERSTANDING A WATER QUALITY COMMUNICATION**.

2.2 IDENTIFYING SUITABLE MEDIA

A simple Excel spreadsheet facility is available based on **Table 1** and **Table 2**. It also provides initial general guidance on the best media and tools based on the attributes in the tables. However, the tables below are also easy to use without the spreadsheet facility.

1. In **Table 1** choose the one **attribute** in the top row (keeping costs down, regular reporting, etc.) that is most important to you.

2. Look for "**High**" suitability in the column of that attribute.

3. Note the corresponding "**recommended media**" listed in the first column.

4. Carefully read, consider and compare the advantages and disadvantages of the media (see **CHAPTER 6: COMMUNICATION MEDIA**). Explore any further reading if necessary. Also re-examine **Table 1** to assess the suitability to other possible media.

5. Having chosen a possible medium, then:
   a. Examine its dos and don'ts (also in **Chapter 6**).
   b. Use **Table 2** to establish the recommended tools (graphs, maps, etc.) appropriate for that medium.

Table 1: The suitability (Hi=high or Lo=low) of various media for specified attributes

RECOMMENDED MEDIA	ATTRIBUTES: *Keeping costs down*	*Regular reporting*	*Reaching technical audiences*	*Reaching non-technical audiences*	*Reaching large audiences*	*Reaching targeted audiences*	*Conveying detail*	*Conveying very large datasets*	*Controlling quality of final product*	*Permanence of message*	*Engaging the target audience*	*Obtaining feedback*	*Urgent messages*
Billboards	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Hi	Lo	Lo	Lo	Hi
Brochures	Hi	Lo	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo
Email attachments	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Lo	Hi	Hi
Email messages	Hi	Hi	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Hi	Hi
Exhibitions	Lo	Lo	Hi	Hi	Lo	Hi	Hi	Lo	Hi	Lo	Hi	Hi	Lo
Newspaper ads	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Hi
Newspaper articles	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Lo	Hi	Lo	Lo	Hi
Popular articles	Hi	Lo	Lo	Hi	Lo	Lo	Lo	Lo	Lo	Hi	Lo	Lo	Lo
Posters	Hi	Lo	Hi	Hi	Lo	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo
Poster presentations	Hi	Lo	Hi	Hi	Lo	Hi	Lo	Lo	Hi	Lo	Hi	Hi	Lo
Radio ads	Hi	Lo	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Lo	Lo	Lo	Hi
Radio interviews	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Hi
Technical reports	Hi	Hi	Hi	Lo	Hi	Hi	Hi	Lo	Hi	Hi	Lo	Lo	Lo
Television ads	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Hi	Lo	Lo	Lo	Lo
Television interviews	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Hi
Verbal presentations	Hi	Lo	Hi	Hi	Lo	Hi	Lo	Lo	Hi	Hi	Hi	Hi	Lo
Water accounts	Hi	Hi	Lo	Hi	Hi	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Lo
Web sites	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Lo	Hi	Hi

2.3 IDENTIFYING SUITABLE TOOLS

1. In **Table 2** choose the **medium** (billboards, brochures, etc.) or **attribute** in the top row (regular reporting, etc.) that is most important to you.

2. Look for "**High**" suitability in that column.

3. Note the corresponding "**recommended tools**" listed in the first column.

4. Carefully read, consider and compare the advantages and disadvantages of the tools (see **CHAPTER 5: COMMUNICATION TOOLS**). Explore any further reading if necessary. Also re-examine **Table 2** to assess the suitability of other possible tools.

5. Having chosen a possible tool, then:
    a. Examine its practical and aesthetic dos and don'ts (also in **Chapter 5**).
    b. Use the examples for guidance.

Table 2: The suitability (Hi=high or Lo=low) of various tools for specified media and attributes

	MEDIA																		ATTRIBUTES						
RECOMMENDED TOOLS	***Billboards***	***Brochures***	***Email attachments***	***Email messages***	***Exhibitions***	***Newspaper ads***	***Newspaper articles***	***Popular articles***	***Poster presentations***	***Posters***	***Radio ads***	***Radio interviews***	***Technical reports***	***Television ads***	***Television interviews***	***Verbal presentations***	***Water accounts***	***Web sites***	***Regular reporting***	***Reaching technical audiences***	***Reaching non-technical audiences***	***Conveying detail***	***Conveying very large datasets***	***Conveying statistics***	***Urgent messages***
Charts	Lo	Hi	Hi	Lo	Hi	Hi	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Lo	Lo	Hi	Hi	Hi	Lo	Hi	Lo	Hi	Hi
Graphs	Lo	Hi	Hi	Lo	Hi	Hi	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Hi	Lo	Hi	Hi	Hi	Lo	Hi	Lo	Lo	Hi
Diagrams	Lo	Hi	Hi	Lo	Hi	Lo	Lo	Lo	Hi	Hi	Lo	Lo	Hi	Lo	Lo	Hi	Lo	Hi	Hi	Hi	Lo	Hi	Hi	Lo	Lo
Icons	Hi	Hi	Hi	Lo	Hi	Hi	Hi	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Hi	Hi	Hi	Hi	Hi	Hi	Lo	Lo	Hi	Hi
Maps	Lo	Hi	Hi	Lo	Hi	Hi	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Hi	Lo	Hi	Hi	Hi	Lo	Hi	Lo	Hi	Hi
Photographs	Hi	Hi	Hi	Lo	Hi	Hi	Hi	Hi	Hi	Hi	Lo	Lo	Hi	Hi	Lo	Hi	Lo	Hi	Lo	Lo	Hi	Lo	Lo	Lo	Hi
Short stories	Lo	Lo	Hi	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Hi	Lo	Lo	Lo	Lo
Tables	Lo	Hi	Hi	Lo	Hi	Lo	Lo	Hi	Hi	Hi	Lo	Lo	Hi	Lo	Lo	Hi	Lo	Hi	Hi	Hi	Lo	Hi	Hi	Lo	Hi

CHAPTER 3: GENERAL RECOMMENDATIONS

This chapter provides recommendations that apply to all communication media and tools.

3.1 COMMUNICATION PRINCIPLES

- **Keep it standard**. Only deviate from standard ways of doing things when:
  - They are convincingly better than existing simple and standard methods, and
  - They address the needs of target users more appropriately.
- **Keep it simple**. The simplest messages are often the most powerful and memorable.
- **Keep it sound**. Ensure your message is soundly scientific (*i.e.* logical and defensible), even in storytelling.
- **Keep it concise**. Use as few words as possible to communicate your message but make sure that it remains clear.
- **Keep it relevant**. Stick to the point of the message you wish to communicate.
- **Keep it targeted**. Tailor your message, media, and tools to the target user. Remember that one size does not fit all.
- **Keep it honest**.
  - Include data and information that communicate a balanced and accurate message.
  - If you know decisions might be based on your communication, ensure that the decision maker can make a truly informed decision.
  - Always acknowledge sources of data, images, text, etc. that are not your own. Do not infringe copyright.

3.2 BASIC WRITING STANDARDS

- **Use an appropriate writing style**. Use a writing style you are certain your target user will be comfortable with.
- **Cater for less-educated users**. For target users with a low level of education, use:
  - Short sentences, and
  - Short words (*i.e.* with few syllables).
- **Focus on "reading ease"**. Use the Flesch Reading Ease Score if possible to check readability of text (see http://en.wikipedia.org for more information). Word processors like Microsoft Word include this facility (use the Help facility to find it). The following shows the scores and education levels of the people who should understand the text easily:
  - 0-30: University graduates.
  - 60-70: Secondary school education.
  - 90-100: Primary school education
- **Cater for non-technical users.** For target users with limited technical expertise don't use jargon or acronyms.
- **Use a spelling checker**.
  - Use the spelling and grammar checker provided with the word processor. However, don't necessarily believe everything it says.
  - Choose a language and be consistent. Choose either English (South Africa) or English (U.K.). Remember that most words ending in "ize" should be "ise", and that color is colour.

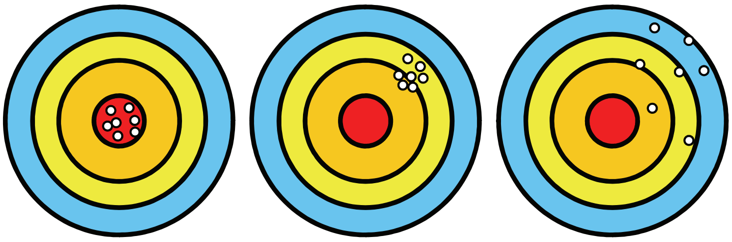
- **First, Secondly, Thirdly**. (First isn't Firstly.)
- **Use acronyms with care**. To avoid any misunderstanding of acronyms:
  - Don't automatically invent new acronyms.
  - In reports, include a list of acronyms if appropriate, or
  - Spell out the full term and put the acronym in parentheses *e.g.* total dissolved salts (TDS).
- **Use double quotes**. Use double quotes only when quoting what someone has said or written (don't use single quotes). However, don't overuse double quotes.
- **Italicise to emphasise**. To emphasise words, use italics. (Don't underline, bold or capitalise.)
- **Italicise foreign words**. For example, *et al.*
- **Following scientific naming conventions:**
  - **Italicise all scientific names**. For example, "*Escherichia coli* (*E. coli*) is a bacterium species in the *Enterobacteriaceae* family".
  - **Start all except species and variety with a capital letter**. In other words, capitalise kingdom, phylum or division, class, order, family and genus names.
- **Use correct plurals**.
  - Note in particular the following singular-plural pairs: bacterium-bacteria, datum-data (NB: "the datum is", "the data are"), genus-genera, medium-media, species-species, taxum-taxa.
  - For all capital abbreviations or acronyms, form the plural by adding "s". For example, RQOs (not RQO's).
  - One page is "p.", many pages are "pp." One species is "sp.", many species are "spp.".
- **Use appropriate units**.
  - **Use familiar units**. Use units that are readily understandable by, and preferably familiar to, the target user.
  - **Preferably use mg/ℓ for concentrations**. Alternatively use mg/L. Don't use mg/l.
  - **Space the unit**. Put a space between the number and its unit (*e.g.* 15 mg/ℓ).
- **Use numbers correctly**.
  - **Spell out numbers under 10**. For example, "On the first day, 15 samples were taken at three monitoring sites". The exceptions are when they are used as page numbers, figure and table numbers or with units of measurement.
  - **Spell out numbers when they start a sentence**. For example, "Fifteen samples were taken at three monitoring sites".
  - **Use a singular verb with quantities**. For example, "then 800 ml was added" (not "were added".
- **Use chemical formulae with care**. Don't use chemical formulae unless you are certain the target user will be familiar with them. If necessary, spell out chemical names (*e.g.* calcium carbonate), or use the name and the formula (*e.g.* calcium carbonate ($CaCO_3$)).
- **Report statistics accurately**.
  - Do not describe differences that are not statistically significant as "insignificant".
  - Do not use the term "significant" to describe results when no statistical tests were run and you merely mean "important".

Matthews *et al.* (1996), Morgan (2005), Truss (2003).

3.3 ACCURACY AND PRECISION

Much of the following is taken from http://en.wikipedia.org.
The reader is strongly encouraged to explore this site for more detailed information.

Accuracy is how close a measured or estimated value is to the true (actual) value. *Precision* is the degree to which further measurements or calculations show the same or similar results. **Figure 1** illustrates the difference using a target analogy. The "true value" is represented by the bull's eye.



Accurate and precise | **Inaccurate but precise** | **Inaccurate and imprecise**

Figure 1: The difference between accuracy and precision

Precision is related to the following:

- Repeatability, the variation arising when all efforts are made to keep conditions constant by using the same instrument and operator, and repeating during a short time period.
- Reproducibility, the variation arising using the same measurement process among different instruments and operators, and over longer time periods.

It is common to express accuracy and / or precision implicitly by means of *significant figures*. The significant figures (also called *significant digits* and abbreviated *sig figs*) of a number are those digits that carry meaning (or contain information) contributing to its accuracy. For example, expressing a number as 43.6 units, or 43.0 units, or 40.0 units would imply a margin of error of 0.05 units (the last significant place is the tenths place). A number expressed as 42 units implies a margin of error of 0.5 units.

Note that the number 43.6 has three significant figures, the "4", "3", and the "6". The number 0.00436 also has three significant figures. However, a number expressed as 8000 is ambiguous because the trailing zeroes may or may not be significant. In this case, use scientific notation. For example, 8.00×10^3 indicates that there are three significant figures.

If the error (uncertainty) in a number is known to be 0.01 units, a measurement of, say, 6.4383 units would then be reported as 6.44 units. Only significant figures in the measured value should be reported. In this example, the digits "83" contain no information since they are beyond the ability of the method to measure.

To minimise problems associated with rounding to a certain number of significant figures, the uncertainty in a number can be reported explicitly. It is also safer to do so because unintended rounding errors are not introduced. For example, if the standard deviation is known to be 0.034 then report a number such as 6.4383 as 6.438(0.034).

Be careful to avoid so-called pseudo-precision when reporting percentages. When a percentage refers to a number of objects (*e.g.* number of monitoring sites), always report the number from which the percentage is determined. For example, if area A had three of five sites reporting pH within guideline levels and area B four such sites, reporting 60% and 80% respectively (without mentioning these values come from 3 of 5 and 4 of 5) can give a very misleading impression of the difference in the two areas.

3.4 ROUNDING

Careful attention should be given to rounding numbers when presenting water quality data. The simple act of rounding communicates an extremely important kind of information to the reader. Getting it wrong can convey an entirely inappropriate message.

Rounding is the process of reducing the number of significant digits in a number. The result of rounding is a shorter number having fewer non-zero digits yet similar in magnitude. The result is less precise but easier to use. For example, 73 rounded to the nearest ten is 70, because 73 is closer to 70 than to 80.

The following are the most commonly-used rounding rules, however, it might be noted that another set of rules can also be used that minimises the possible bias introduced by these rules (see Wikipedia):

- Decide which is the last digit to keep. This will depend on the uncertainty of the number (which is related to its accuracy and precision).
- Increase it by 1 if the next digit is 5 or more (this is called rounding up)
- Leave it the same if the next digit is 4 or less (this is called rounding down)

One can round to a certain number of significant figures or to a certain number of decimal places. For example:

- 3.044 rounded to two decimal places is 3.04 (because the next digit, 4, is less than 5).
- 3.045 rounded to two decimal places is 3.05 (because the next digit, 5, is 5 or more).
- 3.0447 rounded to two decimal places is 3.04 (because the next digit, 4, is less than 5).

Values expressed as, for example, thousands can also be rounded to give fewer non-zero digits, as follows:

- 6 148 rounded to three significant figures is 6 150.
- 6 148 rounded to two significant figures is 6 100.
- 6 148 rounded to one significant figure is 6 000.

If such a number only has, say, two significant figures then the number should be rounded. Don't display the number as, for example, 6 148 which, as noted above, implies that there are four significant figures. Furthermore, the number 6 100 is much easier to read and interpret than 6148, making communication not only more effective (*i.e.* correct) but also more efficient.

There is one important context in which rounding should be either avoided or applied with particular care. Do not round numbers if the numbers are to be used subsequently for further numerical processing. When rounding numbers one can introduce small so-called rounding errors. For example, an original 3.55 may be rounded to 3.6 and, as a result, have a small error introduced. Rather avoid the possibility of introducing any error by not rounding it in the first place. Your best estimate of the true value is the actual measurement, not the rounded measurement. If someone intends to subject the dataset to an analysis (*e.g.* for determining summary statistics), then ideally these small potential rounding errors should be avoided so that the analysis is not affected by them in any possible way. If the numbers need to be rounded for some reason, include at least one extra figure beyond the number considered significant based on the error.

3.5 IMPORTING IMAGES

Once a chart or map has been produced, it is often necessary to include it in a word processing file. The following are some of the options available.

- **Inserting a graphics file only (recommended)**. Save the chart or map as a graphics file (*e.g.* .wmf, .emf, .jpg, etc.) then insert that file into the word processing file. This file is then independent of the original programme that produced the image. To make changes to the image the original programme must be used independently and the image re-saved as a graphics file and then re-imported.
- **Inserting a graphics file with link**. Insert the graphics file and a link to the location of the file. In this way, when the graphics file is updated using the original programme that produced it, the image is automatically updated in the word processing document.
- **Inserting a link only**. Insert only the link to the graphics file. While this minimises the size of the word processing file, this has the danger that when the word processing file is transmitted, it may be sent without the graphics file.
- **Copying and pasting**. The original copied chart or map is pasted directly into the word processing file. This embeds the image in the file in such a way that one can edit the image automatically using the programme used to produce it.

What kind of graphics file should be inserted into the word processing file depends on a number of factors:

- Whether it is black and white or colour;
- The simplicity of the image;
- The size of the image file;
- The practical maximum size of the final main file; and
- The required resolution of the image in the main file (which will depend on the printing process).

The following are some basic recommendations for this process:

- Decide on:
  The practical maximum size of the final main file; and
  The kind of resolution required in the main file.
- Save the main file and note its size in megabytes. After importing any image, save again and note the size. The difference gives the effect on the main file size of the image you have imported. Use this is one indicator of the suitability of the file type you have chosen.
- Use a Windows Metafile for very simple black and white images. This usually gives a sharp image and the size of the file is small.
- If a Windows Metafile is not satisfactory, and the image is fairly simple (even with some colour) then try an Enhanced Windows Metafile.
- If neither a Windows Metafile nor an Enhanced Windows Metafile works (*i.e.* the resolution is not good enough and / or the file is too large) then try other file types like:
  Graphics Interchange Format (.gif);
  Portable Network Graphics Format (.png);
  Joint Photographic Expert Group (.jpg);
  Tagg Image File Format (.tif); or
  Bitmap (.bmp).
- Choose the one that gives you adequate resolution and the least increase in main file size.

CHAPTER 4: DATA CATEGORIES

This chapter describes the characteristics and pros and cons of three kinds of data you can communicate.

4.1 INTRODUCTION

An important consideration when communicating water quality data is the degree of "integrative processing" to subject the data to. There are three basic levels:

1. **Minimal integrative processing**. This essentially amounts to presenting the primary ("raw") data of any number of water quality variables.
2. **Intermediate integrative processing**. This typically involves presenting basic summary statistics of the primary data for individual water quality variables.
3. **Highly integrative processing**. This involves calculating aggregated values from the primary data of many water quality variables, often called indices (or indicators).

In effect, these levels represent different degrees to which the data disseminator may add value to the primary data. The optimal degree depends on a number of factors including the technical competence of the target users, how specific their needs are, and their need for further numerical processing of the data.

4.2 GLOSSARY

Accuracy. How close a measured or estimated value is to the true value. (See ***Precision***.)
Analytical method. An experimental technique used to determine, for example, the concentration of a water quality constituent.
Data. A series of observations or measurements.
Data quality. The accuracy and precision of data determined by the observation or measurement method.
Index / Indicator. A characteristic (possibly simplified) of a system that provides a means of communicating information about status and trends in that system.
Information. The meaning given to data by the way it is interpreted.
Invertebrate. An animal lacking a backbone and internal skeleton.
Macroinvertebrate. Invertebrates visible to the naked eye.
Outlier. A value so far removed from the other values that it is likely to be in error.
Precision. The degree to which further measurements or calculations show the same or similar results. (See ***Accuracy***.)
Spatial. Relating to area or distance.
Temporal. Relating to time.

4.3 PRIMARY DATA

Characteristics

- The results presented to the target user comprise detailed numerical datasets or observations that show directly how the measurements of selected water quality variables or characteristics vary over time or space.
- The data may be original laboratory or field measurements and observations.
- The data themselves are at least assessed in ways to establish their quality. This may be done by:

  Ensuring that the correct data collection procedures were followed in the laboratory or in the field (a quality control process); and / or

  Performing numerical analyses that test the reasonableness of the data and possibly remove outliers (though this should only be done for good reasons).
- The data may be assessed against water quality guidelines or standards (see Section 8.2). However, the primary data are presented with the point-by-point assessment.
- Most effectively presented in tables (*e.g.* **Table 3**) and time series graphs (see for example Section 0) if there are not too many points. The graph can also display water quality guideline values for easy visual comparison. Maps and icons are not appropriate.
- No assessment of the data is undertaken to produce any mathematical summary statistics. If this is required, it is left to the target user.
- Large primary datasets (for example comprising many water quality variables over decades) are typically presented in electronic form (in a spreadsheet or database).

Advantages

- Suitable for a target audience with high technical competence in water quality who typically will wish to analyse and assess the data themselves.
- Relatively simple to prepare because the data disseminator does not have to make any decisions about what statistics of indices are most appropriate.

Disadvantages

- Not suitable for a target audience with low technical knowledge.
- Supplying simple numbers to an incompetent or unscrupulous target user can result in unscientific conclusions being drawn which can cause undue problems.

Dos and don'ts

- **Describe analytical methods**. Include an adequate description of the analytical methods used to measure the data so that the target user can establish the degree to which the method determines the quality of the data.
- **Distribute in electronic form**. Ensure your database has facilities to extract (export) selected datasets into convenient forms like spreadsheets or space- or comma-delimited files.
- **Don't round numbers unnecessarily**. Don't introduce rounding errors especially when the data are going to be subjected to analysis, for example, for summary statistics. (See Section 3.4.)
- **Minimise the use of printed tables**. Large tables in reports can be extremely bulky, even if relegated to an appendix. If the primary data are likely to be required, consider supplying them on a CD, a web site or attached to an email.

Table 3: Primary data example. pH and concentrations (mg/ℓ) at site X for 2005.

Date	pH	Fluoride	NH_4(N)	NO_3(N)	TDS
06-Jan	8.01	0.3	0.03	0.06	161
13-Jan	7.74	0.3	0.09	0.24	138
20-Jan	7.77	0.3	0.08	0.39	163
27-Jan	7.87	0.2	0.02	0.06	162
03-Feb	7.70	0.2	0.02	0.17	175
10-Feb	8.02	0.2	0.02	0.13	167
17-Feb	7.95	0.3	0.02	0.04	190
24-Feb	7.91	0.3	0.06	0.16	181
03-Mar	7.74	0.2	0.02	0.12	166
10-Mar	7.60	0.2	0.06	0.15	149
17-Mar	8.00	0.2	0.06	0.10	134
24-Mar	8.01	0.2	0.08	0.15	169
31-Mar	7.81	0.2	0.05	0.11	145
07-Apr	7.83	0.3	0.02	0.09	196
14-Apr	7.97	0.2	0.02	0.17	176
21-Apr	7.64	0.2	0.02	0.10	197
28-Apr	7.98	0.2	0.02	0.15	214
05-May	7.90	0.3	0.02	0.04	233
12-May	8.06	0.2	0.02	0.04	232
19-May	8.19	0.2	0.19	0.04	246
26-May	8.03	0.2	0.02	0.08	250
02-Jun	8.30	0.2	0.02	0.04	262
09-Jun	8.25	0.2	0.02	0.04	279
16-Jun	8.16	0.3	0.02	0.04	283
23-Jun	8.34	0.2	0.04	0.04	297
30-Jun	8.17	0.2	0.05	0.04	299
07-Jul	8.15	0.2	0.02	0.04	296
14-Jul	8.18	0.3	0.07	0.04	322
21-Jul	8.21	0.2	0.06	0.04	318
28-Jul	8.24	0.2	0.12	0.04	330
04-Aug	8.01	0.3	0.02	0.04	329
11-Aug	8.31	0.2	0.05	0.04	323
18-Aug	8.28	0.2	0.02	0.13	315
25-Aug	8.47	0.2	0.02	0.09	339
01-Sep	8.30	0.2	0.02	0.04	337
08-Sep	8.39	0.2	0.02	0.04	345
15-Sep	8.50	0.2	0.02	0.04	329
22-Sep	8.47	0.3	0.02	0.04	357
27-Oct	8.50	0.3	0.02	0.04	376
03-Nov	8.34	0.3	0.02	0.04	403
10-Nov	8.01	0.4	0.06	0.73	166
17-Nov	7.41	0.3	0.11	0.63	123
24-Nov	7.95	0.2	0.02	0.04	123
07-Dec	7.98	0.3	0.02	0.04	145
08-Dec	7.89	0.2	0.07	0.45	182
15-Dec	8.03	0.2	0.02	0.17	194
22-Dec	8.17	0.3	0.02	0.08	239
29-Dec	7.33	0.3	0.06	0.55	195

4.4 SINGLE-VARIABLE SUMMARY STATISTICS

Characteristics

- Applies to a single water quality variable, for example, pH, calcium concentration, etc.
- Results are presented as a series of statistics (see Section 8.6) such as:
  - Averages / means;
  - Standard deviations;
  - Medians;
  - Minima, maxima, and ranges;
  - Percentiles, and
  - Numbers of samples.

Advantages

- The information contained in a large primary dataset is easily summarised, communicated and understood by a wide target audience.
- Statistics can smooth the noise in primary data and make the data more understandable.
- They can provide good order of magnitude representations of the primary data.
- Statistics such as averages, medians and 90th percentiles can easily be assessed against water quality guidelines or standards (see Section 8.2).
- Statistics can integrate data over different temporal scales (*e.g.* from daily to annual) and spatial scales (*e.g.* from river reach to catchment).

Disadvantages

- Assessments of the overall water quality status (which depends on many variables) may be difficult for non-experts to deduce because the statistics are reported per variable.

Dos and don'ts

- **Provide a reference to the primary data when appropriate**. If the possibility exists that some target users may wish to examine the primary data themselves, advise them on how to obtain the data.
- **Don't communicate inappropriate messages**. For example, averages, while well-defined, may be less appropriate in Africa where water resources can be dominated by extreme conditions varying from droughts (involving possibly no flow at all) to floods. Use averages with care.
- **Use tables for many variables at many sites**. Summary statistics for many variables at many sites are usually best presented in tables (see Section 5.10). Graphs are usually inappropriate.
- **Use graphs for one variable**. Some statistics for single variables can be well presented in graphs. See, for example, Section 0, **Figure 21** and **Figure 22)**.
- **Consider pie charts when there are a few variables**. A pie chart (*e.g.* **Figure 2**) can be used on a map (*e.g.* **Figure 3**) (Hohls *et al.*, 2002). (See Section 5.3 for another kind of pie chart.) A concentration (like the median) is depicted in a pie wedge. It projects beyond the circular pie only when the concentration falls outside of the "Very Good" range for domestic use. The extent to which it projects indicates the extent of deviation from the "Very Good" range. The colour also classifies the water quality as natural (blue), moderate (green) or poor (red).
- **Also consider Maucha diagrams**. These are useful for displaying concentrations of the major ions. See Section 5.4.1.

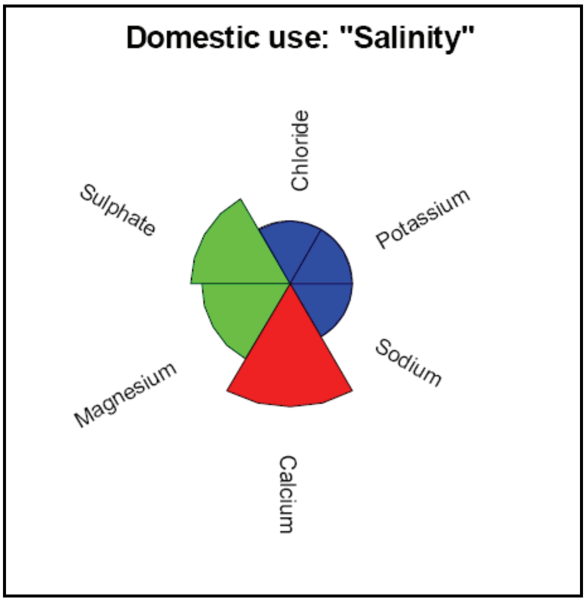


Figure 2: Summary statistics example. Pie chart indicating comparison with "Very Good" water quality.

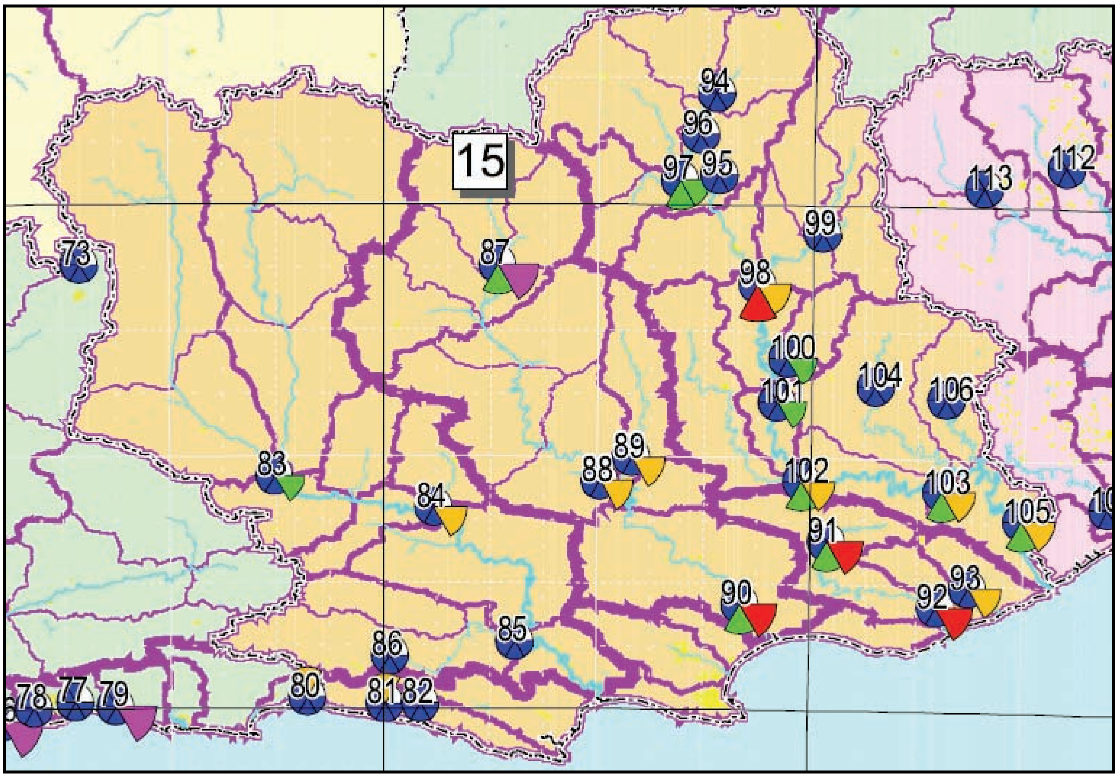


Figure 3: Summary statistics example. Pie charts on a map with numbers identifying the monitoring site.

4.5 MULTIPLE-VARIABLE INDICES

Characteristics

- An index is a single indication (*e.g.* number, phrase, word, letter, size, symbol, or colour) of an overall assessment of water quality.
- It typically contains the information, sometimes summary statistics, of many water quality variables.

Advantages

- An index can combine various measurements of a variety of variables.
- It can combine measurements in different units (*e.g.* pH and mg/ℓ).
- It can provide a useful summary of overall water quality status and trends.
- Indices can be made easily understandable by non-technical people.

Disadvantages

- A significant criticism of indices is the loss of detailed information on the variables and statistics contributing to them. In effect they can easily oversimplify. This can make them misleading especially to the uninformed.
- There is loss of information on interactions between variables.
- Indices can be very sensitive to the methods used to calculate them.
- A method used in one context (say for fish or macroinvertebrates) is not easily used in another context (like water quality).

Dos and don'ts

- **Consider the pros and cons**. Carefully consider the above pros and cons before deciding to use an index. Do not use an index just because you can produce simple good-looking maps with it. It must communicate useful and unambiguous information.
- **Don't use too many categories**. Three or four categories are often sufficient. Three categories could simply be Good, Fair, Poor. The high degree of simplification (integration) of an index means that a high number of categories becomes meaningless.
- **Use icons and maps**. Icons are well suited to representing indices. Icons can also communicate effectively on a map. See for example **Figure 4** which shows the Integrated Ecological Assessment method used by the Queensland Environmental Protection Agency to provide a single rating of the current water quality at monitoring sites (QEPA, 2008).
  - Green = ecologically healthy / slightly impacted site;
  - Yellow = a slightly / moderately impacted site with some signs of ill-health;
  - Red = moderately / heavily impacted site.
- **Also consider tables**. The General Quality Assessment (GQA) method is used by the Environment Agency of the UK (EA, 2008). It allocates grades (A=very good to F=poor) for the overall water quality of monitored rivers (**Table 4**). It is presented as a percentage of the total river length (*e.g.* 20% of the length of river X has a water quality category of A).
- **Check out other examples**:
  - The calculation of the Ecological Category for water quality variables uses the Physico-Chemical Driver Assessment Index (PAI) (Kleynhans and Louw, 2007).
  - The CCME Water Quality Index adopted in Canada integrates numerous water quality variables to provide a single number representative of the water quality (CCME, 2006).

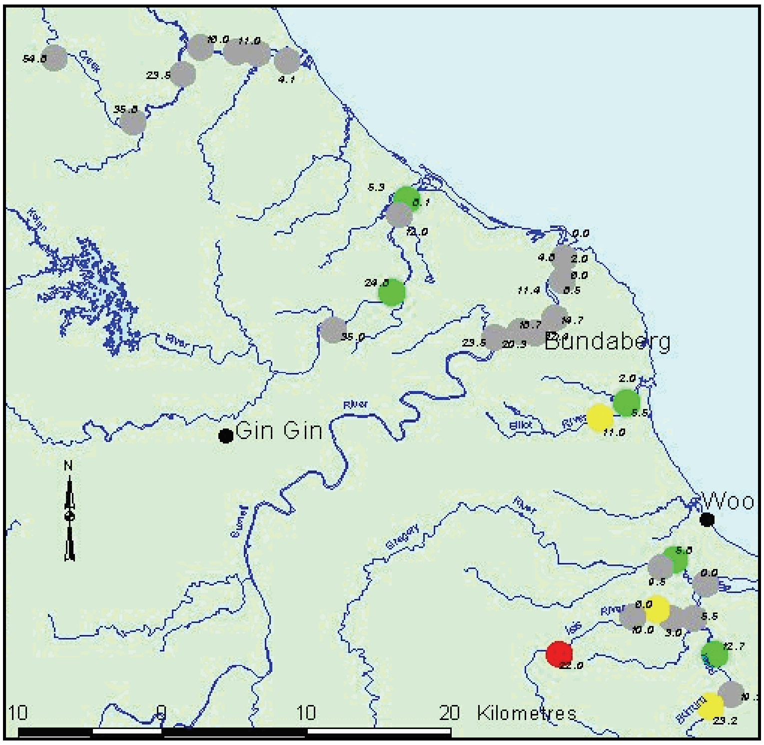


Figure 4: Indicator example: Overall water quality status on a map with numbers indicating concentrations.

Table 4: Indicator example. Chemical quality as percentage of the total length of rivers.

	Chemical quality						Length
	A	**B**	**C**	**D**	**E**	**F**	**(km)**
Anglian	12.1	35.2	27.5	14.5	10.4	0.2	4 803.2
Midlands	25.5	38.5	20.0	9.0	6.7	0.4	6 731.2
North East	32.0	40.5	15.4	6.8	4.8	0.5	6 187.7
North West	39.9	24.3	18.2	10.2	6.6	0.9	5 744.9
Southern	17.2	39.2	25.3	10.0	7.8	0.5	2 229.4
South West	44.2	39.0	10.6	3.3	2.9	0.0	6 063.1
Thames	25.5	38.6	18.9	9.6	7.0	0.4	3 807.7
Wales	78.0	17.4	2.1	0.7	1.7	0.2	4 776.7
England and Wales	35.7	33.8	16.7	7.7	5.8	0.4	40 606.4

CHAPTER 5: COMMUNICATION TOOLS

This chapter describes the tools that can be used to present data (dos and don'ts, etc.).

5.1 INTRODUCTION

"Scientific images satisfy our desire to see and understand complex phenomena. These idealized, attractive artificial objects can stand in for information; however, the creators of these images must balance persuasion with accuracy.

Some have considered this balancing act a design problem consequent to the scientific process, yet scientists continue to communicate visually to their peers and the public and to incorporate mental models into their work.

The nature and limitations of visualisation are more than a matter of design. Producers and consumers of visualisation must also address the interpretive and communicative power of scientific images in society."

Kallick-Wakker (1994)

Maps, graphs, charts and illustrations have helped people understand scientific data and concepts for centuries. However, the data are still often considered self-evident. Sometimes this is justified, sometimes not. The process of visualisation (*i.e.* forming some kind of mental image) does not leave the data intact. Typically, the data must be transformed several times before final images can be produced and each transformation requires a measure of subjective judgement (Kallick-Wakker, 1994).

Models of a scientific process are often visualised in the mind. Aesthetic qualities of a scientific visualisation such as simplicity, familiarity and visual completeness enhance the viewer's confidence in the underlying model (Kallick-Wakker, 1994). Visual insight has also been considered fundamental to problem solving. Mental images and models are commonly referred to as sources of inspiration and discovery in science. Mental images are also identified as the source of aesthetic pleasure that motivates research.

Schnotz (2002) has specifically noted that visual presentation of data can complement information conveyed in text. However, he also notes that an essential precondition is that such presentations interact appropriately with human visual perception and the individual's cognitive system, which is characterised by prior knowledge, cognitive abilities and learning skills. Therefore, the choice of data presentation or visualisation tool depends critically on the abilities of the target audience.

First and foremost, it is important that you (as the disseminator of data) have your message clear in your own mind. What is the point of your communication? What message do you want the target users to get? In a water quality monitoring context the message may be closely related to the original objectives of the monitoring.

When using this chapter also consider the following whenever a visualisation tool is produced:

- Does it present an accurate picture (or model) of the underlying data or aspects of the data? Equivalently, when considered on its own, does it present an unambiguous and clear message?
- Is it aesthetically pleasing?
- Does your intended audience have the necessary abilities to understand the image in the way you want it to be understood?

5.2 GLOSSARY

Continuous. Uninterrupted, like the actual change in pH in water. (Compare with ***Discontinuous***.)
Dependent variable. A variable that changes as another variable (typically an independent variable) changes. For example, pH, the concentration of calcium, or temperature. Always appears on the vertical axis of a graph. (See ***Independent variable***.)
Discontinuous. Discrete, like daily measured pH in water. (Compare with ***Continuous***.)
Icon. A picture or symbol with a single, unitary interpretation or meaning. In the context of computing it refers to a small image which embeds meaning (Richards *et al.*, 1994).
Independent variable. A variable that does not change as a function of another variable. For example, time or distance. Always appears on the horizontal axis in a graph. (See ***Dependent variable***.)
Log. Short for logarithm, the power to which 10 must be raised to give the number, *e.g.* log100 = 2 because $100 = 10^2$.
Metaphor. Language or a symbol that means something literally but which is actually used to mean something else. For example, "That person is a snake" or the mouse pointer hourglass icon in software packages that means a program is busy.
Trendline. A line plotted on a graph to indicate a trend usually over time.

5.3 CHARTS

Characteristics

- A chart depicts the relationship between sets of numbers or quantities by means of bars or pie sections.

Advantages

- Charts are useful for displaying proportions, rankings, and discrete distributions within a single dataset.
- Charts are useful for comparing different datasets.
- They make good use of the ability of our eye-brain system to perceive geometric patterns.
- Besides facilitating visual comparisons, they can also present actual numerical values.
- Many widely-used software packages exist that allow effective charts to be created.
- Charts are useful for displaying highly integrated data like summary statistics and indices.

Disadvantages

- Only useful for small datasets.

Practical dos and don'ts

- **Limit the number of values**. The number of values being displayed should be limited to about 6.
- **Consider black-and-white legibility**: If you use colour and you wish to ensure that black-and-white photocopies remain legible then ensure that the colours or patterns have sufficient contrast.
- **Link to the text***:* Ensure that the graph is explicitly referred to in the text. It helps to bold this reference (*e.g.* **Figure 4**). This helps readers locate the text that is directly relevant to the table.
- **Try to make the graph stand alone**: Ensure everything on the graph is explained, either in the graph caption, the legend, or in the text.

Aesthetic dos and don'ts

- **Avoid fancy effects**: Avoid unusual (fancy) effects like 3-D, shading, ribbon lines etc. They distract and increase clutter.
- **Don't clutter the text**: Too much text inside the plotting area may interfere with the reader's perception of patterns. Consider putting text outside the plotting area.
- **Frame graphs**: Frame each graph completely in a rectangular border.
- **Use gridlines sparingly**: Use only enough data labels and gridlines needed to get the message across.

(Ashton, 2007; Cleveland, 1984; Matthews *et al.*, 1996; Smartdraw, 2007; Vekiri, 2002)

5.3.1 Bar charts

Example data

Consider the hypothetical dataset in **Table 5**. The kind of chart you use to display this data depends critically on the message you wish to communicate or, equivalently, what aspect of the information the data provides you wish to bring to the attention of the target reader (Smartdraw, 2006).

Table 5: Constituent concentration dataset for chart examples

	Borehole A mg/ℓ	Borehole B mg/ℓ	Borehole A mmol/ℓ	Borehole B mmol/ℓ
Na	46	149	2.0	6.5
Cl	35	18	1.0	0.5
SO_4	48	288	0.5	3.0
Ca	40	120	1.0	3.0
CO_3	60	180	1.0	3.0

Example chart: Stacked column bar chart

Use a stacked column bar chart to show the comparison between the mix of absolute (actual) constituent concentrations (mg/ℓ) from the two boreholes (**Figure 5**). It also emphasises the difference in the sum of the concentrations which may approximate the total dissolved salts (TDS).

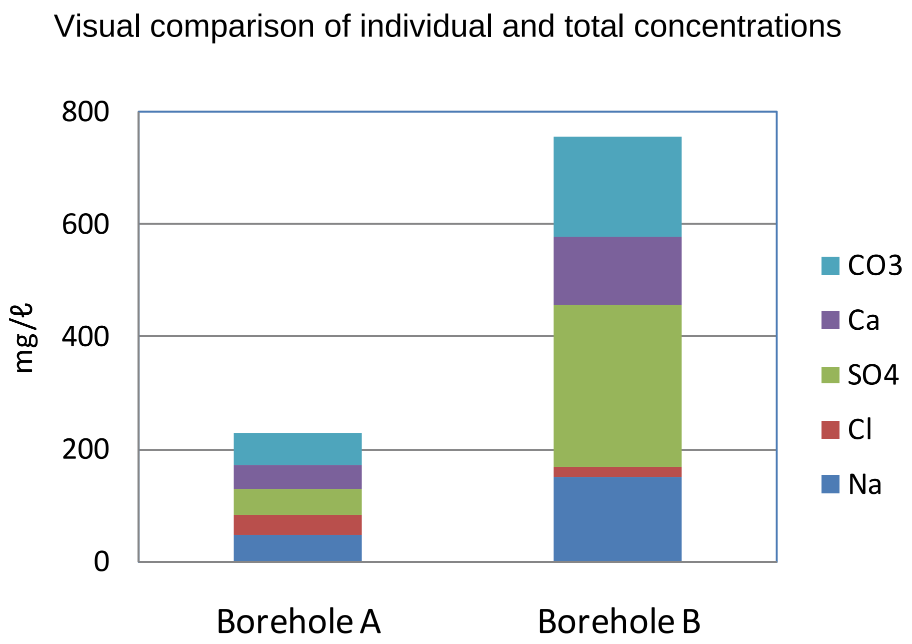


Figure 5: Stacked column example. Comparing absolute concentrations.

Example chart: 100% stacked column bar chart

The same data in **Table 5** can be displayed in a bar chart, each bar of which is stretched to the same height (representing 100%) (**Figure 6**). Use this chart to illustrate the *relative* concentrations of constituents at each site.

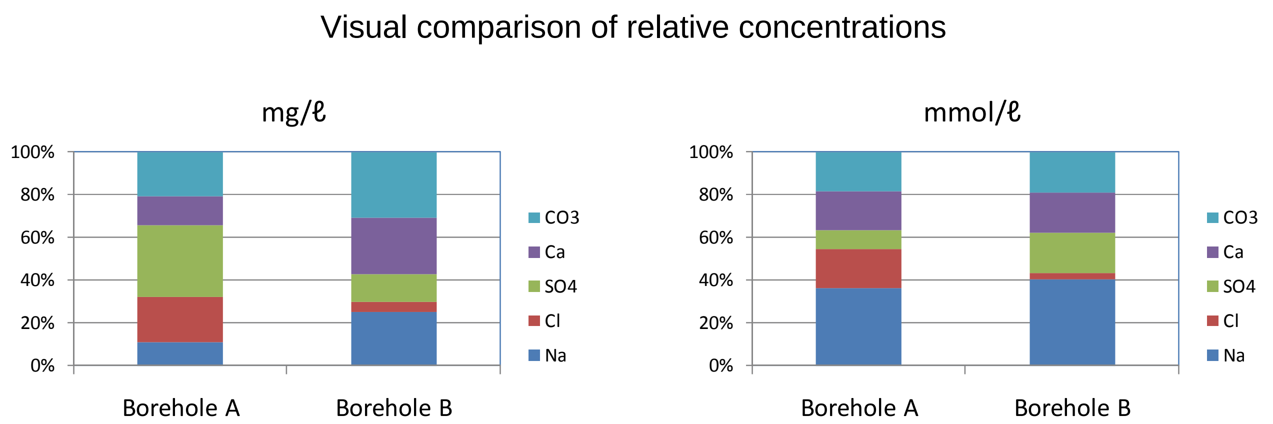


Figure 6: 100% stacked column example. Comparing relative constituent concentrations.

Note that comparing relative concentrations in mmol/ℓ units (instead of mg/ℓ) provides the reader with a fundamentally different kind of insight. It reveals the relative numbers of ions in solution (not the mass of them given by mg/ℓ). The right hand bar chart quickly reveals that, for example, in both boreholes the number of calcium ions equals the number of carbonate ions (per unit volume). (See the mmol/ℓ concentrations in **Table 5** used to produce this chart.) This suggests that a calcium carbonate rock or mineral may have dissolved to give these concentrations. Units of mmol/ℓ can provide elementary chemical insights not immediately possible using mg/ℓ.

Example chart: Paired horizontal bar charts

The data in **Table 5** can also be displayed in a pair of horizontal bar charts (**Figure 7**) to allow comparison of the *absolute* (actual) concentrations of each constituent at each site. These charts also allow easy comparison of the *relative* concentrations within each site. To ensure an accurate comparison is made, make the X-axis range the same (in this case 0 to 300 mg/ℓ).

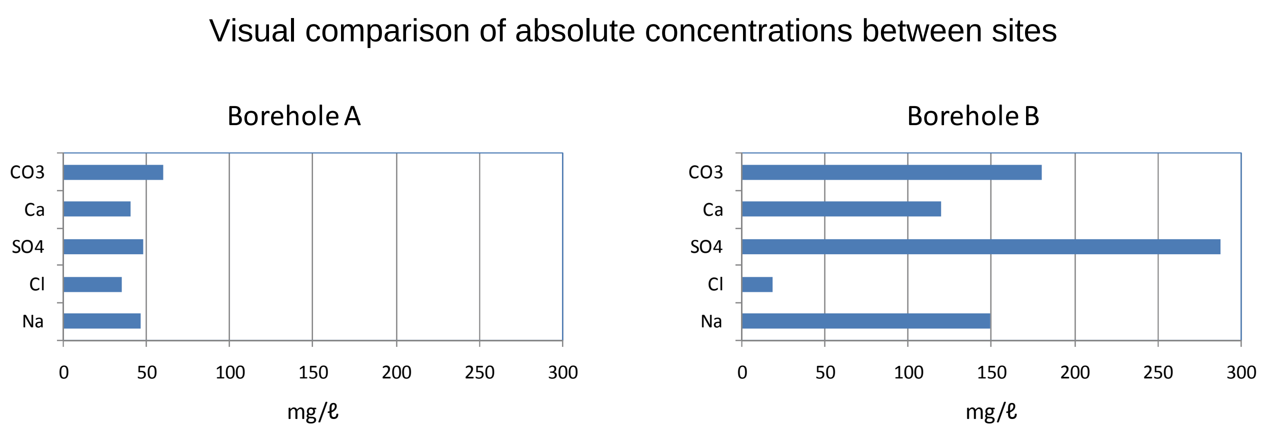


Figure 7: Horizontal bar charts example. Comparing absolute concentrations.

Example chart: Reflected horizontal bar charts

The data in **Table 5** can also be displayed in a pair of horizontal bar charts, one of which is reflected (**Figure 8**). Use these for the same reasons as the above paired horizontal bar charts. Reflecting the one chart simply allows a slightly easier comparison of the concentrations between the sites.

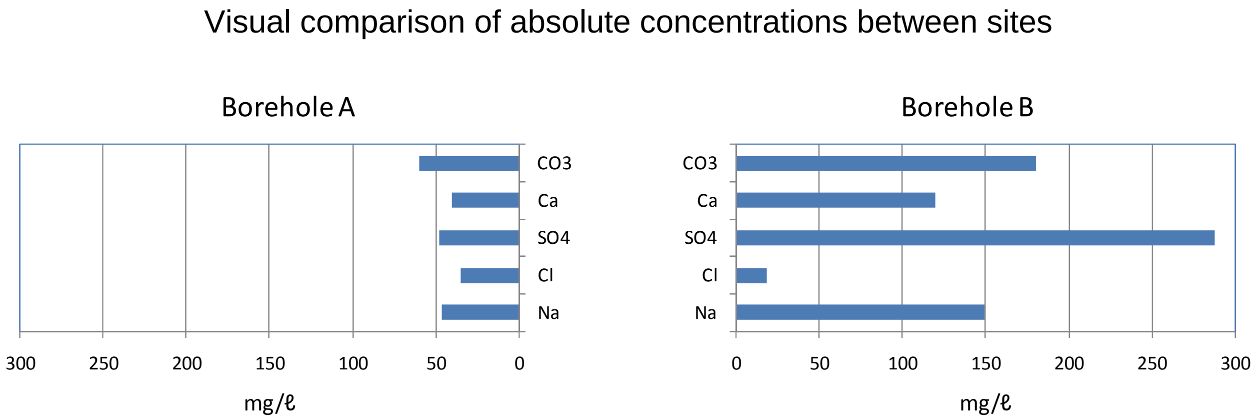


Figure 8: Reflected horizontal bar charts example. Comparing absolute concentrations.

Example chart: Sorted horizontal bar charts

The data in **Table 5** can also be displayed in a pair of sorted horizontal bar charts (**Figure 9**) to highlight the highest concentrations. These would be, for example, those contributing most to a measurement of total dissolved salts (TDS) or electrical conductivity (EC). Simply sort the data in your source table to obtain the sorted bar chart.

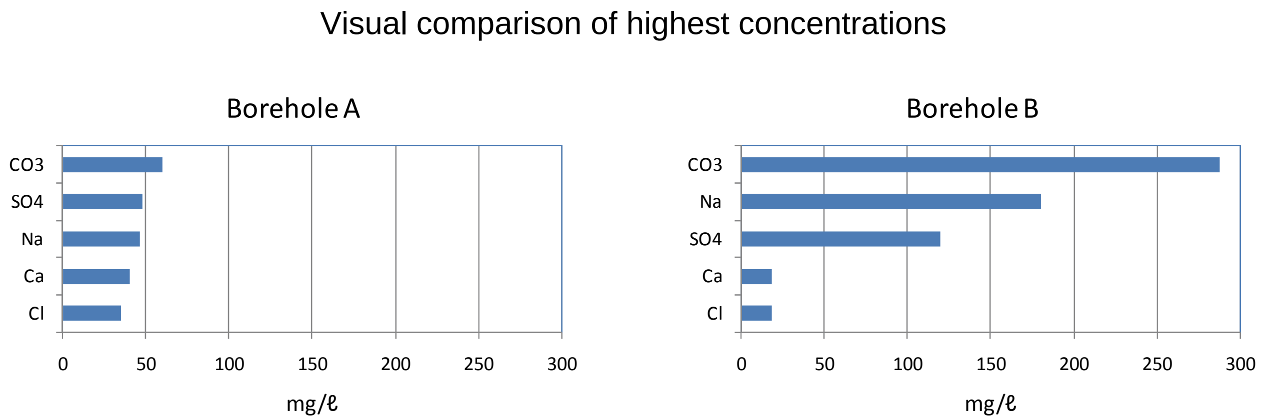


Figure 9: Sorted horizontal bar charts example. Emphasising the highest concentrations.

Example chart: Clustered horizontal bar chart

The data in **Table 5** can also be displayed in a clustered horizontal bar chart (**Figure 10**). Use this to allow direct comparisons to be made between constituent concentrations at the different sites. Only use these charts for limited numbers of different constituents otherwise the chart becomes cluttered and more difficult to interpret. Occasionally it may be appropriate to display the data values particularly if the chart is not displayed near the table containing the data.

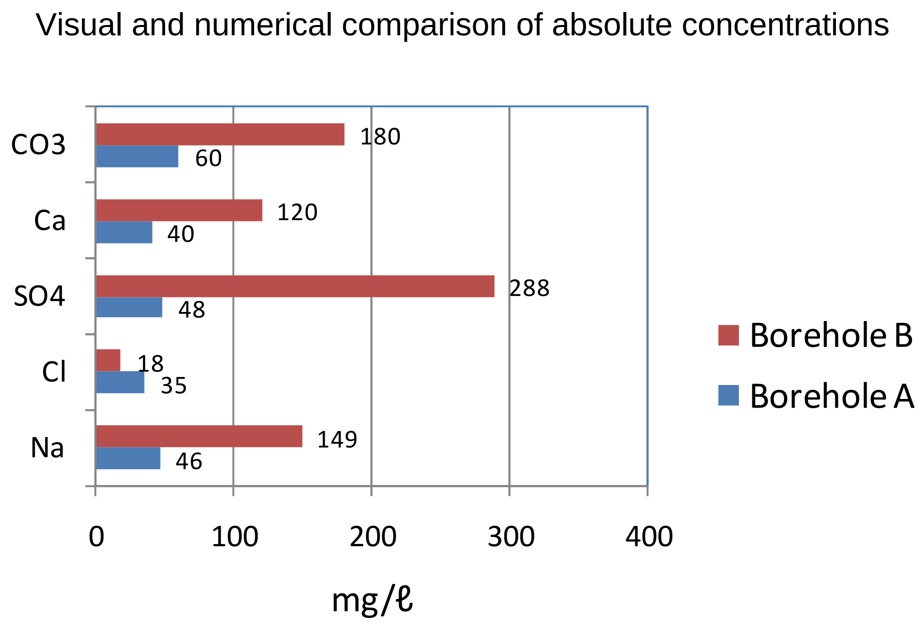


Figure 10: Clustered horizontal bar chart example. Direct comparisons of concentrations.

Example chart: Image bar charts

For verbal presentations and less formal media like brochures a bar chart can be made somewhat more aesthetically interesting and compelling by incorporating an image into the bars (**Figure 11** and **Figure 12**). By including the data values the bar chart can then also provide exact numerical data which may be important to some in the target audience.

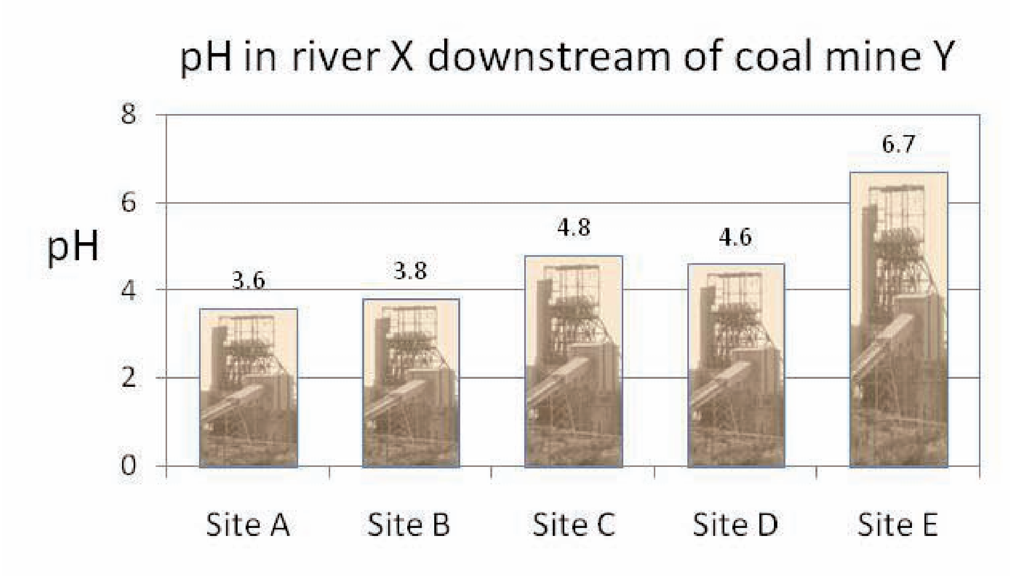


Figure 11: Image bar chart example. Eye-catching reinforcement of message.

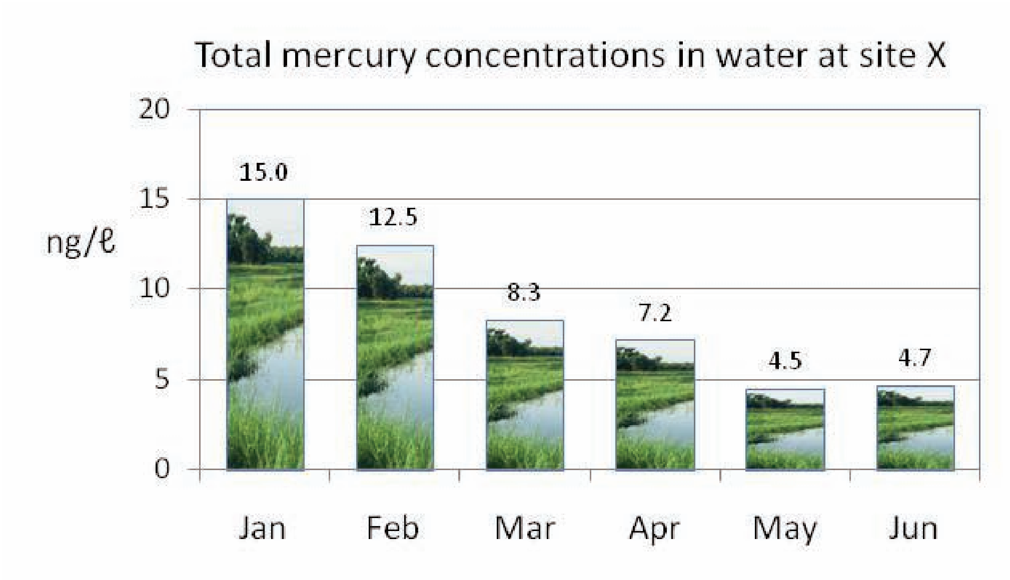


Figure 12: Image bar chart example. Aesthetically pleasing bars.

5.3.2 Pie charts

Example chart: Paired pie charts

The data in **Table 5** can be effectively displayed in a pair of pie charts (**Figure 13**). Like the above 100% stacked column bar charts, use these to illustrate the *relative* concentrations of each constituents at each site.

Visual comparison of relative concentrations

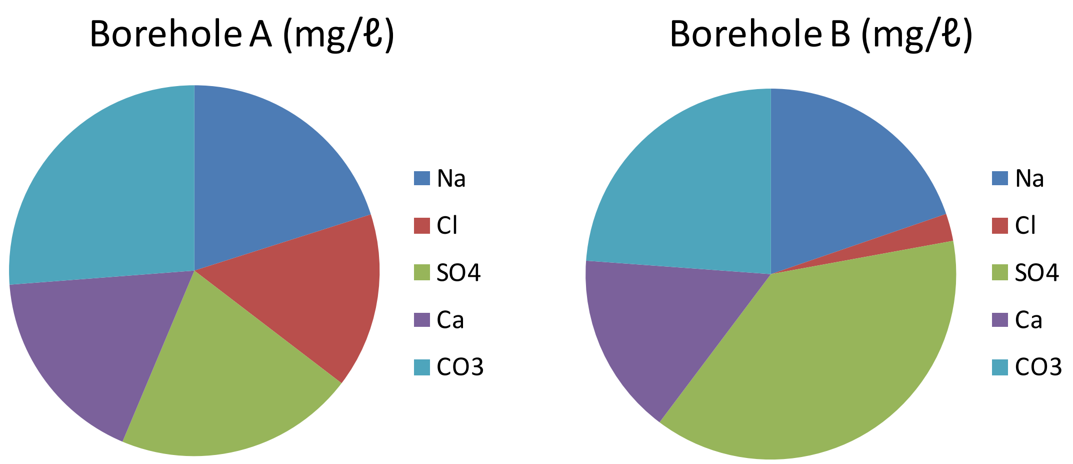


Figure 13: Paired pie charts. Comparing relative concentrations.

5.4 DIAGRAMS

5.4.1 Maucha diagrams

Characteristics

- Maucha diagrams summarise the concentrations of the major ions in water in a way that allows easy comparisons to be made between two water samples (Maucha, 1932).
- It is an eight-pointed star symbol with four anionic concentrations on the left and four cation concentrations on the right (**Figure 14)**.
- Concentrations are expressed in milliequivalents per litre so that the balance of cation and anion charge can be seen at a glance (see Section 8.3).
- A 1960s modification to the symbol scales the whole star in proportion to the total dissolved salts (Broch and Yake, 1969), the circle representing the median.
- A log scale is used where the data set consists of samples with widely differing salinities (Silberbauer and King, 1991).

Advantages

- Simultaneously illustrates the total dissolved salts and relative anion and cation concentrations.
- Conveniently used on maps.

Disadvantages

- Often difficult for non-experts to interpret.
- Requires specific software to produce.
- Specific to total dissolved salts.
- They can only be used for an analysis of a single water sample.

Example Maucha diagram: Basic structure

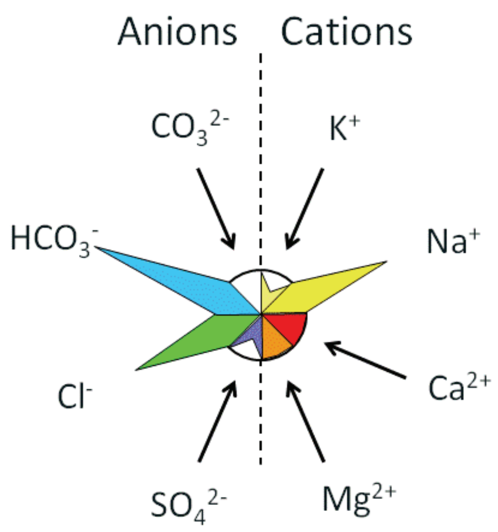


Figure 14: The basic structure of a Maucha diagram

Example Maucha diagram: Comparison between two waters

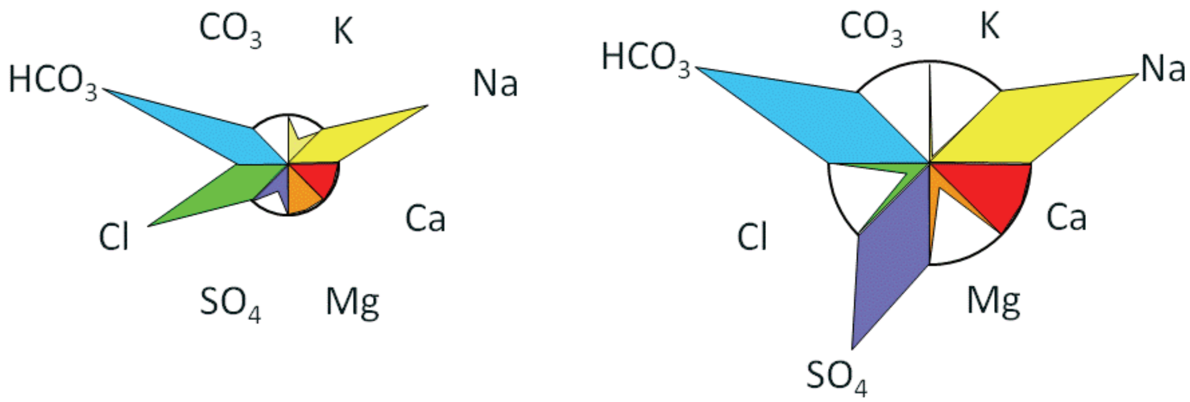


Figure 15: Maucha diagram example. Comparison between two waters.

The two Maucha diagrams in **Figure 15** refer to two water samples. Note the following:

- For simplicity, the charges are omitted from the anion and cation symbols (since ions are implied). If the readers of these symbols are sufficiently familiar with them then the symbols can be omitted altogether, as long as the structure (**Figure 14**) is displayed somewhere for reference.
- The second diagram is larger than the first because the total dissolved salts (TDS) level is greater in the second than in the first. The relative sizes of the circles in each represent the medians of the eight concentrations in each case.
- The second diagram shows a decrease in the relative amount of chloride (compared to the first water) and an increase in the relative amount of sulphate.

5.4.2 Piper and Expanded Durov diagrams

Characteristics

- These diagrams show graphically the relative abundance of the major ions in multiple water samples.
- Typically used to describe the chemistry of groundwater samples, in particular relating to total dissolved salts.
- Their main purpose is to depict clusters of data points which indicate samples with similar compositions.
- The plot shows the major ions as percentages of milliequivalents/ℓ (meq/ℓ) in triangles. In the Piper diagram, the relative abundances of the cations Na^+, Ca^{2+}, and Mg^{2+} are first plotted on the cation triangle. The relative abundances of Cl^-, SO_4^{2-}, and HCO_3^-+CO_3^{2-} are then plotted on the anion triangle. The two data points on the cation and anion triangles are then combined into the quadrilateral field that shows the overall chemical composition of the water sample. In the Expanded Durov diagram, the points are projected onto a grid of nine squares.

Advantages

- Simultaneously illustrates the total dissolved salts and relative anion and cation concentrations.
- Useful for classifying many different waters on the same diagram.

Disadvantages

- Often difficult for non-experts to interpret.
- Requires specific software to produce.
- Specific to total dissolved salts.
- They do not indicate absolute concentrations (only relative concentrations).
- They cannot easily accommodate waters in which other cations or anions dominate.

More information on these and other diagrams commonly used for illustrating groundwater chemistry (like Stiff and Schoeller diagrams) can be found in the following publications:

Loyd and Heathcote (1985); Back and Freeze (1983); Freeze and Cherry (1979); Mattess (1982); Hem (1985); and Todd (1980).

Example: Piper Diagram

Figure 16 shows the relative abundances (in meq/ℓ) of the cations Na^++K^+, Ca^{2+}, and Mg^{2+} and the anions Cl^-, SO_4^{2-}, and CO_3^{2-}+HCO_3^- of a single hypothetical water quality. The short arrows indicate the axes from which the percentages are read. If different points are plotted for a series of water quality analyses, points close together indicate similar kinds of waters, at least in respect of their major ions. The location of a point within the triangles and those projected onto the upper parallelogram allow the type of water to be classified (**Figure 17**).

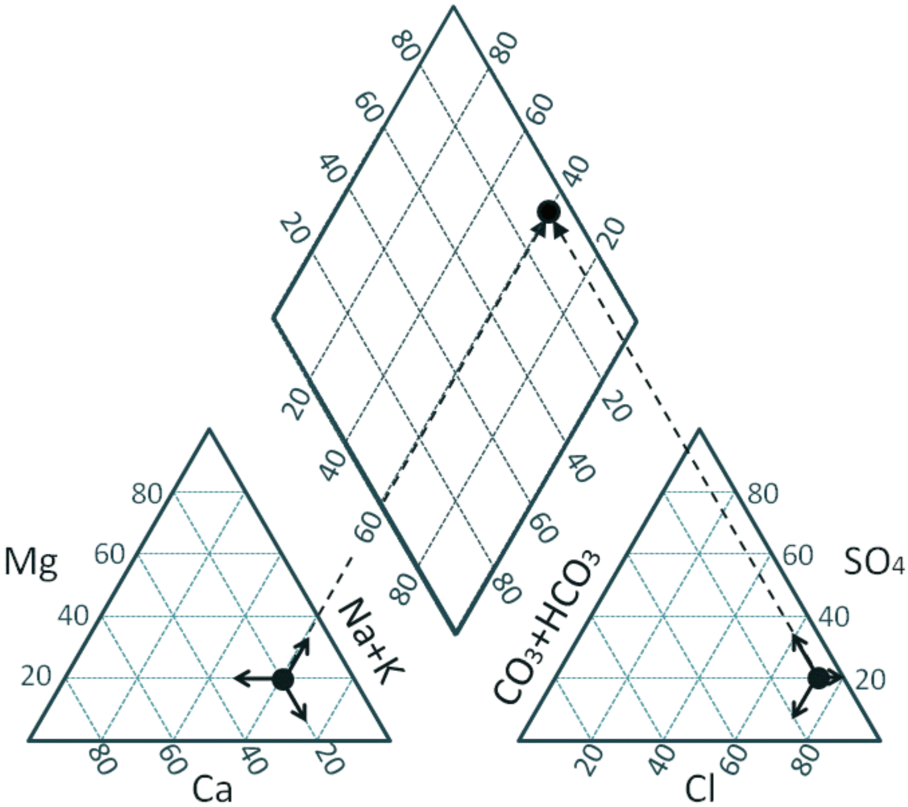


Figure 16: Piper diagram example. Relative concentrations in meq/ℓ of major ions.

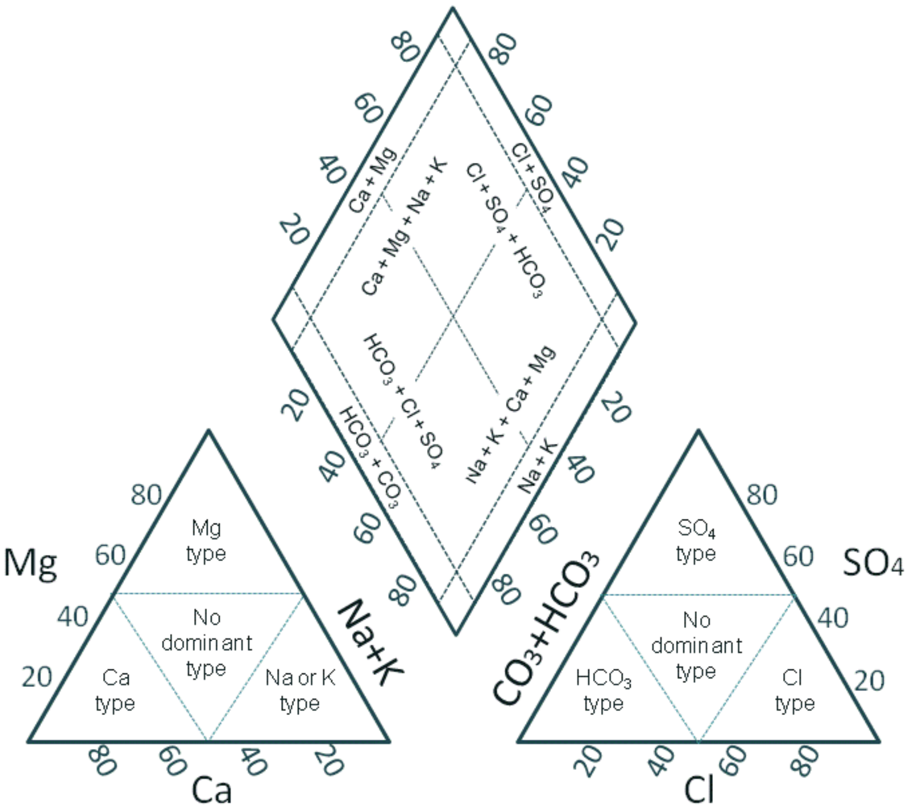


Figure 17: Piper diagram example. Classification of major ion types.

Example: Expanded Durov Diagram

Figure 18 illustrates the expanded Durov diagram. The arrows indicate the projection of the two points in the triangles onto the centre square and outer squares. The outer squares allow any two other variables, in this case pH and temperature, to be depicted for each water sample. It might be noted that there is some disagreement in the literature about exactly what an expanded Durov diagram. However, the form depicted in **Figure 18** is the form generally accepted in South Africa.

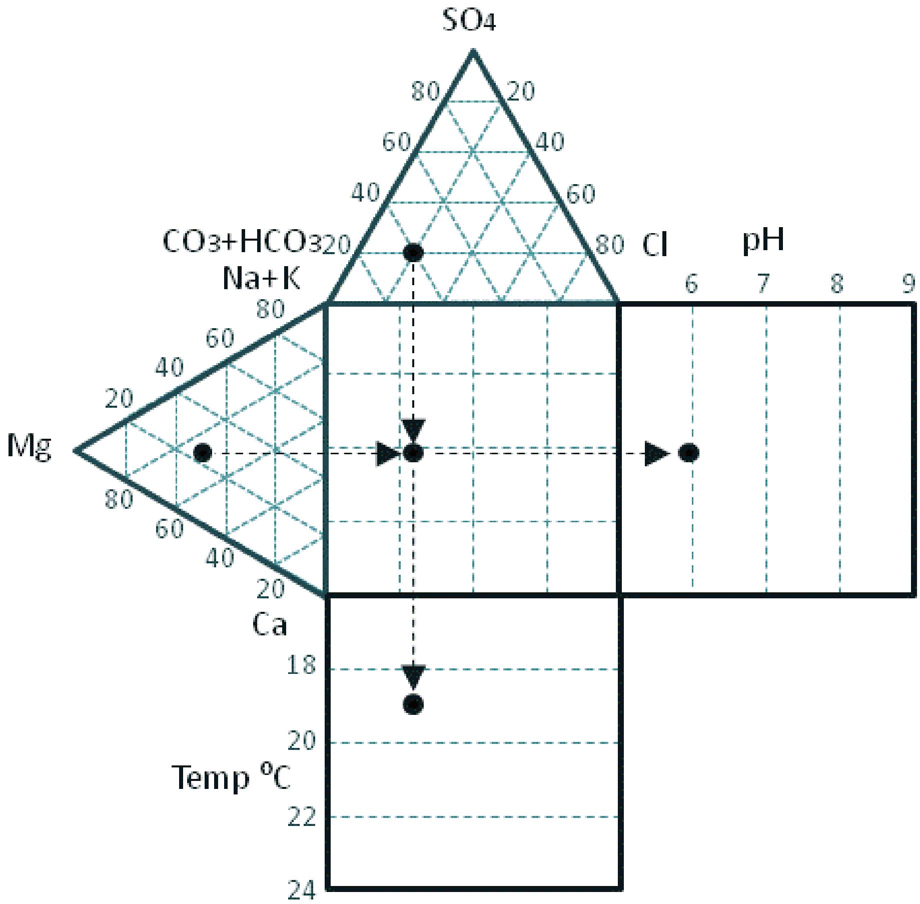


Figure 18: Expanded Durov diagram

5.5 GRAPHS

See Section 8.7 for a very basic introduction to interpreting graphs.

Characteristics

- A graph depicts the relationship between sets of numbers or quantities by means of a series of dots, lines, etc., plotted with reference to a set of axes.

Advantages

- Graphs can communicate trends well.
- Compared to tables, graphs are better when people need to use their judgement to make forecasts.
- Graphs can be used to present primary data or summary statistics (*e.g.* median or average data; see Chapter 4).
- Graphs can clearly illustrate the relationship between two or more variables.
- Like charts, they make good use of the ability of our eye-brain system to perceive geometric patterns.
- Many widely-used software packages exist that allow effective graphs to be created.

Disadvantages

- Graphs cannot easily provide exact numerical values.
- Graphs are not useful for displaying highly integrated data, like indices (see Chapter 4).

Practical dos and don'ts

- **Dependent vertical versus independent horizontal***:* Always have the independent variable (like time or distance) on the horizontal axis and the dependent variable (like pH or temperature) on the vertical axis.
- **Limit the number of lines**: Limit the number of lines per graph (to, say, three).
- **Display error bars**: Include errors bars on points whenever possible except when there are so many points that it clutters the graph.
- **Use sensible axis values**: Ensure that the values on axes:
  - Start and end at sensible values, and
  - Are either whole numbers or sensible fractions (0.5, 0.1, etc.) for small ranges.
- **Avoid log scales for non-expert audiences**. Log scales are useful, if not essential, when the numbers you are plotting differ by orders of magnitude (*i.e.* hundreds, thousands, or millions), as is often the case with microbiological data. However, do not assume non-expert audiences will be able to read the log scale correctly. (For basic information on interpreting log scales, see Section 8.7.3.)
- **Don't connect discontinuous points**: Monitoring data are seldom continuous so just plot the points. Connecting the points is seldom justified. Continuous graphs will typically be calculated functions of the set of discontinuous points (like a moving average).
- **Consider black-and-white legibility**: If you use colour and you wish to ensure that black-and-white photocopies remain legible, then:
  - Use lines of different thicknesses (or use solid and dashed lines), and
  - Use point symbols of different shapes.
- **Consider legibility when reduced**: Consider whether or not the graph might be reduced in size by the target user. If so, ensure text sizes, line thicknesses, and so on, are such that readability will be maintained.

- **Link to the text***:* Ensure that the graph is explicitly referred to in the text. It helps to bold this reference (*e.g.* **Figure 4**). This helps readers locate the text that is directly relevant to the table.
- **Try to make to graph stand alone**: Ensure everything on the graph is explained, either in the graph caption, the legend, or in the text. Ensure that the particularly important elements are noted, particularly if you anticipate that your target users may not be very familiar with reading graphs. Use annotations on the graph if necessary (but be careful not to clutter the graph).

Aesthetic dos and don'ts

- **See aesthetic dos and don'ts for charts**. Section 5.3.

(Ashton, 2007; Cleveland, 1984; Matthews *et al.*, 1996; Smartdraw, 2007; Vekiri, 2002)

Example graph: Time-series

Time-series graphs display how a water quality variable has changed over time. (**Figure 19** is an example of phosphate concentrations at a site C2H018Q01 on the Vaal River.) They plot, for example, the value (like concentration) of the variable at a specified monitoring point on the Y-axis against time (on the X-axis). The following are some further hints:

- **Comparison values**. When appropriate, include a horizontal line representing a fixed value with which you can compare the measured values. These fixed values may include:
  A water quality guideline value, like the upper limit of a target water quality range. It is then easy to see when the value was exceeded.
  A management target, like a resource quality objective relating to water quality. It is then easy to see, for example, how progress is being made towards it.
- **Comparison graphs**. Sometimes it is helpful to display a second graph on the same axes but with the dependent variable represented on the right hand side of the plot. This can help identify possible correlations between the two graphs.

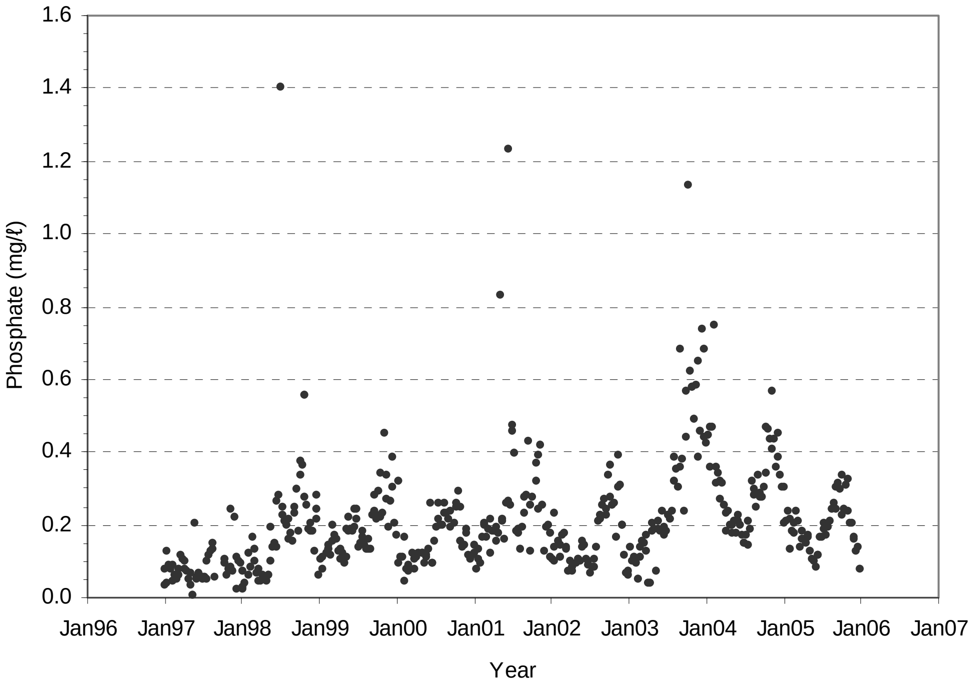


Figure 19: Time series graph example. Concentrations at site X.

Example graph: Exceedence diagram

This displays what percentage of a series of water quality variable values exceeds the value on the Y-axis. **Figure 20** shows this for the set of phosphate concentrations in **Figure 19**. The graph shows, for example, that 10% of the values exceeded 0.3 mg/ℓ and 90% exceeded about 0.11 mg/ℓ..

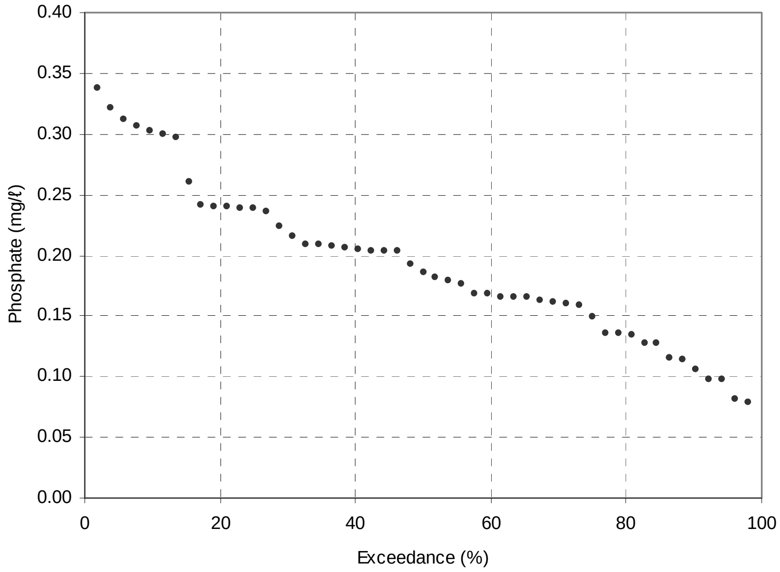


Figure 20: Exceedence diagram example: Concentration.

Example graph: Box-and-Whisker

These are very useful for displaying the spread of values within a set. **Figure 21** shows how phosphate concentrations varied from one year to the next. The box indicates, for example, the 25th and 75th percentile. A line through the box is the median (or 50th percentile). The ends of the whiskers show, for example, the 5th and 95th percentiles. Dots beyond the whiskers indicate those values that are greater or less than the 90th or 10th percentiles, respectively.

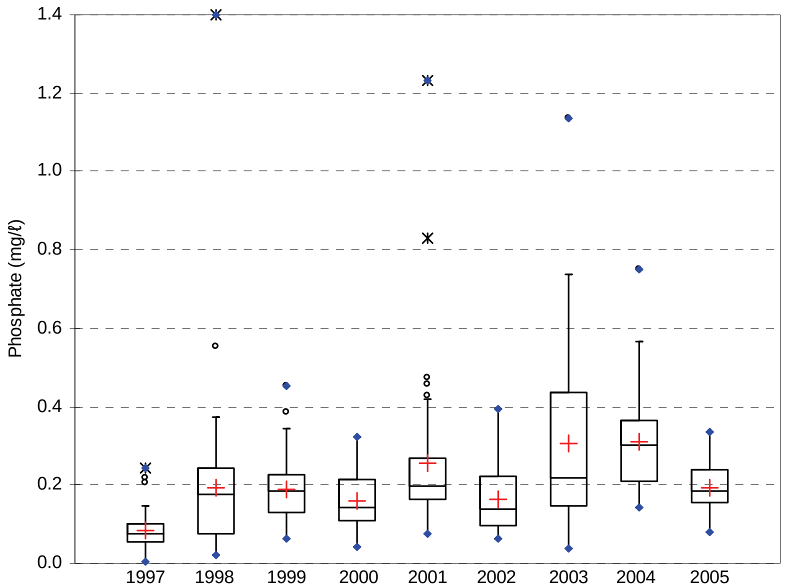


Figure 21: Box-and-Whisker graph example: Concentration percentiles at site X over time.

Box-and-Whisker plots can also be used to display spatial changes along the length of a river. **Figure 22** shows phosphate concentration percentiles for a particular year at monitoring points (Site 1 to Site 4) along a river.

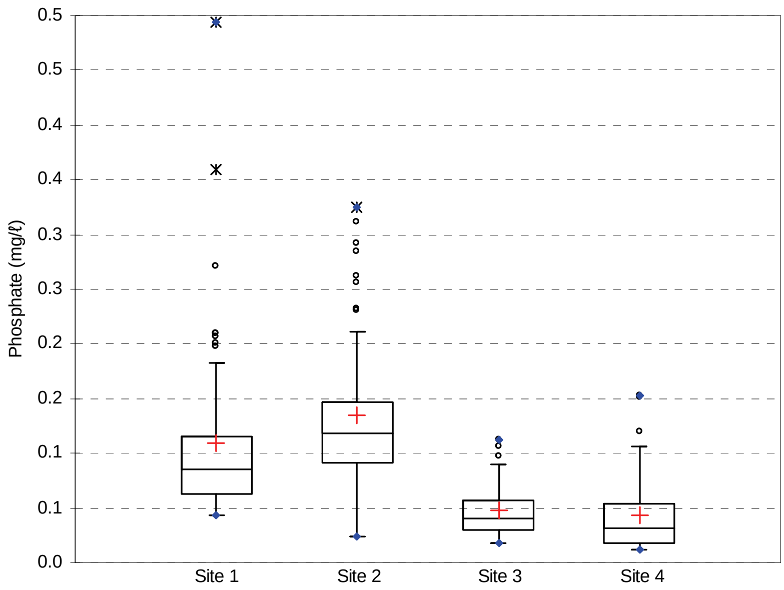


Figure 22: Box-and-Whisker graph example: Concentration percentiles along river X in 2005.

Example graph: Flow-Concentration

These plot the concentration of a water quality variable (Y-axis) at a particular monitoring point against average (or instantaneous) flow at that point (**Figure 23**). Statistically significant upward or downward trendlines can help show whether or not there is a correlation between concentration and flow.

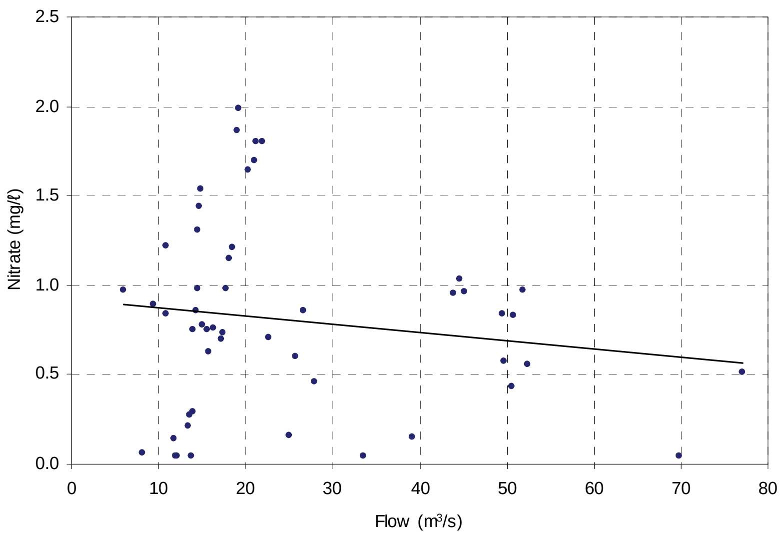


Figure 23: Flow-concentration graph example. Concentration versus flow at site X in 2005.

Example graph: Vertical profiles

To allow better visualisation of the way, for example, temperature changes as a function of depth in an impoundment, the profile can be plotted with depth as the vertical axis (**Figure 24**). In this case, the temperature values are best located at the top of the graph. The graph shows clearly how the temperature drops from about 18ºC at the surface to about 8ºC at nearly 40 m depth.

This kind of graph is also useful for displaying how variables change as a function of depth in groundwater at a specific location, like in a borehole.

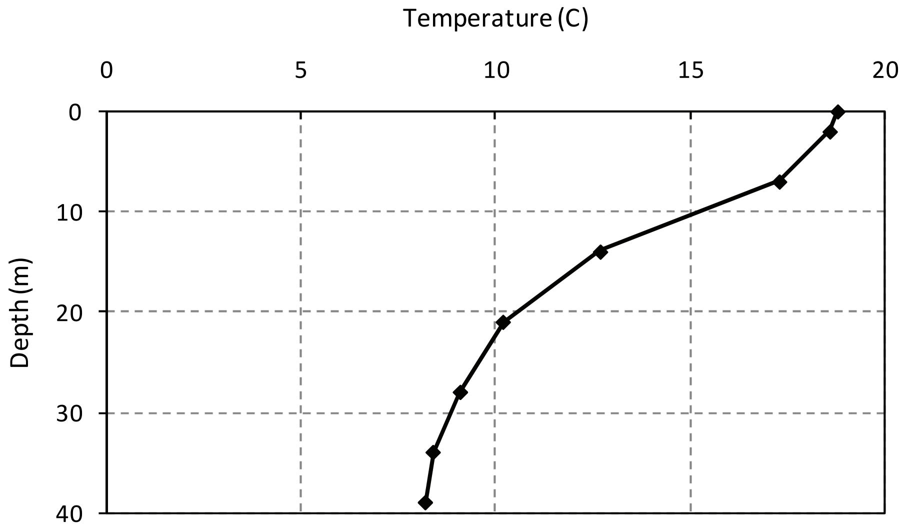


Figure 24: Vertical profile graph example. Temperature profile as a function of depth.

5.6 ICONS

Characteristics

- Icons are simple or pictorial symbols that are used to provide a qualitative representation of the status of water quality.
- Icons are often presented in different colours, each of which is representative of the status of the water quality (*e.g.* red=poor, green=fair, blue=good).
- Icons are most commonly used in combination with maps to provide a geographic context of the status of water quality.

Advantages

- If chosen well they can be interpreted by a wide target audience.
- They can communicate a very simple message.
- Icons are very useful for communicating integrated data such as summary statistics (Section 4.4) or indices (Section 4.5).

Disadvantages

- They can have different meanings in different cultures. Finding appropriate icons that communicate across cultures can be difficult.
- Poor use of metaphors can make the icons confusing.
- Their small size limits message space.
- They are not suitable for communicating primary data.

Practical dos and don'ts

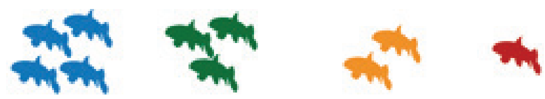
- **Ensure inter-cultural appropriateness**: Ensure your icon communicates the intended message to cultures other than your own.
- **Use standard metaphors**:
  Don't dismiss metaphors; they can be a crucial.
  Use standard metaphors where they exist.
  When a metaphor is used in several applications implement it in a standard way.
  Use the full extent of a metaphor.
  Avoid similar metaphors when using multiple metaphors.
  Don't overuse metaphors. Acknowledge their limitations.
- **Also use the icon to indicate location**. Besides indicating water quality status, the position of the icon on a map can also indicate the location of the water.

(Richards *et al.*, 1994)

Example icons:

The South African River Health Programme uses icons very effectively to present information on the ecological health of rivers in South Africa. They even have an icon for water quality. **Table 6** illustrates their icons (blue=natural, green=good, orange=fair, red=poor).

Table 6: Icons example. SASS (macroinvertebrates), water quality status and fish.

Water quality status:	
The SASS (South African Scoring System) index provides information on the water quality and habitat conditions at a site based on the macroinvertebrate assemblage at the site:	
The Fish Assemblage Integrity Index (FAII) expresses the degree to which a fish population differs from its expected undisturbed condition:	

5.7 MAPS

Characteristics

- Maps communicate water quality data and information in a geographic (*i.e.* spatial) context.
- Maps can communicate water quality data and information at different spatial scales, ranging from specific monitoring points to an entire catchment.
- Maps typically use symbols (like icons) to indicate location and some property of the locations.
- Maps can be used for two fundamentally different purposes:
    - Providing a visual record of spatial differences in water quality (the main purpose assumed here); or
    - Providing a tool for finding physical locations in the field.

Advantages

- Maps are very useful for communicating integrated data such as summary statistics (Section 4.4) or indices (Section 4.5).
- Can also be used to display trends in water quality (*e.g.* improvement, deterioration or no change).
- In many cases, people extract information more easily from spatial than non-spatial representations.
- A map provides a spatially structured repository for the storage and retrieval of information.
- Additional geographic information can be incorporated into maps, thereby providing an intuitive reference to the features and activities of an area of interest.
- Maps connect us with our environment with directness and un-ambiguity.
- Printed maps are portable. They display information you can read outdoors without having to take your computer.
- Sometimes large printed maps (*e.g.* displayed on a wall) provide an overview and a good balance of reasonable detail and a large view that cannot be obtained otherwise.

Disadvantages

- Not suitable for presenting numerical data.
- Data is often summarised or processed to a high level and hence detail on primary data may be lost.
- The image a map creates in a person's mind is highly dependent on that person's previous knowledge of maps in general and specifically maps of that area.

(Lohse *et al.* (1991); Kennedy (2006); Kulhavy and Stock, 1996)

Practical dos and don'ts

- **Ensure legibility**. Differences between colours, patterns and shadings of different symbols must be visually distinct. Symbols that are familiar are usually also more legible, so use well-known symbols when possible. Size the symbols so that they can be read from appropriate distances (**Table 7**)
- **Use only relevant text**. Keep text clear, correct and concise.
- **Show orientation and scale**. Always include a true north indicator and a scale bar to indicate distance.
- **Have a clear legend**. Include a legend explaining the meaning of symbols.

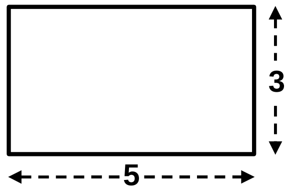
(Clarke, 1997; Robinson *et al.*, 1995)

Table 7: Recommended minimum widths for legibility of point symbols on maps

Viewing distance (m)	Width (mm)
0.5	0.3
2	1.15
5	2.9
10	5.8
15	8.7
20	11.6
25	14.5
30	17.4

Aesthetic dos and don'ts

- **Consider 3:5 border proportions**. A rectangle with sides having a proportion of about 3:5 is a pleasing format. For a large map to be read at normal reading distance it is desirable to have the short dimension vertical. Not only does this reduce neck-stretching, it also allows easier use of bifocal reading glasses.



- **Use effective visual contrast**. Contrast is the basis of seeing. How crisp, clean and sharp a map looks depends largely on the amount of contrast it contains. However, too much contrast can also be undesirable. Consider the possibility that black-and-white photocopies of the maps may be produced. The advantages of colour are often lost. If you wish to cater for this possibility, then use sufficient contrast to maintain readability. Also consider using lines of different thicknesses. **Figure 26** shows an effective use of a two-tone colouring gradient to create contrast between different areas.
- **Ensure good visual balance**. A good layout of map components achieves a proper balance. In a well-balanced design nothing is too light or too dark, too long or too short, too small or too large, in the wrong place, or too close to the edge. Visual balance depends on each item's relation to other items and the map's "visual centre" (which is very close to the actual centre). The combined effect of all elements should be to draw the eye naturally to this visual centre.
- **Keep patterns and colours simple**. Don't use too many different colours to illustrate change. Similarly, when using monochrome shade sequences should be even, flowing from dark to light with dark usually meaning high and light low. Also use white as a shade tone. It leaves the map looking less cluttered. Combinations of crosshatching, dot patterns, and so on can also be very confusing so avoid them whenever possible. Use cartographic conventions as much as possible. Background colours are usually white, grey or cyan, not black or bright blue. Contours are frequently brown, roads red, vegetation and forests green, and so on.

(Clarke, 1997; Robinson et al., 1995)

Example map: Single locations

Different coloured symbols on maps are useful for identifying both the location of monitoring sites and water quality. **Figure 25** illustrates this for Queensland, Australia (green=good, yellow=moderate, red=poor) (QEPA, 2008).

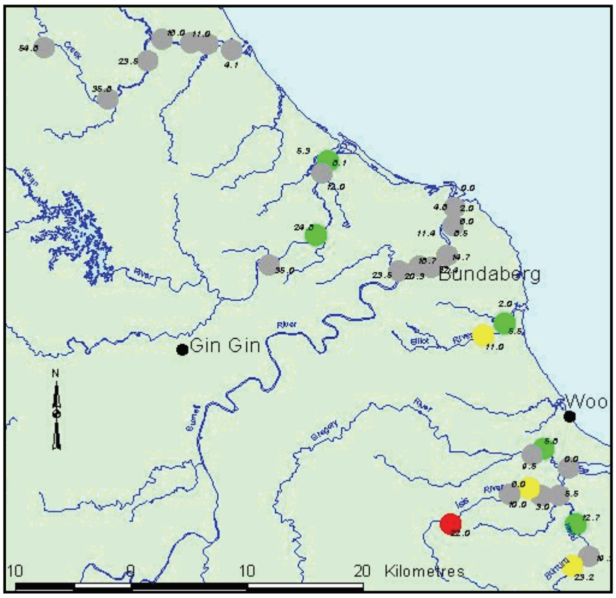


Figure 25: Map example. Coloured symbols showing water quality status at single locations.

Example map: River reaches

Colouring whole river reaches can be effective at communicating water quality over long distances. **Figure 26** shows measured salinity of the Vaal River and some tributaries (DWAF, 2006d).

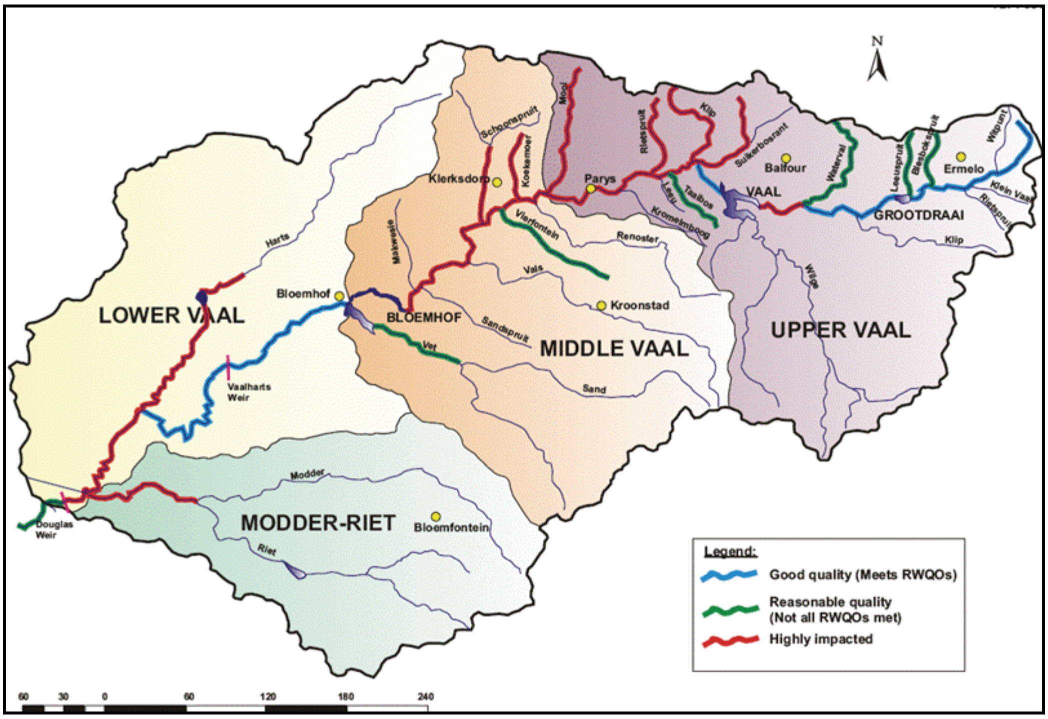


Figure 26: Map example. Coloured river reaches showing water quality status.

Example map: Trends

Colour along river reaches can also be used to illustrate change in water quality. **Figure 27** shows this for phosphate concentrations (mg/ℓ) in rivers in Wales and England from 2000 to 2006 (EA, 2008).

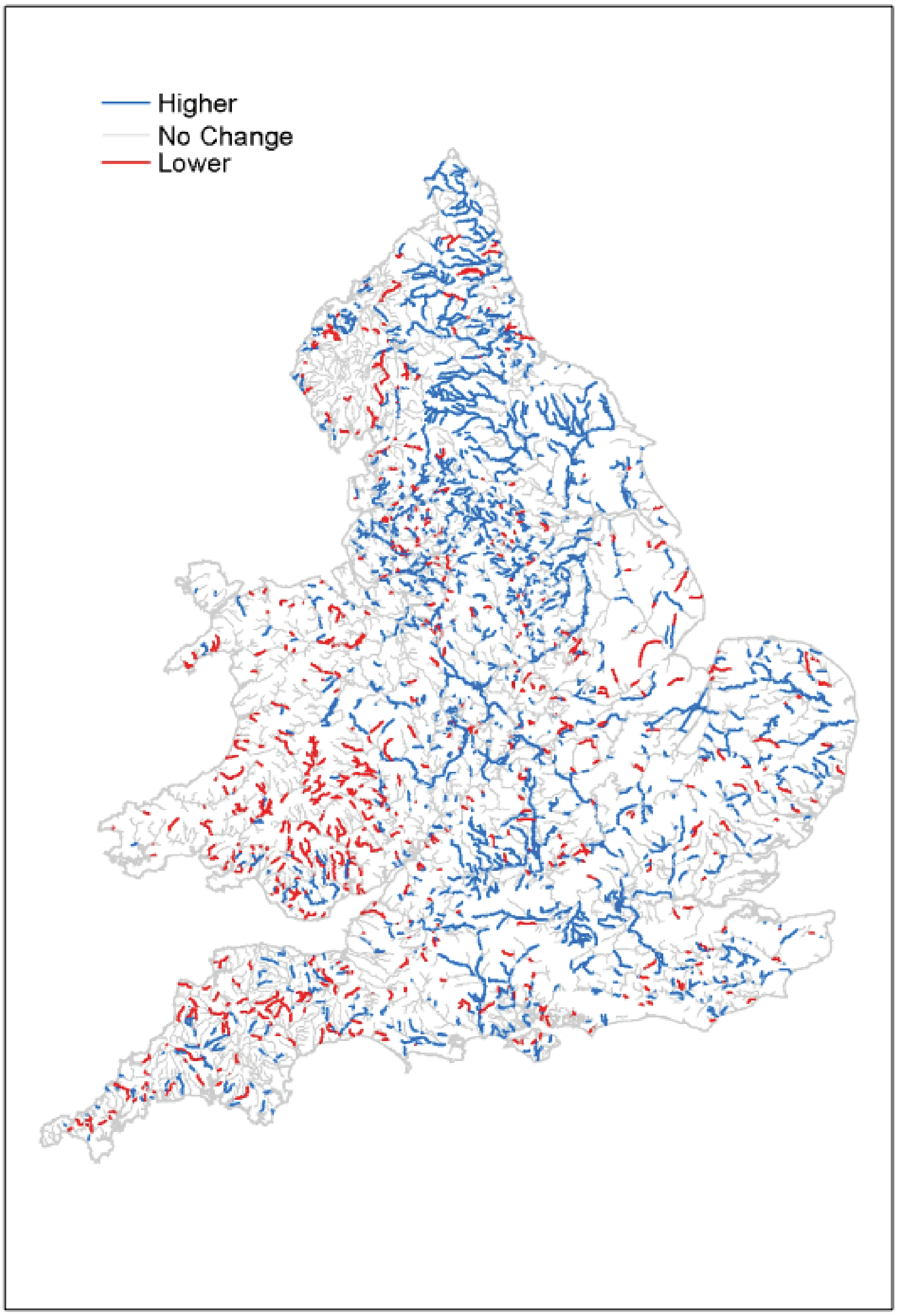


Figure 27: Map example. Coloured river reaches showing changes in concentrations over time.

Example map: Google Earth

Maps using Google Earth have been used to display data from the National Chemical Monitoring Programme (**Figure 28**). This is an interactive tool which allows users to select monitoring points of interest and obtain site-specific monitoring information (description of the location of the site and number of samples taken at the site), monitoring data (either in graph or raw data format) and flow data.

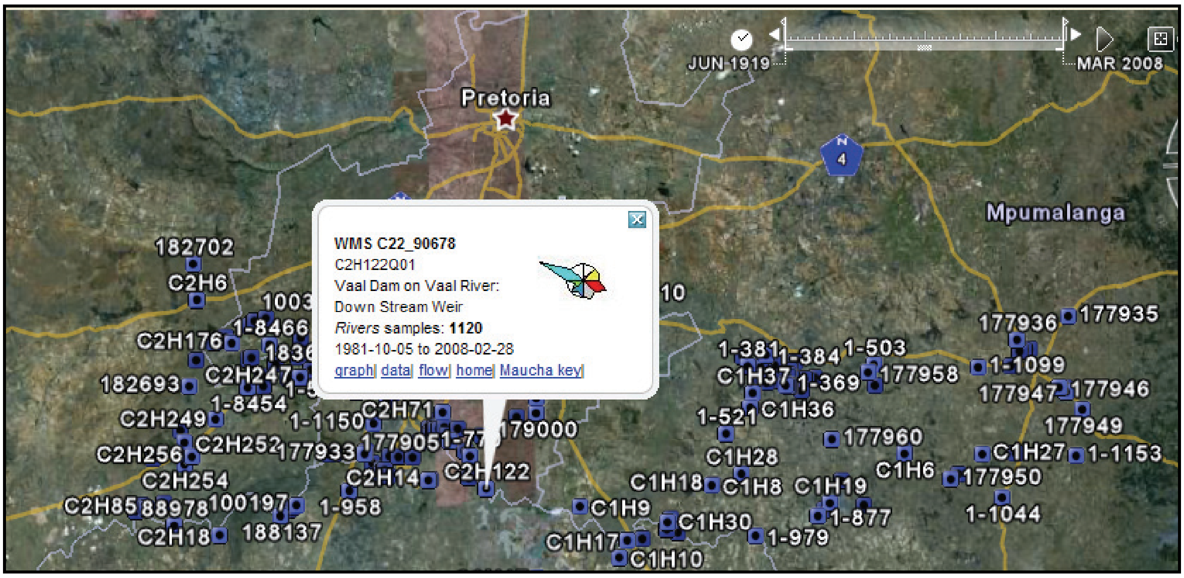


Figure 28: Map example. Google Earth used to present chemical data.

5.8 PHOTOGRAPHS

Characteristics

- Photographs can provide real-life illustrations that can communicate very useful information.

Advantages

- A good (and relevant) photograph can communicate information directly (without detailed descriptions being necessary).
- Good photographs can greatly improve the aesthetic quality of many kinds of communication.
- Digital photographs are very easy to take. They are also easily reviewed on site and re-photographed if necessary.
- Digital photographs are convenient to store, manipulate, annotate and use in communications.
- There is an enormous literature available on how to take good photographs.

Disadvantages

- Cameras are expensive items and therefore require care in the field.
- Cameras rely on batteries which can run flat at critical times.

Practical dos and don'ts

- **Always take a camera**. Take field photographs whenever possible and encourage others to do the same.
- **Check your battery strength**. Before going into the field, check that your batteries will last. Significant battery power can be consumed by some cameras if not used for long periods (like months), even if switched off. Take a spare or take a battery charger for rechargeable batteries.
- **Protect your camera**. Take a camera bag. Avoid dust and water.
- **When taking photographs**:

    Check your camera settings. Ensure that your camera is set to take the kind of photograph you want. Sometimes the settings can be changed inadvertently when handling the camera resulting in the camera not being optimised for the scene you want to photograph.

    Preferably have the light source behind you. Don't take photographs with, for example, the sun in front of you.

    Hold the camera very still. Use a tripod if necessary.

    Use the view finder. Don't use the screen on the back of the camera. You can frame your photographs much more accurately using the view finder.

    Depress the shutter release slowly.

    Take important photographs a few times. Sometimes it is not easy to return to a scene at a later date to retake a photograph. Take a few photographs from different angles and distances so you can pick the best one later.

    Review important photographs. If your camera allows it, check the photograph on-site. Take it again if you have any doubts.
- **When back from the field**:

    Download immediately. Capture your photographs on a computer as soon as possible.

Don't immediately delete from the camera disk. Only delete the photographs from the camera disk after you have made a backup of the computer disk. This way at least the camera acts as a temporary backup for your downloaded files.

Modify copies only. Either change the properties of the original files to be "read only" or keep them in a special folder, perhaps with the name "Read only originals". When you want to make any changes to the files (like resizing or cropping), only modify copies. You may wish to return to the original in future and modify it in a different way for some other communication.

- **When using digital photographs in communications**:

  Resize to minimise file size. The original file created by the camera can be very large (megabytes). Don't import the original file into your presentation unless absolutely necessary (for example, if required for a large poster). Rather reduce the size (say to a 20 cm width if the figure is to be the width of an A4 page or a pixel size of 1280(height) x 1024(width)). However, don't reduce it so much so that after inserting the picture you need to drag a corner to increase its size. This causes considerable loss of resolution. Using smaller file sizes keeps the overall document size to manageable levels, also facilitating easier transmission as an email attachment.

  Minimise special effects. Unless you deliberately want to create something artistic, avoid using effects like changing hue. It can easily make the image look unnatural. However sometimes slight adjustments to contrast and brightness can significantly improve an image.

  Provide adequate supporting text. Different people interpret photographs in different ways. Provide an adequate description of what you want the message to be. Use either the associated main text or the caption. However, keep it concise.

Aesthetic dos and don'ts

- **When taking photographs**:

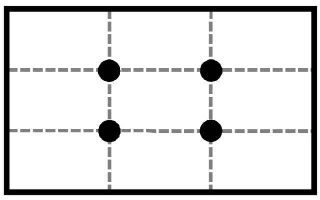
  Photograph either early or late. When the sun is high the lighting is harsh and flat.

  Beware of high contrast. Contrast problems commonly occur when a nearby subject or landscape is in shadow and the sky is bright. Try minimising the amount of sky in the frame.

  Don't place the horizon in the centre. A more interesting picture is produced if the horizon is high or low. If it is flat, be careful to keep your camera horizontal.

  Find a centre of interest. Try to locate an object (house, tree, rock in river, etc.) or natural formation (hill, river bend, etc.).

  Use the intersection of thirds rule. Try to place the centre of interest of your photograph at the points indicated in the adjacent figure.

  Fill the frame. If the purpose is to photograph a nearby object or person, try to get as close as possible so that the object or person fills the frame as much as possible. If possible, in so doing avoid using a zoom lens, which can create somewhat flat images. Rather move closer so that a zoom is not necessary. This creates a picture with more depth. Remember that software is available that allows you to zoom in to objects on your computer.

  Balance subject and background. It is not always appropriate to fill the frame with only the subject. Including background can provide a better perspective of the interaction between the subject and the immediate environment.

- **When back from the field**:

  Crop if necessary. When back in your office, remove outer edges of the original photograph to frame the subject matter properly. Cropping is very simple and can greatly improve the aesthetic quality of your picture.

5.9 SHORT STORIES

Characteristics

- Short stories convey simple messages in an informal way.
- They can be humorous and entertaining.

Advantages

- Short stories can be particularly effective with primary school children.
- The message can be transferred via the children into the community.

Disadvantages

- Not suitable for communicating large amounts of data. A single story will typically only convey a few critical ideas.
- Requires careful construction and presentation to ensure the message is conveyed as intended.
- They can take time to develop and publish.

Practical dos and don'ts

- **Planning**: Before you start, and when you are writing, document briefly and then refine the:

  Idea;
  Theme (the point it makes);
  Plot;
  Setting (feel and mood of surroundings);
  Physical scene location;
  Conflict (without which stories are lifeless);
  Event (that the story describes);
  Characters (unusual behaviours, drives, emotional states);
  Background (what happened to create the event); and
  Outline of story.

(Bonanno, 2004)

Aesthetic dos and don'ts

- **Illustrations**: Employ an effective illustrator to make the story more visually pleasing when being presented.

Examples

Some examples of water-related short stories can be found in Holtzhausen (2006).

5.10 TABLES

Characteristics

- Tables present data or information in rows and columns.

Advantages

- A clear and efficient way for providing exact numerical values.
- Can present data on water quality variables that have different measurement units (*e.g.* concentrations in mg/ℓ and pH).
- Short tables are very suitable for reports.
- Tables can also be made available in spreadsheets and distributed conveniently as, for example, an email attachment. The spreadsheet also facilitates (a) easy assessment of data against guidelines or standards and (b) production of graphs.

Disadvantages

- Tables cannot easily communicate trends.
- Tables cannot provide any spatial representation of data.

Practical dos and don'ts

1. **Round numbers sensibly**: Round numbers to the appropriate number of significant figures.
2. **Include uncertainty**: Include error ranges whenever possible. This is an important way of conveying to the reader how reliable (*i.e.* accurate) the number is.
3. **Provide all column headings**: Provide headings for all columns and give the units whenever units apply. For clarity, if a number is unitless (because, for example, it is a ratio), say so.
4. **Use a concise complete caption**: Remember that the caption may appear in a list of tables at the start of the document. The contents of the table should be clear from the caption when read in this list.
5. **Link to text**: Ensure that the table is explicitly referred to in the text. It helps to bold this reference (*e.g.* **Table 3**). This helps readers locate the text that is directly relevant to the table.
6. **Try to make the table stand alone**. Notwithstanding ensuring a link to the text, the reader should be able to understand the table without referring to the text. So the caption must be adequate, the headings complete and explanatory and the data arranged logically.
7. **Consider row numbering in large tables**: Very occasionally it is useful to number the rows of large tables. This allows text discussions to refer to rows, guiding the reader directly to the relevant data. For example, one might say "The concentration was below the guideline level on all but two occasions (rows 16 and 27)".
8. **Consider appendices**: Consider placing a large table in an appendix, particularly if (a) it is not absolutely essential to the message being communicated in the text (although in this case consider whether or not the table is necessary at all) or (b) it interferes significantly with the flow of the text.

(Ashton (2007); Matthews e*t al.*, (1996))

Aesthetic dos and don'ts

1. **Keep it neat**: Avoid clutter (and hence confusion).
2. **Avoid vertical lines**: Avoid using vertical lines. Use horizontal lines at the top of the table, at the bottom, and to separate the column labels from the data (**Table 8**).
3. **Space columns carefully**: Place the columns sufficiently close to one another, though not too close so that it looks cluttered, so that the reader can clearly relate numbers in the same row.
4. **Justify to improve neatness**:
   a. Centre the table between the left and right margins.
   b. Bold and centre the caption.
   c. When applicable, right justify a column of numbers that are expressed to the same number of decimal places (including integers). This makes the numbers easier to compare.
   d. Use matching justification in the column label and column of data.

(Ashton (2007))

Example table:

Table 8: Table example. Total dissolved solids and hardness on 12-Dec-2006 at site X.

Monitoring site	Total dissolved solids (mg/ℓ)	Hardness (mg $CaCO_3$/ℓ)
A (below discharge)	343.1	132.3
B (immediately above weir)	267.2	97.2
C (200 m downstream of weir)	96.7	84.6
D (500 m downstream of weir)	89.5	72.1
E (below confluence with Vaal River)	377.1	288.5

CHAPTER 6: COMMUNICATION MEDIA

This chapter describes the communication media that can be used (pros and cons, etc.).

6.1 INTRODUCTION

Many media described here may be regarded as unusual in the water quality field. However, this chapter intends to raise awareness about some options that may be appropriate under special circumstances. Many media are extensively used (and well-studied) for advertising purposes and their properties are well known. In some contexts, transferring water quality-related messages has many parallels with advertising so much can be learned from that well-established field.

Each medium (presented in this chapter in alphabetical order) can make use of various communication tools (Chapter 5) and present one or more data categories (Chapter 4). Specific tools and data categories may be more appropriate for some media and less so for others. **Table 2** indicates which tools are most appropriate for the selected media. Apply the general recommendations (in Chapter 3) throughout.

Also keep the following in mind:

- **Consider the expertise of your target readers**. If necessary and appropriate, supply them with this manual and point out that Chapter 8 provides some basic information that may help them better understand your communication.
- **Communicate to those involved in collecting the data**. Consider communicating results to those involved in data collection. It provides them with an understanding of how they are contributing to the objectives of the monitoring, maintains a sense of importance and relevance. This may contribute to better data quality.
- **Report the good and the bad**. Remember to report good news stories as well as bad news stories. A single bad news story can have a lasting influence on people's perceptions of water quality. If they never hear any good news, such perceptions last indefinitely.

Further reading: The internet contains enormous amounts of easily-accessible information about communication media. Much of the information in the following sub-sections comes from web sites (many of which are referenced). The reader is encouraged to explore the internet to obtain more detail.

The following key phrases are useful: "*dos and don'ts*", "*dos and don'ts*", "*how to* …", "*pros and cons*", "*advantages and disadvantages*", "*best practice*", "*guidelines for* …"

6.2 BILLBOARDS

Advantages

- Colourful large roadside billboards with striking images and brief messages get noticed.
- A variety of billboards are available. ***Traditional*** billboards are large wooden or metal signs. ***Mechanical*** billboards attract attention by rotating or scrolling. A mechanical tri-faced billboard contains three advertisements. ***Digital*** billboards can show animations. Some digital billboards can even be made to interact with web browsers. ***Mobile*** (trailer) billboards can increase mobility and allow more control over placement.
- Advertisements can be placed on well travelled roadways, or strategically located on the way to shopping centres.
- Effective for building general awareness.
- On display 24 hours a day if illuminated, 365 days a year.
- Good for supporting advertisements in other media.
- Can provide a high frequency and repetitive message.

Disadvantages

- Communication time is very short.
- Must communicate simple ideas/messages.
- Cannot communicate detail.
- No ability to target demographically.
- Readability can deteriorate in bad weather.
- Costs of production and display can be high.
- Audience is often disengaged, for example focused on driving.
- Outdoor media viewed as "eyesores" in many communities.
- Difficult to provide contact information.

Dos and don'ts

- **Keep it brief**: Don't exceed 10 words. Rather focus on visual ploys to communicate your message.
- **Contrast colours**: Use contrasting colours to ensure your display can be seen from a distance.
- **Placement**: Place billboards along major arterial roads and at intersections.
- **Avoid competition**: Try to place your billboard where there are few other billboards.
- **Try walls**: Instead of a free-standing billboard, consider a highly visible wall.
- **Split costs**: Consider sharing costs with an organisation with a related (though reputable) mandate (like a water board, water user association, catchment management agency, etc.).

Further reading

- Comparative mass media information
  http://www.massmonopoly.com/CompetitiveMediaFacts.htm
- Billboard technologies and billboard case studies
  http://www.syl.com/bc/advertising/billboards/

6.3 BROCHURES

Advantages

- Useful for providing general overviews of programmes and results.
- Useful for providing summaries of information and contact numbers for interested readers.
- Useful as handouts at exhibitions, presentations, meetings, etc. Brochures are a good mobile form of communication.
- Brochures provide a permanent record of the content.
- Can also be distributed as inserts in other publications like magazines, newspapers, water accounts, etc.
- Relatively cheap to produce in large numbers.
- Variety of paper qualities available.
- Common word processors (like Microsoft Word) and more specialised publishing software (like Microsoft Publisher) allow brochures to be designed in-house.
- On-line software is available (*e.g.* http://www.mybrochuremaker.com).
- e-Brochures can be sent as Email attachments or downloaded from websites.

Disadvantages

- Not appropriate for small audiences and highly targeted messages.
- Not useful for information that changes quickly.
- Some audiences are not receptive to brochures as a means of communication.
- Because brochures are widely used, it may be difficult to make yours stand out.
- If not distributed wisely they may have little impact.

Dos and don'ts

- **Understand your target audience**: This is critical for focussing your message. Understand their needs and interests. Know where they usually get their information.
- **Confirm that brochures are best**: Explicitly confirm that a brochure is the best medium for getting the message across to the people you are trying to reach. Also decide how you will distribute them.
- **Write it right**: Use simple, concise, accurate, and compelling language.
- **Design it right**: Get the help of a professional designer if possible. It may increase costs but the impact may make it worth it.
- **Make a good first impression**: You never get a second chance to make a good first impression. In particular, grab attention with the cover.
- **Be consistent**: Use colour, text, and visual images consistently throughout the brochure.
- **Use your organisation brand**: Ensure the brochure is consistent with your organisation's brand.
- **One panel per concept**: In a folded brochure, use one panel per concept, message or idea.
- **Divide and conquer**: If you have too much important information to convey for one brochure, consider creating two brochures dealing with different themes (like the nature of the water quality monitoring programme and results so far).

Further reading

- Good brochures (www.practitionerresources.org/cache/documents/36798.pdf)
- Brochure templates (http://office.microsoft.com/en-us/templates/CT101043031033.aspx)

6.4 EMAILS

Advantages

- Emailing is a fast and efficient and very cheap means of communication.
- Emails can be used to transmit attached electronic versions of brochures, technical documents, popular articles, short stories, etc.
- Emails can draw customers to your website which can provide more detail.
- Emails can target specific groups of consumers.
- Emails can be highly personalised.
- Messages can be fairly detailed.

Disadvantages

- Emails can be filtered (for example by internet service providers who remove spam) and therefore not reach the intended recipient.
- Received emails can be deleted before they are read.
- Email lists can go out of date quickly.
- Viruses and worms are commonly transmitted via Emails.
- Transmitted Emails can be hacked into and read by a third party.
- Email transmission is not 100% reliable. Sometimes they do not reach their intended recipients. And worse, sometimes you are not notified of this.
- Can be resource-intensive with large numbers of Email addresses, frequent transmissions and personalisation of individual messages.

Dos and don'ts

- **Obey netiquette rules**: Netiquette is the conventions of courtesy and conduct observed on the internet. If your organisation has specific netiquette, observe it.
- **Don't spam**: Target your audience very carefully. Preferably only send to those who have expressed a desire to receive your Emails. Sending carelessly to an enormous number of recipients is inconsiderate and it wastes time and network resources (bandwidth, storage, etc.).
- **Use a descriptive subject line**: Use a short accurate descriptive subject line. This (a) prevents your Email from being unintentionally deleted by someone who would have wanted to read your message and (b) gives the genuinely uninterested reader the option of deleting without opening it.
- **Get to the point**: In the first few sentences. If sending an attachment, summarise what is in it. Give the recipient (non-threatening) reasons for going to the trouble of opening it and saving it.
- **Get a response**: If you want people to respond, explicitly say who should respond and by when.
- **Don't be emotional or sarcastic**: Emotion and sarcasm are very difficult to convey accurately in writing. They are therefore unlikely to be understood in the way you intended. Rather stay matter-of-fact and professional.
- **Don't attach unnecessary files**: They simply waste resources.
- **Include a disclaimer**: Just in case you have made some mistake.

Further reading

- Comparative mass media information http://www.massmonopoly.com/CompetitiveMediaFacts.htm
- Dos and don'ts (Asaravala, 2007)
- Email Netiquette (http://www.rocketreader.com/newsletter/newsletter22.html)

6.5 EXHIBITIONS

Advantages

- Useful for creating awareness.
- Exhibitions allow for personal engagement with a target audience, not only for providing information but also for soliciting feedback and comment.
- Exhibitions provide an opportunity to distribute brochures and reports.
- Exhibition posters and multi-media tools can be re-used in other locations.

Disadvantages

- You are dependent on people coming to you.
- Only appropriate for very small groups at any one time.
- Considerable time is required to prepare a professional exhibition.
- Costs can be relatively high. They include preparation of posters (typically making using of a professional designer) and multi-media, travel and the stand space.

Dos and don'ts

- **Set objectives**: Be clear about what the objectives of the exhibition are.
- **Have a clear message**: Ensure you understand beforehand what the general message is that you wish to communicate.
- **Select a good site***:* If exhibiting with many other exhibitors, select a site that is as visible as possible.
- **Advertise beforehand***:* Ensure local interested persons are aware of your intended exhibition. Advertise in local newspapers and consider sending personal invitations (*e.g.* using Emails) to selected target people.
- **Draw attention***:* Use appropriate means to attract the attention of passing people. Remember, exhibitions are primarily visual experiences.
- **Use media appropriately**: Ensure your posters and multi-media presentations present a professional image of your organisation and are appropriate to the message you wish to convey. Don't overuse special effects. Ensure multi-media presentations are adequately visible from some distance away. Remember, people are unlikely to sit down in front of a computer to watch a presentation. Ensure audio effects are not loud and intrusive.
- **Provide take-away documentation***:* Ensure you can provide brochures or reports to those who want to take away information. Remember that some visitors may be intimidated by talking to you. Also ensure you can provide contact information, either in brochures or using business cards.
- **Man the stand**: Ensure someone is at the stand all the time.
- **Cater for physically disadvantaged persons**: For example, ensure there is sufficient space for people in wheel chairs.
- **Anticipate language requirements**: Having people manning the stand who speak the languages of the people likely to be visiting the exhibition.
- **Engage interested persons**: Exhibitions are about personal engagement. Engage interested persons politely and helpfully.
- **Be receptive**: Listen attentively to the requirements and perceptions of people who stop at the stand.
- **Follow up when necessary**: If an interested person requires a follow-up action after the event, don't forget to do so. Keep a book in which contact details can be noted along with the required action.

6.6 NEWSPAPERS

Advantages

- Can be targeted at a broad range of readers. Can also be used to target a certain local community (*i.e.* can be geographically selective). Certain sections of the newspaper also target certain markets.
- Messages can be conveyed to target readers relatively quickly.
- It provides a permanent record of the message.
- Allows for some but not excessive detail.
- Advertisements and press releases can be used to control what appears in print. They are usually printed verbatim.
- Costs usually relatively low. A wide variety of cost options may be available (varying from high rates for once-off use to discount rates for regular use). Advertisements costs are usually based on (a) circulation (number of readers), (b) size of the advertisement, (c) whether or not colour is used and (d) where it appears in the newspaper.
- Can be used to distribute separate pre-printed inserts.

Disadvantages

- Difficult to measure day-to-day readership.
- Generally not very selective in respect of target reader.
- Using colour is expensive.
- Reproduction quality can vary greatly.
- Deadlines can restrict your flexibility.
- For articles, you are not in control of what appears in print.

Dos and don'ts

- **Write the right length**: Write the article or press release with the number of words requested by the editor.
- **Write in the right format**: Write press releases in the format required by the editor.
- **Use a press release for news**: A press release should provide news, not be an advertisement.
- **Provide image captions**: Provide captions for images sent to editors. This avoids the editor having to decide on captions, which may be incorrect because he/she may not have the technical background.
- **Provide high resolution images**: Provide high resolution images when possible.
- **Grab attention fast**: Grab the attention of the reader in the title and first paragraph.
- **Include contact details**: Include them so that readers know who to contact if they want more information.

Further reading

- Comparative mass media information (http://www.massmonopoly.com/CompetitiveMediaFacts.htm)
- Using newspapers (http://www.schools.utah.gov/ATE/Marketing/documents/curriculum/advertising/Standard6CreatingAndUsingPrintMedia/Standard6PrintMedia.pdf)
- Newspaper advertising (www.brownsvilleoregon.org/chamber/marketinghandbook1.pdf)
- Press releases (http://www.animenewsnetwork.com/how-to-format-a-press-release)

6.7 POPULAR ARTICLES

Advantages

- Can be used to communicate complicated technical issues to non-technical readers.
- Can be used for educating readers in an informal way.
- Well-written popular articles contribute to the status of the scientists who write them.
- Publishing is usually cheap.
- The printed article can be kept as a permanent record by interested readers.

Disadvantages

- Requires creative writing skills.
- Needs practice.
- You don't always have control over what appears in print. Editors may make changes without consulting you.
- Not suitable for conveying much detail.

Dos and don'ts

- **Know your goals**: Be very clear from the outset what the purpose of the article is.
- **Know where you will publish**: Know beforehand where and when it will be published (popular magazine, website, etc.) and be certain that the readership contains those you wish to target.
- **Know your subject**: The writer of the article must be an expert in the subject so that the appropriate context is conveyed.
- **Make it relevant**: Make the article relevant to something people are genuinely interested in. For example, relate it to health, the environment, their future, high-profile current events or trends, etc.
- **Tell a story**: Try to structure the article so that it tells a story.
- **Be up-to-date**: Ensure the article contains the most recent information on the topic.
- **Capture your readers quickly**: Remember that you do not have a captive audience. You will also be competing with many other articles. Attract attention with a catchy title and introduction. Do this by making your most important points first. (This is opposite to a scientific publication which gradually leads up to its final conclusions.)
- **Use recognised themes**: Consider making your story more appealing by using writing themes that are well-known to create interest. These include *conflict*, *progress* (improvements on the way things are done), *oddness* (extraordinary ideas, people, events, etc.), and *human interest*.
- **Use an easy writing style**: Don't write it like a scientific publication. Avoid jargon.
- **Be accurate**: Don't use language that is inaccurate. Although the language style should be informal, it must still be accurate.
- **Use illustrations**: Remember "a picture says a thousand words". Use appropriate and aesthetically pleasing pictures to illustrate your points.

Further reading

- Guidelines for popular articles (www.worldagroforestrycentre.org/downloads/publications/PDFS/B09400.pdf)

6.8 POSTERS

Advantages

- The location of the poster is very flexible.
- A creative poster can be a visually pleasing means of transferring information.
- Suitable for conveying simple messages.
- A poster is a permanent means of conveying a message.
- A poster is a useful mechanism for feedback to a local community after a monitoring project in their area.
- A poster can be used as a backdrop to a verbal presentation to selected small audiences.
- Such a verbal presentation can be interactive, allowing for questions and misunderstandings to be addressed on the spot.
- Can be used as an opportunity to distribute other data and information (technical reports, brochures, etc.).

Disadvantages

- Posters typically only reach a small audience.
- Not suitable for conveying very detailed messages.
- Verbal poster presentations are not suitable for large audiences because they cannot all get close enough to read it at the same time.

Dos and don'ts

- **Allow enough time**: Allow enough time to take photos, order enlargements, design and print the poster (possibly many weeks).
- **Keep it visual**: Posters are a visual information transfer medium. Use it as such. Don't only use text. Convey much of your message with photographs, graphs, diagrams, etc.
- **Keep it simple and brief**: Have some open space. Don't clutter your poster with detail that is not necessary for conveying your core message. Keep your text to the point.
- **Order sections**: Order the sections of the poster (which may be the separate A3 panels) so that they are read from top to bottom and then left to right. Consider numbering the sections, or using arrows, so that the order is clear.
- **Label sections**: Use clear section labels and state exactly what each section is about (*e.g.* Abstract, Introduction, Background, Site descriptions, Monitoring results, Conclusions, Acknowledgements, References, etc.)
- **Use a catchy title**: Keep it short and relevant and readable from 5 m.
- **Use a readable font size**: Ensure all text is readable from about 1-2 m (use not less than 18 point). Be consistent in your choice of font sizes throughout the poster.
- **Use colour**: Use colour to add extra meaning but also remember that many people are green-red colour blind.
- **Make it transportable**: A single large rolled (typically laminated) poster can be clumsy to transport. Consider producing a series of, for example, A3 panels.
- **Locate strategically**: Locate posters in places where people have the time to read and absorb them, for example, where people wait in queues (like in clinics) or spend leisure time (like tearooms). Don't place them in passages where people are not likely to stop.

Further reading

- Poster presentations (www.biophysics.org/education/block.pdf)
- Preparation guide (http://www.sou.edu/AAASPD/PosterPrep.html)
- Scientific posters (www.uic.edu/sph/dua/Churchill/Posters1.rtf)

6.9 RADIO

Advantages

- Radio stimulates the imagination.
- It speaks to millions.
- It addresses the individual (it appeals to inner thought processes).
- It is transportable (can be listened to anywhere).
- Distribution is easy and information transfer is immediate (over the air).
- Usually highly targeted (there are many radio stations catering for specific audiences). For example, community radio stations (as opposed to commercial stations) target local communities.
- Relatively low cost.
- Advertisements can be used to control the message conveyed.

Disadvantages

- Radio is transient – it leaves no trace unless specifically recorded.
- In personal interviews, you are not in total control about what is communicated. You also need to be able to think on your feet.
- There is often only a small audience in any given time slot.
- Audience may be disengaged if they are busy doing something else (like driving or working).
- Feedback on effectiveness can be slow.

Dos and don'ts (interviews)

- **Know the program***:* Be familiar with the radio program you will (or want to) appear on.
- **Structure your contact**: Don't call at random – producers and show hosts are busy and are annoyed by unsolicited telephone calls. Email them. Use a creative yet accurate title in the subject line. Be brief and perhaps refer them to a website for more (and complete) information. Make it clear who should be contacted for more information.
- **Be entertaining**: Remember that radio is entertainment. You must simultaneously inform and entertain. Be something that the audience will not expect (over-excited, outrageous, funny).
- **Be regular**: Consider becoming a regular caller with a reputation for providing the kind of value the program needs.
- **Be reliable**: Call when you say you will. Don't make the radio station look bad.
- **Keep control**: Suggest questions that can be put to you.

Further reading

- Radio interviews (Henrie, undated, URL2).
- Radio in southern Africa (Teer-Tomaselli and de Villiers, 1998)

6.10 TECHNICAL REPORTS

Advantages

- Can provide detailed explanations.
- Can provide significant amounts of data, especially in tables.
- If available in electronic form (like a .pdf file) and not too large, they can be distributed very cost-effectively by email or downloaded from websites.

Disadvantages

- Print quality is variable when distributed electronically (since it depends on the quality of the target user's printer).
- Can be time-consuming and costly for the disseminator when distributed by mail.
- Can be time-consuming for the target user when distributed by mail if he/she has to collect it personally from a Post Office because it is too large to fit into a post box.

Dos and don'ts

- **Avoid footnotes**: They are distracting.
- **Have page numbers**: Always.
- **Executive summary**: Always have one for those readers who don't have time for the detail. There are two kinds. One summarises what is actually said in the report (*e.g.* the objectives, main findings, conclusions and recommendations). Others (like the one for this manual) summarise what is dealt with but not what is actually said. This is appropriate when the report contains too much information to summarise easily. In both cases, it is often useful to structure the summary in alignment with the chapters.
- **Table of contents**: This shows how the report has been organised and allows readers to locate relevant sections quickly.
- **Lists of tables and figures (including maps)**: If the report is long, a list of table captions and another of figure captions allow readers to locate tables and figures directly.
- **Glossary**: This is particularly useful for defining terms for non-experts.
- **Introduction**: This describes why the report was produced, its objectives, scope and limitations, sources of data and information and a summary of the chapters it contains.
- **Body of report**: This contains the bulk of the detail, the data, tables, figures, and associated discussion.
- **Conclusions**: This section summarises what can be concluded from the data and information presented in the body of the report. Use Conclusions as the chapter heading, not Conclusion. (You are not concluding the monitoring. You are providing conclusions drawn from the monitoring.)
- **Recommendations**: These summarise what action should be taken as a consequence of the main findings and the conclusions. It is often useful to list these as bullet points.
- **References**: Use the Harvard system consistently and in detail. There are few things more frustrating for a reader than a reference that they think is important but cannot locate. Go to http://en.wikipedia.org and search for "Harvard referencing" to see the rules. Remember that many readers can use http://scholar.google.co.za/ to locate and download peer-reviewed articles.
- **Appendices**: Place supplementary data and information in appendices that is too bulky or unnecessary for the body of the report.

Further reading

- English punctuation for the purist (Truss, 2003)
- Technical (including mathematical) report writing (Morgan, 2005).

6.11 TELEVISION

Advantages

- Can reach a mass audience.
- Information transfer is immediate (over the air).
- Provides an opportunity to communicate creatively (using sound, colour, action, special effects).
- Audience numbers often measurable.
- Advertisements can control the message conveyed and target specific audiences.

Disadvantages

- Television is transient – like radio it leaves no trace unless specifically recorded.
- In personal interviews, you are not in total control about what is communicated. You also need to be able to think on your feet.
- Advertisement production costs can be high but depend on (a) how elaborate the advertisement is, (b) the choice of music (copyrights can be expensive), (c) whether or not actors are required and (d) the number of locations. (http://216.194.93.103/peakvisiontv/pvpages/pvtvadd.htm).
- Advertisement broadcasting costs can be high but depend on (a) the target audience, (b) the length of the advertisement, (c) the time of day it is broadcast, (d) the choice of broadcasting network and (e) the frequency of transmission.
- Not easy to target specific geographic regions.
- People in rural areas generally have less access to television than in urban areas.
- Feedback on effectiveness can be slow.

Dos and don'ts (interviews)

- **Arrive on time**: Plan to arrive well before your interview starts.
- **Plan well**: Know clearly what the message is you wish to convey before you arrive. Know how long the interview will be. Watch the programme you are appearing on beforehand to get an idea of their style.
- **Look professional**: Don't let your clothes distract the viewers.
- **Pay attention to the floor manager**: He/she will be telling you what is happening.
- **Ask for a glass of water**: It not only refreshes but can be used as a prop in emergencies.
- **Put up with make-up**: It will improve your appearance.
- **Suggest discussion points**: Ask your interviewer to cover certain points (though they have no obligation to do so).
- **Don't take notes**: Don't take notes into the studio. They can distract the audience.
- **Alcohol beforehand**: Don't even think about it!
- **Explain technical issues**: Explain technical issues carefully but without using jargon or using unnecessary detail. Remember that many viewers will not be as technically competent as you.
- **Keep replies relevant**: Don't simply answer yes or no but also don't ramble on at length. Give short relevant replies.
- **Learn from your mistakes**: Watch a recording of yourself afterwards.

Further reading

- Comparative mass media information (http://www.massmonopoly.com/CompetitiveMediaFacts.htm)
- Dos and don'ts (http://www.esrc.ac.uk/ESRCInfoCentre/about/CI/CP/best_practice_guides/television_and_radio)

6.12 VERBAL PRESENTATIONS

Advantages

- Can be interactive, allowing for questions and issues to be addressed on the spot.
- The same presentation can be tailored to different audiences with relative ease.
- Training as a presenter is readily available (for example, through Toastmasters).
- The main messages of the presentation can be permanently stored in, for example, a Powerpoint presentation. This can be made available on websites or Emailed.

Disadvantages

- Typically each presentation only reaches a small audience
- The detail and nuances of the verbal message typically cannot be stored in, for example, a Powerpoint presentation. These will therefore not be available to those who might examine the presentation in future.

Dos and don'ts

- **Practice**. Always practice your presentation. This also ensures you keep to time limits.
- **Arrive early**: Arrive early and ensure the room and all equipment are ready.
- **Use aide memoirs**: Have something to remind you what you want to say. You can use the slide presentation itself or use small cards. Only note key words or phrases so that when you are presenting you come across as more spontaneous.
- **Handle questions**: Make it clear from the outset whether or not the audience may interrupt you or rather keep questions until afterwards.
- **Make eye-contact**: Make eye-contact with as many people in the audience as possible.
- **Use interesting visuals**: Use visual tools (like maps, graphs, pictures, etc.) to make the presentation visually appealing.
- **Keep it simple**: Don't have too many words on a slide. Don't overuse special effects – they can be very distracting. Also limit the number of important messages.
- **Use laser pointers**: Only use them for diagrams or graphs, not text. Move it slowly so that the audience can keep track of it.
- **Minimise the number of slides**: Ensure the number of slides is appropriate to the time you have available. Flashing too quickly through too many slides will simply confuse the audience. Similarly, not having time for a series of slides towards the end of the presentation may cause you to miss certain critical messages.
- **Take a break**: In longer presentations use one or two blank slides or slides with pleasant pictures simply to provide your audience with a break from concentrating on your slides or to provide an opportunity to ask questions.
- **Consider handouts for note taking**: If you think your audience may wish to take notes during your presentation, it may be convenient for them to be provided with a copy of your slides with sufficient space next to each slide to make notes.
- **Consider detailed handouts**: If necessary, produce a handout with more detail that people can take away with them. Hand it out at the end of the presentation.
- **Assess and improve**: Ask experienced people how you can improve your presentation.

Further reading

- Dos and don'ts of using Powerpoint (http://www.microsoft.com/smallbusiness/resources/technology/business-software/presenting-with-powerpoint-10-dos-and-donts.aspx)
- Dos and don'ts of presentations (www.office.xerox.com/business-resources/DosANDdonts_A4.pdf)

6.13 WATER ACCOUNTS

Advantages

- Targeted at consumers of water.
- Can provide the level of contaminants detected in drinking water and a comparison with drinking water standards.
- Can provide information on the potential health impacts of contaminants in the local drinking water supply.
- Can provide information on how and why water is treated (*i.e.* addition of chlorine and fluoride).
- Creates a link between the water's source and the point of use. This improves understanding of drinking water and the environment.
- Creates an improved understanding of what variables are monitored and why. This improves understanding of factors that impact on water quality and human health.
- Promotes a client base that is environmentally aware.
- Can describe likely sources of contaminants that may occur in drinking water.
- Enables consumers to make practical decisions about their health and the environment.
- Informed consumers make wiser decisions, which in this context may include investments or initiatives made to protect and improve water quality.

Disadvantages

- Sometimes the account is not read in detail by the target audience.

Dos and Don'ts

- **Establish link to water resource**: Describe the water resources from which drinking water is obtained.
- **Define terms**: Provide a description of water quality terms, the variables that are monitored and why they are monitored.
- **Summarise results**: Give a summarised version of monitoring data and do not provide pages and pages of raw data.
- **Keep it brief**: Keep the report as short as possible.
- **Provide contact details**: Provide contact details of the water supplier.
- **Summarise contaminant levels**: Provide a summary of levels of detected contaminants compared to drinking water standards.
- **Highlight special vulnerability**: Some individuals, particularly immuno-compromised people (*e.g.* very young and very old people, persons undergoing chemotherapy or those with HIV/AIDS) may be more susceptible to certain contaminants. Highlight this in the report.

Further reading

- Drinking Water Quality Reports – Your Right to Know (https://engineering.purdue.edu/SafeWater/drinkinfo/WQ-33.htm)
- Consumer Confidence Reports (http://www.epa.gov/safewater/ccr/index.html)
- Emanti Management Group – Water Quality Information (http://www.emanti.co.za/ewqms/water_qinfo.htm)

6.14 WEB SITES

Advantages

- Readily available to people with access to the internet.
- Available at all times all over the world.
- Your message or information is easily updatable at any time and immediately available.
- Costs are relatively low.
- Web sites allow supporting information to be made available that can educate the non-technical readers.
- Large quantities of data and information can be made available for downloading on the reader's computers (*e.g.* as .pdf files) for perusal at their leisure.
- Many people expect organisations to have web sites so many will quite naturally connect to your web site when looking for information.

Disadvantages

- Not available to the many people without access to computers or cell phones with internet-access capabilities.
- Although updatable at any time, whether or not your message is received depends on the target users actively looking for your message (*i.e.* connecting to your web site).
- The use of links and hypertext may send the reader elsewhere, away from the message and information you wish to communicate.
- Not everyone with internet access has a sufficiently fast connection (broadband) to the internet to allow convenient downloading of large files.
- A badly-protected web site does provide a window onto your computer system to hackers who may want to cause harm.

Dos and don'ts

- **Update regularly**: Display the date updated. Don't design a web site and think it is finished. Keep it dynamic. Experiment with new ways of communicating your message.
- **Use multi-media**: Use them to communicate both visual images and sound.
- **Ask for feedback**: Also monitor it. Remember, internet user habits are changing rapidly. Ensure you understand your target users and how they are using your web site. Be prepared to adapt to the times.
- **Check links**: Check them regularly. However, don't provide links within your message that could result in losing communication with the reader (because they go elsewhere and do not completely read your message).
- **Have a table of contents**: This helps with navigation.
- **Identify keywords**: Think of the keywords that your target readers might use if they were looking for the kind of information you have to offer. Ensure these keywords (a) are registered with search engines and (b) appear in your message.
- **Be consistent**: Provide a consistent look and feel to all pages.
- **Use thumbnails**: Use thumbnail images (small copies) of large images that users may wish to download.
- **Low resolution**: Test your site with a low resolution screen.
- **Register your site**: Register your site with search engines and directories.
- **Include contact information**.

Further reading

- Web site design dos and don'ts (Kampherbeek, 2001).

CHAPTER 7: SCENARIO-SPECIFIC RECOMMENDATIONS

This chapter makes recommendations for some specific kinds of reporting of particular importance in South Africa.

7.1 GLOSSARY

Fitness for use. A scientific judgement, involving objective evaluation of available evidence, of how suitable the quality of water is for its intended use or for protecting the health of aquatic ecosystems.

Catchment visioning. The iterative process of evolving, over time, a more relevant and more detailed: (a) Collective statement from all stakeholders of future aspirations of the relationship between the stakeholders, in particular their quality of life in its broadest sense, and the water resources in a catchment, and (b) strategy to move towards that vision, being either the catchment management strategy itself or one that directly supports it.

Monitoring. The measurement, assessment and reporting of selected properties of water resources in a manner that is focussed on well-defined objectives.

Reserve. Defined by the National Water Act as the quantity and quality of water required: (1) To satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act (108:1997), for people who are now or who will in the reasonably near future, be (a) relying upon, (b) taking water from or (c) being supplied from, the relevant water source; and (2) To protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.

Resource quality objectives (RQOs). Numeric or descriptive (narrative) goals for resource quality within which a water resource must be managed. These are given legal status by being published in a *Government Gazette*.

Resource water quality objectives (RWQOs). Numeric or descriptive (narrative) in-stream (or in-aquifer) water quality objectives that are typically set at a finer resolution (spatial or temporal) than RQOs, and that provide greater detail upon which to base prudent management of water quality.

Water quality guideline. Information provided for a water quality constituent to support and maintain a designated water use. It includes water quality criteria for that constituent and supporting information (such as the occurrence of that constituent in the aquatic environment, the norms used to assess its effects on water users, how these effects may be mitigated, possible treatment options, etc.).

Water quality standard. A regulatory criterion with a legal status that facilitates its enforcement, usually based on a water quality guideline.

7.2 CATCHMENT ASSESSMENT

Context

Catchment assessment is the process of collating, processing and interpreting data and information about water-related conditions, issues and developments in a catchment for the ultimate purpose of providing a sound technical basis for catchment management strategies (DWAF, 2003).

Water quality is an important component of catchment assessments and the transfer of related data and information to stakeholders will be increasingly demanding in coming years as CMAs become established. It is the CMA's responsibility to evolve a catchment management strategy for their water management area.

The production of a catchment assessment report is primary a once-off endeavour taking place when a catchment management agency is first established although it may iterate and evolve considerably in this time.

Target users

The target users comprise:

- Relevant authorities, the two most important being the catchment management agency and the Department of Water Affairs and Forestry (DWAF);
- Other local stakeholders, including all users of water in the water management area.

Users of catchment assessments will therefore vary greatly in expertise.

Message to be communicated

The primary purpose of a catchment assessment is to provide useful information on a catchment for the following (DWAF, 2006b):

- Catchment visioning;
- Resource directed measures;
- Water quality management programmes and plans;
- Catchment management strategies;
- Source directed controls (particularly source-specific management interventions);
- The National Water Resource Strategy;
- Institutional development;
- Water quality reconciliation foresight and scenario planning; and
- Water resource development.

Effective stakeholder engagement is a fundamental requirement of any catchment assessment (DWAF, 2006a). Therefore, the information in the catchment assessment must be conveyed in easy-to-understand ways so that less-technical readers are sufficiently well-informed to partake effectively in the catchment visioning process.

Decision makers also play a critical role in the catchment visioning process and the implementation of the catchment management strategy. They require more detailed information to enable sound and effective informed decision making.

Recommendations

All three data categories can be reported in a catchment assessment:

- Primary data (Section 4.3). The very wide range of potential target readers makes it necessary to at least allow access to primary data to those who wish to analyse the data themselves. The data can be provided in databases or spreadsheets.
- Single-variable summary statistics (Section 4.4). Water resource and water quality managers need detailed "cause-effect" information (DWAF, 2006a) for, for example, source directed controls. Information on individual variables is therefore important.
- Multiple-variable indices (Section 4.5). All stakeholders in the catchment will require catchment-wide status and trends information.

Whatever media are used during the evolving catchment assessment process, they must allow for readers to digest and assess the data and information provided. The media must therefore provide a permanent record, at least until replaced with an updated version.

The most appropriate media in the overall process of catchment assessment are therefore the following:

- Technical reports (Section 6.10);
- Web sites (Section 6.14);
- Verbal presentations (Section 6.12); and
- Posters (Section 6.8).

Technical reports, web sites and posters provide the data and information in a way that can be perused at leisure. Verbal presentations, sometimes using posters, are essential for not only conveying important messages personally but also for allowing for face-to-face engagement with stakeholders. This allows them to raise uncertainties and concerns and for the presenter to deal with these on the spot.

Based on **Table 2** the following tools are appropriate for presenting the three data types in these media:

- Charts (Section 5.3);
- Diagrams (Section 5.4);
- Graphs (Section 0);
- Icons (Section 5.6);
- Maps (Section 5.7);
- Photographs (Section 5.8); and
- Tables (Section 5.10).

7.3 ANNUAL NATIONAL STATE OF WATER RESOURCES

Context

Chapter 14 of the National Water Act (Act No. 36 of 1998) specifically requires the Minister to establish national monitoring systems that can assess, among other matters, the quality of water resources and the health of aquatic ecosystems. Annual national state of water resources reports rely on data collected from these monitoring programmes to provide an overview of the aquatic resource (*i.e.* rivers, wetlands, groundwater and impoundments) quality conditions in South Africa. This includes characterising water quality, identifying water quality problems of national significance, and the description of measures and programmes that are in place to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled in a sustainable way.

Currently, the following national programmes are being implemented or have been designed:

- **National Chemical Monitoring Programme (NCMP)**. Monitors the status and trends of major inorganic ions and attributes such as pH, electrical conductivity, etc.
- **National Microbial Monitoring Programme (NMMP)**. Monitors the status and trends of either faecal coliforms or *E. coli*. Surface water monitoring has been implemented in some water management areas. The design for groundwater microbial monitoring has been developed.
- **National Eutrophication Monitoring Programme (NEMP)**. Monitors the status and trends of mainly chlorophyll a and total phosphorous in impoundments only and determines their trophic status (oligotrophic, mesotrophic, trophic, hypertrophic). It also monitors algae and cyanobacteria. It also monitors inputs and impacts of nutrients from anthropogenic sources and the performance of remediation measures.
- **National Toxicity Monitoring Programme (NTMP)**. Monitor status and trends of (a) toxic effects on selected organisms (algae, invertebrates and fish), and (b) selected individual toxicants in water (including some persistent organic pollutants (POPs)). A design is currently being tested.
- **National Radioactivity Monitoring Programme (NRMP)**. Monitors the status and trends of radioactivity. A design has been developed.
- **Ecological Reserve Determination and Monitoring**. Will monitor the status and trends and compliance of those variables important to the ecological Reserve.

Target users

The users of the monitoring information are specifically those that are interested in a more strategic (national and long-term) perspective of the state of water quality in water resources. While catchment management agencies (CMAs) are likely to be delegated the responsibility for implementing national programmes, target users go well beyond CMAs. However, CMAs can (and, indeed, should) benefit directly from the information contained in national reports.

Primary target users include:

- The Minister of Water Affairs and Forestry;
- DWAF Director General;
- Water Resource Quality Managers and Water Quality Managers (DWAF head office and regional offices);
- Water Management Institutions (like catchment management agencies); and
- Water User Associations.

Secondary target users include:

- National, provincial and local government authorities;
- Non-Government Organisations;
- All industrial sectors; and
- Public.

Message to be communicated

The generic objectives are:

- To measure, assess and report on a regular basis the status and trends relating to water quality in South African water resources, in a manner that will support strategic management decisions in the context of fitness for use of water resources and aquatic ecosystem integrity (DWAF, 2006c).
- To produce a clear overview of the state of the country's water resources.
- To produce an integrated report (for various reporting requirements) on the various components of the water cycle.
- To provide information on the factors that impact on the status and sustainable use of our water resources.
- To promote better management and protection of our water resources by making information on the state of water resources available to all stakeholders on an annual basis.
- To identify issues that need to be addressed, important information gaps and emerging water problems

"Strategic" is used in the sense of being large in scale, both spatially and temporally. The spatial scale is national and the temporal scale for reporting would typically be annual.

Recommendations

The strategic nature of national programmes requires two levels of information communication:

- Multiple-variable indices (Section 4.5). Use these for those who wish to simply have an idea of whether the situation is "good or bad" or "worsening or improving". These include all the primary and secondary target users noted above. Indices are particularly useful for the Minister and the public.
- Single-variable summary statistics (Section 4.4). Water resource and water quality managers need more detailed information that helps them identify what the causes of the problems might be. Information on individual variables is therefore important.

The following media are the most appropriate for the bulk of the message:

- Technical reports (Section 6.10); and
- Web sites (Section 6.14).

To provide summaries that can be easily distributed, the following medium can be used:

- Brochures (Section 6.3).

Based on **Table 2** the most appropriate tools for presenting the data in the above media are:

- Charts (Section 5.3);
- Diagrams (Section 5.4);
- Graphs (Section 0);
- Icons (Section 5.6);
- Maps (Section 5.7);
- Photographs (Section 5.8); and
- Tables (Section 5.10).

If serious water quality problems arise that are of immediate national or regional importance, the following media (with the indicated tools, **Table 2**) should be considered to communicate (a) the nature of the problem, (b) the extent of the problem (typically with multiple-variable indices) and (c) ways of dealing with the problem:

- Television (Section 6.11);
- Radio (Section 6.9);
- Newspapers (Section 6.6);
    - Icons (Section 5.6); and
    - Photographs (Section 5.8).
- Water accounts (Section 6.13);
    - Icons (Section 5.6);
- Billboards (Section 6.2);
    - Icons (Section 5.6); and
    - Photographs (Section 5.8).

7.4 STATE OF DRINKING WATER

Context

Access to a constant supply of safe drinking water is a basic human right and essential to people's health and well-being. DWAF, as national custodian of the country's water resources, has the ultimate responsibility for water services which include the management of information to be used for support, monitoring, regulation, and planning purposes. Local government, through the constituted Water Services Authority (WSA), is primarily responsible for the provision of water services and hence the provision of safe drinking water (DWAF, 2005).

A number of legislative provisions, frameworks and strategies pertaining to water services, make provision for the supply and regulation of safe drinking water quality. The Drinking Water Quality Framework in particular, has been prepared to enable effective management of drinking water quality to protect public health. The Framework presents an integrated system of approaches and procedures to address and report on key factors that govern drinking water quality protection (DWAF, 2005).

As water services providers, the WSAs are required to implement suitable monitoring programmes which address both operational and compliance aspects. These monitoring systems have to be registered with DWAF and results must be submitted to DWAF (DWAF, 2008). Reporting is to take place at regular intervals (*i.e.* monthly, quarterly and annually) in order to provide a basis for effective communication within the organisation and with various stakeholders. It is to furthermore ensure that relevant stakeholders receive information required to make informed decisions about the management or regulation of drinking water quality.

Target users

The primary users of this information include:

- Regulatory authorities;
- Water Services Authorities;
- Department of Health;
- Parliamentarians; and
- Public (consumers).

Message to be communicated

The overall objective of monitoring and reporting on drinking water quality is to enable effective management of drinking water quality to protect public health. Drinking water quality results have to be made available to consumers and appropriate authorities and any health risks must be communicated to consumers.

The Drinking Water Quality Framework (DWAF, 2005) proposes that the following drinking water quality information be communicated where relevant to consumers and other stakeholders:

- A monthly summary of the compliance of drinking water quality during the month. This information is also useful for benchmarking purposes. Benchmarking plays an important role in assessing the performance of a water services authority or institution against other institutions. This promotes learning and exchange of information;
- A quarterly compliance assessment of each WSA against the Compulsory National Standards for the Quality of Potable Water. These audits can also be used to determine the required regulatory intervention, assess progress in achieving drinking water quality compliance, and recommend Municipal Infrastructure Grant and Capacity Building Grant funding where capacity is lacking.

- An annual summary of drinking water quality performance over the preceding year against numerical guideline values and regulatory requirements. This includes targets for water services quality, performance against targets, interventions undertaken to improve water services, system failures and actions taken to resolve them.

Recommendations

Drinking water quality information has to be communicated in various ways that would address the requirements of a broad range of stakeholders.

Reporting on all three data categories is appropriate:

- Primary data (Section 4.3). Drinking water quality monitoring takes place on a frequent basis (*i.e.* daily, weekly, etc). Some of the stakeholders may wish to analyse the data themselves. It is therefore necessary to be able to provide access to this data through databases or websites.
- Single-variable summary statistics (Section 4.4). Water resource management authorities require detailed information that helps them identify what the causes of problems might be or whether or not targets and standards are being met. Information on individual variables is therefore important.
- Multiple-variable indices (Section 4.5). These are useful for consumers in particular those who simply wish to know whether the quality of their drinking water is "good" or "bad" or is "worsening" or "improving".

The following media are most appropriate:

- Emails (Section 6.4);
- Newspaper, radio and television ads (Sections 6.6, 6.9 and 6.11);
- Newspaper articles (Section 6.6);
- Radio and television interviews (Section 6.9 and 6.11);
- Technical reports (Section 6.10);
- Verbal presentations (Section 6.12);
- Water accounts (Section 6.13); and
- Web sites (Section 6.14).

The most appropriate tools for presenting the data in the above media are:

- Charts (Section 5.3);
- Diagrams (Section 5.4);
- Graphs (Section 0);
- Icons (Section 5.6);
- Maps (Section 5.7);
- Photographs (Section 5.8);
- Tables (Section 5.10).

7.5 PERFORMANCE MONITORING OF RQOS

Context

Performance monitoring refers to the ongoing water resource monitoring of the degree to which the conditions in the resource are in accordance with objectives that have been defined for that resource. In performance monitoring these objectives are specifically "Resource Quality Objectives (RQOs)".

RQOs have a formal legal status while Resource Water Quality Objectives (RWQOs) do not. RWQOs facilitate management of the water resource towards achieving the RQOs. RWQOs may therefore have a higher spatial and temporal resolution than the RQOs (DWAF, 2006c). (See Glossary for definitions.)

Only water quality aspects are addressed in this section.

Target users

The primary responsibility for management and implementation of performance monitoring programmes, and compliance with the Reserve and RQOs, will lie ultimately with the catchment management agency (CMA) (DWAF, 2006c). Therefore the CMA will be the primary target user.

Message to be communicated

The generic objectives are (DWAF, 2006c):

- To measure, assess and report on a regular basis:
    - The degree to which the resource water quality complies with the requirements of the determined ecological Reserve; and
    - The degree to which present resource water quality conforms to (a) resource quality objectives (RQOs) relating to water quality, and / or (b) resource water quality objectives (RWQOs); and hence
    - Whether a water resource is within its designated management class (in respect of water quality).

The message to be communicated to the CMA must therefore cover these three objectives.

Recommendations

Because the Reserve and RQOs have a significant legal status, the confidence with which results are reported should be as high as possible. The most important issue is the relationship between the present state of the resource and its designated management class. The RQOs themselves are the objectives against which monitoring data are assessed (DWAF, 2006c).

Assessments of RWQOs need not be as formal, although it will be sensible to perform the same kinds of assessments as RQOs (since these protocols will exist anyway).

The recommended data categories, tools and media are the same as those for national status of water resources (Section 7.3).

7.6 COMPLIANCE MONITORING

Context

Compliance monitoring refers to the ongoing monitoring of the degree to which a water user is meeting the terms stated in a water use licence.

Water use covers a wide spectrum. The National Water Act (No. 36 of 1998) states these include taking and storing water, activities which reduce stream flow, waste discharges and disposals, controlled activities (activities which impact detrimentally on a water resource), altering a watercourse, removing water found underground for certain purposes, and recreation. However, only those affecting water quality are addressed here.

The Act also states that in general a water use must be licensed unless it is listed in Schedule 1 (a list of permissible uses of water), is an existing lawful use, is permissible under a general authorisation, or if a responsible authority waives the need for a licence. This water use licence is issued by the relevant authority and explicitly states what conditions must be met by the water user. These conditions may include monitoring of:

- Conditions existing at "end-of-pipe" (the point of discharge of any water containing waste); and
- Conditions in the receiving water resource, possibly both upstream and downstream of any discharge.

Target users

The primary users of the monitoring information are the following (DWAF, 2006c):

- **The water user**. The information will indicate to the water user the extent to which adequate measures have been taken to limit and control the likely impacts on water quality in the local water resource. Non-compliance can indicate the need for pro-active corrective actions by the water user.
- **The relevant authority**. The information will indicate whether or not the water user is complying with the conditions of the water licence. Non-compliance may lead to a number of possible actions by the authority in order to ensure compliance.

Message to be communicated

The generic objectives are (DWAF, 2006c):

- To measure, assess and report on a regular basis the degree to which individual water users are:
    - Complying with the "end-of-pipe" conditions defined in their water use licence (if any); and
    - Impacting on the local water resource water quality.

The message to be communicated must therefore cover these two objectives.

Recommendations

There are two management responsibility perspectives (DWAF, 2006c):

:

- **The water user**. The primary responsibility for licence compliance monitoring lies with the individuals or organisations whose water use is being monitored. Licence conditions typically stipulate upstream and downstream monitoring and monitoring of any discharge of water containing waste.
- **The relevant authority**. The authority has the responsibility to audit these results by occasionally performing their own sampling and analysis.

Measured data will usually need to be compared with (assessed against) stipulated conditions. These can include any of the following:

- End-of-pipe effluent data can be compared with General or Special Effluent Standards.
- Water resource measurements can be compared with:
    - South African water quality guidelines (among others); or
    - Resource Water Quality Objectives (RWQOs) back-calculated from Resource Quality Objectives that may exist downstream.

Reporting the following data categories are appropriate:

- Primary data (Section 4.3). Monitoring is likely to be fairly frequent (weekly or perhaps monthly for surface waters). In the case of groundwater, the monitoring frequency will be less frequent (possibly six-monthly). However, the reporting frequency should be sufficiently frequent to allow for prompt action when deviation from stipulated conditions occurs. Therefore, reports are not likely to be communicating large amounts of data so presenting primary data is acceptable.
- Single-variable summary statistics (Section 4.4). Simple statistics, like minima and maxima, can help the reader quickly identify instances of non-compliance. If the water use licence states conditions in terms of statistics like averages or percentiles, then these would naturally be reported.

The following media are the most appropriate:

- Very short technical reports (Section 6.10). Since reporting is frequent, only very brief introductions and conclusions are necessary.
- Email attachments (Section 6.4). These can be the short technical reports or be spreadsheets. Spreadsheets are useful because tables can be very conveniently analysed (*e.g.* compared with licence conditions) and graphs easily produced.

Based on **Table 2** the most appropriate tools for presenting the data in the above media are:

- Tables (Section 5.10);
- Charts (Section 5.3); and
- Graphs (Section 0). Time-series graphs, exceedence diagrams, and box-and-whisker plots are appropriate.

All should contain clear presentations of the stipulated conditions against which actual monitoring results can be compared. Emphasis must be on using the tool in such a way that this comparison can be made at a glance.

CHAPTER 8: UNDERSTANDING A WATER QUALITY COMMUNICATION

This chapter is fundamentally different from the others.
It is aimed primarily at those people *receiving* a water quality communication.
However, it will also be useful to those preparing such a communication.
It provides basic information that can help better understand a water quality communication.

8.1 INTRODUCTION

Unfortunately, understanding water quality is not as easy as many might think, as is evident from its definition (see Glossary below). An expert in water quality needs to be a "Jack of all trades". It involves, for example, chemistry, biology, microbiology, and biotoxicology and various other skills.

No matter how professional the communication of data might be (as described in Chapters 2 through 7) if target readers do not have a certain minimum degree of expertise in such disciplines, they are likely to misunderstand what is presented to them. This can greatly diminish the potential value that can be achieved from the hard work and resources that have gone into obtaining the primary measurements and presenting them in a professional communication.

While this manual cannot hope to replace basic courses in these disciplines, it can present very brief summaries of core concepts relating to water quality that can serve to jog memories or prompt further reading. The primary target readers of this chapter are primarily those who *receive* the carefully prepared water quality communication no matter what its form. However, it is also useful to those preparing such a communication and those who train such people.

All the disciplines presented relate directly to water quality which is only one dimension of the more general context of water ecosystems. For a good and simple summary of water ecosystems in general see Palmer *et al.* (2002).

This chapter is deliberately very brief. It provides individual glossaries, identifies some common misunderstandings and provides some basic reminders about a few of the fundamentals important to understanding water quality. The contents of this chapter can be made available to those receiving water quality communications in the following ways:

- Provide this whole manual;
- Photocopy and supply only the relevant pages; or
- Copy and paste relevant sections from an electronic version of this document into communications like technical reports.

8.2 WATER QUALITY GUIDELINES

8.2.1 Glossary

Water quality. The physical, chemical, radiological, toxicological, biological and aesthetic properties of water that (1) determine its fitness for use or (2) that are necessary for protecting the health of aquatic ecosystems. Water quality is therefore reflected in (a) concentrations of substances (either dissolved or suspended), (b) physico-chemical attributes (e.g. temperature), (c) levels of radioactivity and (d) biological responses to those concentrations, physico-chemical attributes or radioactivity.

Water quality constituent. Any of the properties of water and / or substances dissolved or suspended in the water. The term constituent is used interchangeably with variable, determinant or characteristic.

Water quality criteria. Numerical and qualitative descriptors for a given water quality constituent describing its potential effects on selected endpoints and water users.

Water quality guideline. Information provided for a water quality constituent to support and maintain a designated water use. It includes water quality criteria for that constituent and supporting information (such as the occurrence of that constituent in the aquatic environment, the norms used to assess its effects on water users, how these effects may be mitigated, possible treatment options, etc.).

8.2.2 How to use them

The South African water quality guidelines are available for the following:

Fresh Water (DWAF 1996a):

- Volume 1: Domestic Water Use
- Volume 2: Recreational Water Use
- Volume 3: Industrial Water Use
- Volume 4: Agricultural Water Use: Irrigation
- Volume 5: Agricultural Water Use: Livestock Watering
- Volume 6: Agricultural Water Use: Aquaculture
- Volume 7: Aquatic Ecosystems
- Volume 8: Field Guide

Coastal Marine Waters (DWAF 1996b):

- Volume 1: Natural Environment
- Volume 2: Recreational Use
- Volume 3: Industrial Use
- Volume 4: Mariculture

The South African water quality guidelines (available both in hard-copy reports and on CD) provide a wealth of information of individual water quality constituents and variables. This information includes:

- Their occurrence in the environment.
- Interactions between constituents.
- Their effects at different levels.
- Methods for their measurement.
- Mitigation options that reduce their levels.
- Water treatment options.
- Water quality criteria (ranges with corresponding effects).
- References to sources of information (including the guidelines of other countries and organisations).

Actual measurements of a water quality variable can be compared with the water quality criteria for that variable (presented as a "No Effect Range" and a "Target Water Quality Range") for a specific water use. This provides an indication of whether or not the water from which the sample was taken is fit (*i.e.* suitable) for that use, at least in respect of the variables for which such comparisons are made. This is a very simple and useful assessment of data.

It is important to remember that the guidelines are just that, *guidelines*. They provide guidance. They are not legally enforceable unless specifically defined so in, for example, a water use licence.

While they might be very easy to use, they also have some fundamental shortcomings:

- Without due consideration being given to the supporting text, the numbers constituting to water quality criteria can easily be misused.
- The South African water quality guidelines are generic. This means that they are assumed to apply everywhere in South Africa. This is a very important assumption.
- They may be either over- or under-protective in specific situations. Indeed, since they are generally conservative, they may often be over-protective.
- Some are unrealistic because they are below analytical detection limits. This means it is not possible in practice to monitor them effectively.

These limitations must be borne in mind whenever the guidelines are used.

It is worth noting here that an initiative is underway in the Department of Water Affairs and Forestry (DWAF) to develop new guidelines that are more explicitly risk-based and are able to be applied in a wide variety of site-specific situations (DWAF, 2008).

The guidelines for domestic use are also available in a user-friendly colour-coded document (DWAF, DOH, WRC 1998). A national standard is also available for drinking water (SANS 241).

8.3 BASIC CHEMISTRY

8.3.1 Glossary

Adsorption. The binding of a chemical (which is usually charged) to the surface of a solid.
Anion. A negatively charged ion (*e.g.* SO_4^{2-} is the sulphate ion).
Atom. The smallest quantity of an element that can take part in a chemical reaction (*e.g.* H, C, O, Cu, Zn, etc.).
Cation. Positively charge ion (*e.g.* Ca^{2+} is the calcium ion).
Heavy metal. Metallic elements with atomic number greater than 20 (*i.e.* that of calcium)
Ion. A charged atom (see ***Anion*** and ***Cation***).
Molecule. The simplest unit of a chemical that can exist, consisting of two or more atoms held together by chemical bonding (*e.g.* NaCl is solid sodium chloride or table salt, H_2O is water).

8.3.2 The elements

The periodic table is an arrangement of atoms in increasing order of size, read from left to right: H, He, Li, Be, B, C, and so on. The position of an atom in the periodic table gives an indication of the atom's properties. For example, **Figure 29** indicates the metals (bold) and non-metals (not bold) respectively.

H																	He
Li	**Be**											B	C	N	O	F	Ne
Na	**Mg**											**Al**	Si	P	S	Cl	Ar
K	**Ca**	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	As	Se	Br	Kr
Rb	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	Te	I	Xe
Cs	**Ba**	*L*	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**	**Po**	At	Rn
Fr	**Ra**	*A*															
		L	**La**	**Ce**	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
		A	**Ac**	**Th**	**Pa**	**U**	**Np**	**Pu**	**Am**	**Cm**	**Bk**	**Cf**	**Es**	**Fm**	**Md**	**No**	**Lr**

Figure 29: The metal elements (bold) and non-metal elements (not bold)

The so-called heavy metals are usually defined as those higher in the sequence than calcium (Ca). Therefore H, Li, Be, Na, Mg, Al, K and Ca are not regarded as heavy metals. **Table 9** gives the names of some of the more common elements in the water quality field.

Table 9: Some common elements and their names

H	Hydrogen	Mg	Magnesium	K	Potassium	Zn	Zinc
C	Carbon	Al	Aluminium	Ca	Calcium	As	Arsenic
N	Nitrogen	Si	Silicon	Cr	Chromium	Sr	Strontium
O	Oxygen	P	Phosphorous	Mn	Manganese	Cd	Cadmium
F	Fluorine	S	Sulphur	Fe	Iron	Hg	Mercury
Na	Sodium	Cl	Chlorine	Cu	Copper	Pb	Lead

If the element symbol is used without any charge then it usually refers to the element in whatever form it might occur in the water, *i.e*. irrespective of its speciation (see Section 8.3.6 below).

8.3.3 Anions and cations

Chemicals can occur in a wide variety of categories. One category is based on their charge:

- Positively charged ions (cations). See **Table 10** for examples.
- Negatively charge ions (anions). See **Table 11** for examples.
- Neutral (uncharged) molecules. An example is dissolved oxygen (O_2).

Table 10: Some common cations and their names

NH_4^+	Ammonium ion	Fe^{3+}	Ferric (iron) ion	Ni^{2+}	Nickel ion
Al^{3+}	Aluminium ion	H^+	Hydrogen ion	K^+	Potassium ion
Cd^{2+}	Cadmium ion	Pb^{2+}	Lead ion	Na^+	Sodium ion
Ca^{2+}	Calcium ion	Mg^{2+}	Magnesium ion	Zn^{2+}	Zinc ion
Cu^{2+}	Cupric (copper) ion	Mn^{2+}	Manganese ion		
Fe^{2+}	Ferrous (iron) ion	Hg^{2+}	Mercury ion		

Table 11: Some common anions and their names

CO_3^{2-}	Carbonate ion	OH^-	Hydroxide ion	SO_4^{2-}	Sulphate ion
Cl^-	Chloride ion	NO_2^-	Nitrite ion	S^{2-}	Sulphide ion
CN^-	Cyanide ion	NO_3^-	Nitrate ion		
F^-	Fluoride ion	PO_4^{3-}	Phosphate ion		

Strictly, the charge is shown explicitly whenever the ion is referred to. However, it is often omitted when (a) it is obvious that only one ion can possibly be relevant and (b) which ion it is commonly understood. In any water, the total negative charge must equal the total positive charge. Therefore, a comparison of these is often made from water quality analyses of the major ions. If they are not balanced, this can mean:

- A major ion has not been analysed; or
- One or more of the analytical measurements is in error; or
- Both the above.

8.3.4 Concentration units

The amount of a chemical in water is usually expressed as a concentration, namely an amount of the substance per unit of volume. A common concentration unit is milligrams per litre (mg/ℓ). Another unit is millimoles per litre (mmol/ℓ) = (mg/ℓ) / (molar mass). The molar mass is expressed in g/mole (= mg/mmole). So 100 mg/ℓ SO_4^{2-} = 100 / (32.07 + 4x16.00) = 100 / 96.07 = 1.04 mmol/ℓ. However charge is usually expressed as milliequivalents per litre (meq/ℓ) = (charge on the ion) x (mg/ℓ) / (molar mass). For example, 10 mg/ℓ Ca^{2+} contributes 2 x 10 / 40.08 = 0.50 meq/ℓ to the overall positive charge. Molar masses can be obtained from most periodic tables.

8.3.5 Organic compounds

Organic compounds all contain carbon (C) and usually hydrogen (H) and sometimes other elements like oxygen (O), nitrogen (N) and sulphur (S). The number of organic compounds is enormous many of which occur naturally in the environment. Organic compounds are used in a very wide variety of applications, many of which result in their entering the natural environment.

Many degrade naturally, albeit at vastly different rates. However, many can produce breakdown products that are themselves toxic (Murray *et al.*, 2003b).

Problematic organic compounds include the following:

- **Pesticides**. These are substances or mixtures of substances intended (i) for preventing, destroying, repelling or mitigating any pest or (ii) for use as a plant regulator, defoliant or desiccant [World Bank, 1999].
- **Petroleum products**. These comprise another extremely wide range of chemicals that occur in, or are derived from, petroleum.
- **Surfactants**. These impart properties such as foaming and particle suspension
- **Pharmaceuticals**. Pharmaceutical compounds comprise drugs and medicinal chemicals used for both humans and animals.
- **Naturally occurring organic toxicants**. A particularly important class of organic toxicants is the cyanotoxins. They are released into the water when the cells of cyanobacteria (also called blue-green algae) are ruptured (*e.g.* by decay or algicides).

Generally, organic compounds tend to occur in low concentrations in water. Because of this, and their great variety, it is usually more difficult to analyse for them.

8.3.6 Chemical speciation

Chemicals in water, especially the charged ones, tend to exist in the water in a number of different forms. The positive charges of cations and the negative charges of anions are attracted resulting in a certain fraction of each existing as bound molecules which remain dissolved.

The extent to which this occurs varies widely. Some like Na^+ and Cl^- bind very weakly and at the low concentrations typical in many rivers, can be regarded as hardly binding at all. Others like PO_4^{3-} and even CO_3^{2-} can bind to cations like Ca^{2+} and Cu^{2+} quite strongly.

Another example is ammonia (NH_3). Ammonia in the form of NH_3 is toxic. However, the ammonium ion (NH_4^+) is not. In the absence of any metals (some of which bind strongly and in complicated ways to ammonia), well above a pH of about 9 it exists as NH_3. Well below about 9 it exists only as NH_4^+.

Most analyses for a chemical provide the total concentration of the chemical in the sample. However, some samples are filtered before analysis. This removes forms of the chemical that may exist in solid particles (having precipitated) or bound (adsorbed) to solid surfaces.

8.3.7 pH

pH is a measure of the degree to which the water is either acid (if pH is less than 7) or alkaline (if greater than 7). pH is a very important water quality variable. This is because the pH has significant effects on the speciation of many chemicals and hence on their behaviour (as described for ammonia above).

For example, any dissolved carbonate in the water will be given off to the air as the gas carbon dioxide (CO_2) if the pH becomes very acidic. Acidic waters also dissolve carbonate rocks. When acidic waters dissolve dolomite (a calcium magnesium carbonate, $CaMg(CO_3)_2$) this can cause sink holes in which huge underground caverns are formed into which the ground above can catastrophically collapse. Acidic waters also tend to dissolve metals. This can, for example, mobilise metals from sediments, soils and rocks.

8.4 BASIC BIOTOXICOLOGY

This section is based on the implementation manual of the National Toxicity Monitoring Programme (DWAF, 2005) which can be consulted for more detail.

8.4.1 Glossary

Acute effect. See ***short-term effect.***
Biotoxicology. The qualitative and quantitative study of the adverse effects of chemical pollutants and other anthropogenic materials on living organisms.
Carcinogenicity. The extent to which a substance can cause cancer.
Chronic effect. See ***long-term effect***.
Definitive test. An experimental technique that estimates the concentration of the toxicant at which a specified percentage or number of organisms exhibit a certain response. Typically reported as a toxicity endpoint, *e.g.* Lethal Concentration (LC), Effect Concentration (EC), Inhibition Concentration (IC), No Observed Effect Concentration (NOEC), etc.
Endocrine disruption. The extent to which a chemical mimics, blocks or alters functions of natural hormones.
Lethality. The extent to which a toxicant can cause death by direct action.
Long-term effect. Any toxic effect (lethal or sublethal) that manifests over a long period (4 days or more) as a result of exposure to the toxicant. Also referred to as a chronic effect.
Long-term exposure. Exposure of the organism to the toxicant delivered in multiple events or continuously over a long period, generally weeks or more. Also referred to as chronic exposure.
Mutagenicity. The extent to which a substance can damage or change an organism's or cell's genetic material.
Screening test. A toxicity test performed on the water or test sample "as is", *i.e.* without dilution. Typically reports a percentage effect or a yes/no result.
Short-term effect. Any toxic effect (lethal or sublethal) that manifests within a short period (4 days) as a result of exposure to the toxicant. Also referred to as an acute effect.
Short-term exposure. Exposure of the organism to the toxicant delivered in a single event or multiple events over a short period, generally hours or days. Also referred to as acute exposure.
Sub-lethality. The extent to which a toxicant is detrimental without causing death.
Target organism. The biological system of concern that will potentially manifest one or more toxic effects.
Teratogenicity. The extent to which a substance is capable of causing the formation of congenital anomalies. (Thalidomide is a well-known teratogen.)
Test organism. The organism used in a toxicity test.
Toxicant. A chemical substance capable of exhibiting a toxic effect.
Toxic effect. A dose-related effect manifest as an impairment of the activity of the organism or the cellular or sub-cellular system. In the current context, these effects are also limited to those that can be detected, either currently or potentially, locally or internationally, by a "toxicity test", as defined here.
Toxicity. In the current context, the degree to which a water exhibits toxic effects.
Toxicity test. An experimental procedure that measures, under defined conditions in the laboratory or in the field, the toxic effects of chemical pollutants in water on a group of living organisms or a cellular or sub-cellular system.

8.4.2 The nature of toxicity

An important basic principle of toxicology is that no chemical is completely safe and no chemical is completely toxic (Rand and Petrocelli, 1995). Even apparently harmless chemical substances can have toxic effects when taken up by an organism in sufficient amounts. Conversely, uptake of small amounts of some toxic chemicals may result in no apparent toxic effect.

For a substance to produce a toxic effect on aquatic or other organisms, the following must occur.

- The substance must come into contact with the organism; and
- It must react with an appropriate receptor site on the organism (a) at a high enough *concentration*, and (b) for a *sufficient length of time*.

Toxicants can affect organisms on land, in the air and in natural waters. However, the current context is restricted to those organisms, including humans, which use or rely on South African fresh and estuarine water resources.

Toxic effects can be reported in three contexts:

- **Short-term versus long-term effect**: One broad classification of toxic effect relates to the time required for the effect to manifest itself. Short-term effects can refer to those toxic effects that manifest relatively quickly (within hours or days). On the other hand long-term effects can refer to those that take longer to manifest. These terms are also commonly referred to as acute and chronic effects. Reporting toxic effects as short-term or long-term is useful to a water quality manager. If water from a particular river reach exhibits acute toxicity to fish, this serves as an immediate red flag in respect of the general health of fish populations and diversity in that area.
- **Lethal or sub-lethal**: The next most obvious distinction that one can make in respect of the nature of toxic effects is whether the effect is lethal or not (*i.e.* sub-lethal). Lethality is usually a short-term effect.
- **Type of sub-lethal effect**: If the effect is sub-lethal, then the type of effect can be reported. Sub-lethal effects include a very wide variety of adverse responses to exposure to toxicants. Typical sub-lethal effects in aquatic organisms include the following [Rand and Petrocelli, 1995]:

  Biochemical and physiological effects. These include effects related to enzyme inhibition, clinical chemistry, haematology and respiration.

  Behavioural effects. Typical behavioural effects include locomotion and swimming, attraction-avoidance, predator-prey relationships, aggression and territoriality and learning.

  Histological effects. These relate to structure and chemical composition of the animal or plant tissues as related to their function.

  Some biochemical and physiological effects can also apply to humans and other mammals. These include mutagenicity, carcinogenicity, tumour promotion, teratogenicity, oestrogenicity and endocrine disruption.

8.4.3 Factors affecting the degree of toxicity

- **Toxicant properties**. These include chemical speciation, purity and specificity to the target organism.
- **Organism factors**. These refer to all factors that determine the susceptibility of the organism to the toxicant, including the life cycle stage, the degree of stress, toxicant excretion rates, genetic selection, metabolic rates, etc.

- **Exposure factors**. These include the mode of exposure (skin contact, ingestions, etc.) and the degree of exposure (exposure time, concentration of toxicant, and frequency of exposure)

8.4.4 Measuring toxicity

Toxicity tests measure directly the degree (*i.e.* extent) of toxicity on specific target organisms. Slabbert *et al.* (1998) should be consulted for more detailed information on various toxicity test methodologies. A wide variety of scenarios and issues are relevant when choosing an appropriate toxicity test.

- ***In situ* versus laboratory**. Some tests are designed to take place in the natural water itself while others require water samples to be transported to a laboratory where the test takes place. Most single-species tests are conducted in the laboratory. Such tests are convenient because they allow a much greater degree of control than those performed in the field. However, the usefulness of tests done in the laboratory will depend on the criteria used to choose the organism. One limitation of such tests is that the effects observed in the laboratory may not occur in exactly the same way in the natural environment.
- **Short-term versus long-term effect**. Some tests are specifically designed to measure effects over the short term and others over the long term. Common short-term tests include measuring fish and invertebrate lethality or algal growth over a fixed period of time. Long-term tests typically can involve exposing organisms to the toxicant over an entire reproductive cycle or part of it and measuring growth and reproduction (Rand and Petrocelli, 1995).
- **Lethal versus sub-lethal**. Lethality can be measured in terms of the percentage of a selection of test organisms that die within the test period. The degree to which sub-lethal effects manifest themselves is also usually reported quantitatively, most commonly as a percentage effect. In particular, this usually refers to the percentage of organisms (or activity) affected.

8.4.5 The nature of toxicants

Toxicants in general can occur in a very wide variety of physical forms, including dusts, fumes, mists, vapours and gases, liquids and solids (Sax, 1974). In the current context, toxicants are confined to chemical pollutants capable of exhibiting a toxic effect.

Toxicants include inorganic compounds, endocrine disrupting compounds, pesticides, persistent organic pollutants, petroleum products, surfactants, pharmaceuticals. There are also naturally occurring toxicants like cyanotoxins that are released into water when the cells of cyanobacteria (also called blue-green algae) are ruptured (*e.g.* by decay or algicides).

8.4.6 Factors affecting toxicant concentrations

- **Toxicant properties**. These include their molecular structure, solubility in water, reactivity, resistance to degradation, etc.
- **Aquatic environment properties**. These include temperature, salinity, pH, suspended solids, depth, flow, sediment particle size, etc.

8.4.7 Measuring toxicant concentrations

The analytical measurement of the concentration of toxicants depends primarily on the nature of (a) the toxicant and (b) the medium in which it occurs. In the current context, three media are possible, namely water, sediment and biological organisms (like fish).

Water is the most common non-gaseous medium in which toxicants occur and is the medium for which most analytical techniques have been developed. The concentration of the toxicant is a well-defined quantity expressed as the amount (usually as mg or µg) per unit volume (usually litre).

In respect of sediments and organisms, toxicants are often thought of as accumulating in these media. Sediments can act as sinks in which toxicants can gradually increase in concentration over time, even though the concentration in the bulk water (with which it is in contact) might remain fairly constant.

Accumulation of toxicants in the organs and tissues of biological organisms is referred to as bioaccumulation. For example, some fish accumulate pesticides and heavy metals.

The toxicant typically needs to be extracted from the sediment or organism into a liquid phase (water or an organic solvent). This liquid phase is then subjected to analytical measurement.

Various reference methods for some toxicants are suggested in the South African Water Quality Guidelines (DWAF, 1996). For more detail these guidelines should be consulted. For details on some individual analytical methods, the latest Standard Methods (1998) can be consulted.

8.5 BASIC MICROBIOLOGY

8.5.1 Glossary

Bacteriophage. A virus that uses bacteria as its host *i.e.* it infects bacteria.
Bacterium. A small relatively simple single cell microorganism.
Coliforms. Bacteria that are members of the *Enterobacteriaceae* family. These bacteria make up about 10% of the intestinal microorganisms of human and other animals.
Disinfection. The killing, inhibition, or removal of microorganisms that may cause disease.
Faecal. Relating to animal and human waste matter.
Faecal coliforms. Thermotolerant (maximum 44.5°C) coliforms derived from the intestines of warm-blooded animals, including man. For a water to be considered potable, faecal coliforms must not be present.
Microorganism. A microscopic organism, too small to be seen by the naked eye.
Parasite. An organism that lives in or on another (the host). It benefits from its host while harming it.
Pathogen. A disease-producing agent, usually referring to living organisms, including microorganisms.
Phage. Abbreviation of ***Bacteriophage***.
Protozoan. A microorganism belonging to the *Protozoa* subkingdom. Most are free living though a few are parasitic in plants and animals. *Cryptosporidium* and *Giardia* are two protozoan genera that parasitise mammals.
Thermotolerant. Able to tolerate high temperatures.
Virus. An infectious microorganism capable of reproducing only within living host cells.

8.5.2 Importance

Water quality goes far beyond just the chemicals in the water. Living microscopic organisms (microorganisms) are also critically important, particularly when human health is an issue.

Microorganisms cannot usually be seen without the help of a microscope. Most are harmless but some can cause disease in people. These disease-causing microorganisms (called pathogens) come from human and animal faecal wastes. They can get washed into both surface waters and groundwater. Sometimes these supply our drinking water. Pathogens transported by water are called waterborne pathogens. They can cause diseases like gastroenteritis, dysentery, cholera, typhoid fever, pneumonia, and viral hepatitis. The risk of being infected typically increases with increasing levels of microbial contamination.

Just a small drop of faeces contains millions of microorganisms. They can consist of a wide variety of viruses, bacteria, parasites and protozoa.

8.5.3 Size of microorganisms

There are huge differences in the sizes of microorganisms (**Figure 30**) although they are all very small (Murray *et al.*, 2003a). For example, the capsule-shaped *Escherichia. coli* (*E. coli*) bacterium is about 2,000 nm long and 500 nm wide. A nanometer (abbreviated nm) is one-billionth (1/1,000,000,000) of a metre or one-millionth (1/1,000,000) of a millimetre. An *E. coli* bacterium is therefore probably about a thousand times smaller than the size of the period at the end of this sentence.

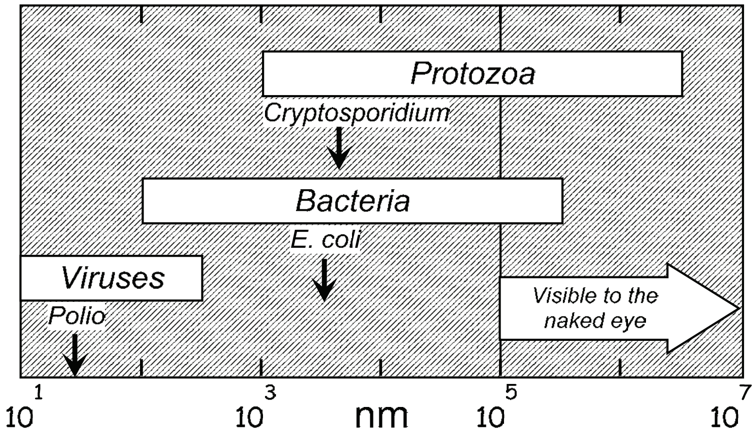


Figure 30: The relative size ranges of microorganisms

8.5.4 Viruses and bacteria

Viruses and bacteria are often confused. In fact, viruses are very different from bacteria. The most obvious difference is their size (**Figure 30**). Viruses are so tiny a powerful electron microscope is needed to see even the largest of them. A bacterium also looks very different from a virus.

Importantly, a bacterium contains all of the genetic information (DNA) needed to make copies of itself. However, viruses cannot reproduce themselves. They invade other living bacterial or human cells and inject their RNA or DNA into them. The invaded cell is then instructed by the virus's genes to produce new viruses. So many viruses are produced that the bacterial cell bursts and dies and in the process releases all the viruses just to infect more bacterial cells in which the process is repeated.

8.5.5 Indicator organisms

There are fundamental problems associated with measuring (or assaying) pathogens in water samples. Because there are so many different pathogens, methods for their recovery and detection become time consuming, complex and costly. The results of such assays can also be misleading.

Because of these problems, so-called indicator organisms are often used to suggest the possible presence of pathogens. The microbiological quality of water is often established with indicators of faecal contamination. The main problem with such indicators is that they are not foolproof. It has been shown in a number of studies that even though the indicator bacteria were not present, some viruses were present. This is known as a false negative result: the indicator indicated a negative result (*i.e.* that there was not a problem) even though problematic (*i.e.* pathogenic) viruses were in fact present. Considerable care should therefore be taken when interpreting the results of such assays (see **Table 12**). The same applies to parasites like *Giardia* and *Cryptosporidium*.

Bacteriophages that infect bacteria share many properties and features with human viruses. Therefore, phages are also used as indicators of the possible presence of viruses because they are viruses themselves.

Table 12: Recommended general assessments of microbial analyses (assuming typical sample volumes)

	General conclusion about the contamination and its source		Conclusion about presence of pathogenic viruses or parasites	
Indicator	**If indicator detected**	**If indicator not detected**	**If indicator detected**	**If indicator not detected**
Total coliforms	Some *Enterobacteriaceae* bacteria are present, some of which can be of faecal origin	No faecal contamination[1] by animals or humans	May be present[2]	May occasionally be present[2]
Heterotrophic / total plate count	Some bacteria are present though no conclusions can be drawn about the presence of pathogens	No bacterial contamination[1]	May be present[2]	May occasionally be present[2]
Faecal coliforms	Reasonable indication of faecal contamination by animals or humans	No faecal contamination[1] by animals or humans	May be present[2]	May occasionally be present[2]
Enterococci / Faecal streptococci	Reasonable indication of faecal contamination by animals or humans	No enterococci bacterial contamination[1] though there may still be some faecal contamination	May be present[2]	May occasionally be present[2]
E. coli	Almost absolute certainty of faecal contamination by animals or humans	No faecal contamination[1] by animals or humans	May be present[2]	May occasionally be present[2]
Bacteriophage			Enteric viruses likely to be present	May occasionally be present[2]
Virus			The virus definitely present	May still be present in very small numbers[3]

[1] Strictly very low levels may exist although associated health risks are likely to be minimal.
[2] If virally- or parasite-infected individuals exist in the source population.
[3] Because of difficulties in taking and analysing sufficiently representative samples.

8.6 BASIC STATISTICS

This section is largely based on Diamantopoulos A and Schlegelmilch BB (2004). *Taking the fear out of data analysis*. Thompson Learning. London.

8.6.1 Glossary

Coefficient of variation. The standard deviation divided by the mean.
Confidence interval. A range of values that we are confident (but not certain) contains a population parameter.
Hypothesis testing. Examines whether a particular proposition (the hypothesis) concerning the population is likely to be true or not.
Maximum. The largest value in a set of values.
Mean. Also called average. The sum of a set of values divided by their number.
Median. The value above and below which one half of the observations fall. It equals the 50th percentile.
Minimum. The smallest value in a set of values.
Mode. The most frequently occurring value.
Moving average. A series of averages each calculated from a continually changing subset of a set of observations. For example, a 5-point moving average calculates the averages of points 1-5, then 2-6, then 3-7, and so on. The moving average smooths the original data.
Outlier. In a set of values, a value so far removed from other values that its presence cannot be attributed to the random combination of chance causes (*i.e.* something is probably wrong with it).
Percentile. Percentiles divide a set of observations into 100 equal portions. A 95th percentile is the point P such that 95% of the observations have values less than P.
Significance level. The probability of making a mistake by rejecting the null hypothesis when it should not be rejected.
Standard deviation. The square root of the variance.
Variance. A measure of variability obtained by (a) subtracting the mean from each individual measurement, (b) squaring these deviations, (c) summing them and (d) taking their average.

8.6.2 Measures of central tendency

Central tendency (or central location) is the point about which the data points tend to cluster. Modes, medians and means are measures of central tendency of a distribution (**Figure 31**).

- **Mode**. This is the least useful measure of central tendency because it is not sensitive to even significant changes in the dataset.
- **Median**. This is usually used when the distribution of data is skewed or dominated by outliers. It is not very sensitive to a few extra data points that may be very large or very small.
- **Mean**. This is usually best used when the distribution of data is not skewed (or dominated by outliers). It is usually sensitive to small changes in the dataset - if the dataset is changed by a single value then the mean will change (unless, of course, the extra value equals the mean itself).

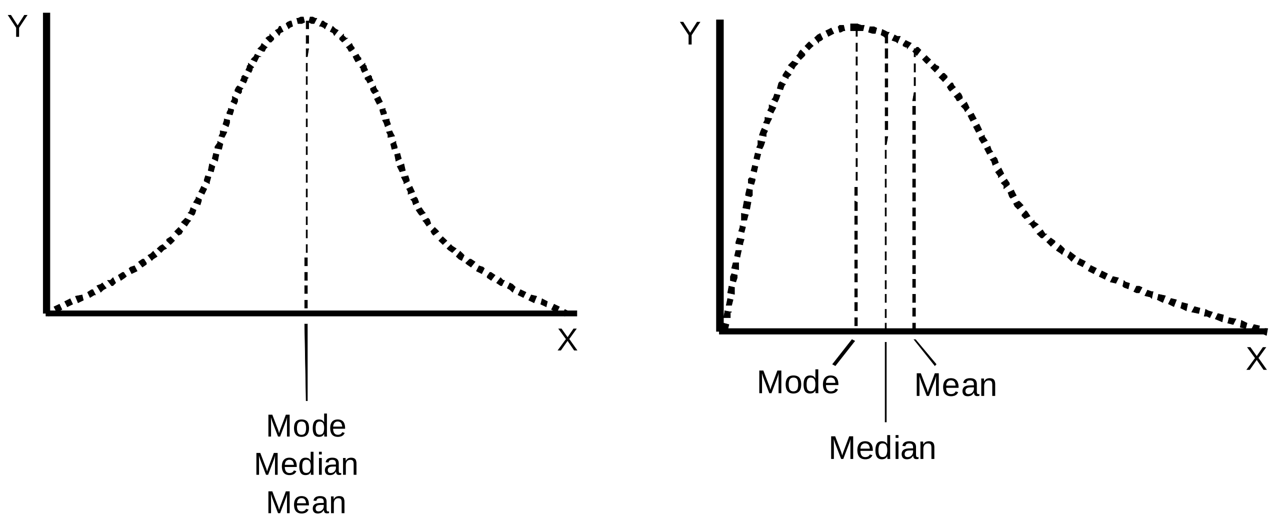


Figure 31: Mode, median and mean of symmetrical and skewed distributions

If, for example, the median and mean of a set of observations are different, it is immediately evident that the distribution is skewed (meaning assymmetrical or not symmetrical). However, it is possible to quantify skewness formally with a coefficient of skewness.

8.6.3 Measures of variability

The standard deviation, variance and coefficient of variation are measures of variability of observations around the central location. The standard deviation and variance are both absolute numbers while the coefficient of variation is a relative number (equal to the standard deviation divided by the mean). Specifically the coefficient of variation relates the standard deviation to the mean and is therefore very convenient for making comparisons of variability across different variables. Note that the coefficient of variation is unitless since the standard deviation and the mean have the same units.

8.6.4 Frequency distributions

Frequency distributions are often used in water quality applications. Using the TDS values (mg/ℓ) in **Table 3**, the following table (**Table 13**) shows the frequency with which the measured values occur within a series of intervals (in this case 20 TDS units).

Table 13: TDS data used for graphs of frequency distributions

TDS Range (mg/ℓ)	Frequency	Cumulative (%)	TDS Range (mg/ℓ)	Frequency	Cumulative (%)
100-120	0	100.0	260-280	2	35.4
120-140	4	91.7	280-300	4	27.1
140-160	3	85.4	300-320	2	22.9
160-180	9	66.7	320-340	7	8.3
180-200	7	52.1	340-360	2	4.2
200-220	1	50.0	360-380	1	2.1
220-240	3	43.8	380-400	0	2.1

The cumulative frequency shows what percentage of observations has values that are greater than the upper end of the range. For example, 4.2 % of the values occur above 360 mg/ℓ. The frequency and cumulative frequency are plotted in **Figure 32** and **Figure 33** respectively.

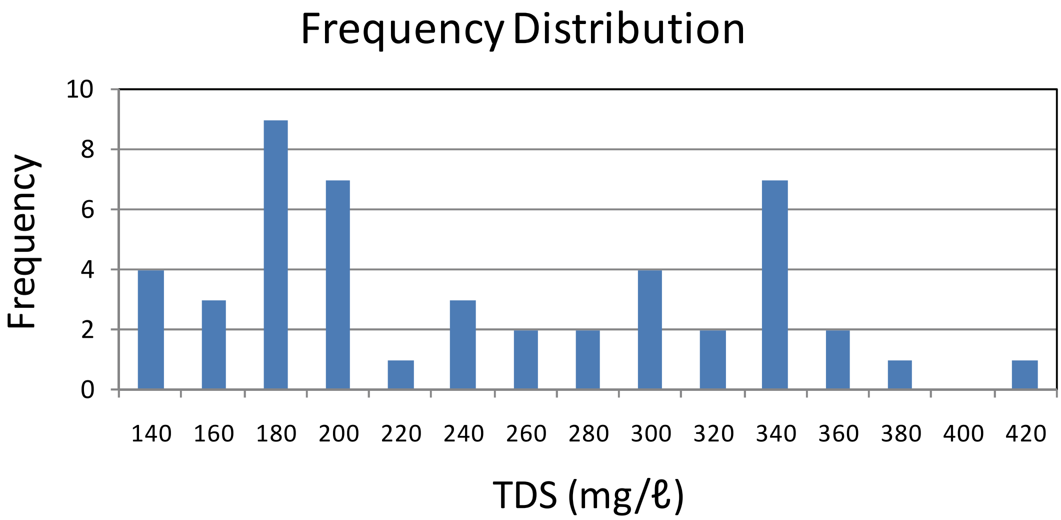


Figure 32: Example frequency distribution for TDS (mg/ℓ) data

Figure 32 shows clearly that the distribution of measured TDS throughout the year is not symmetrical about any central value.

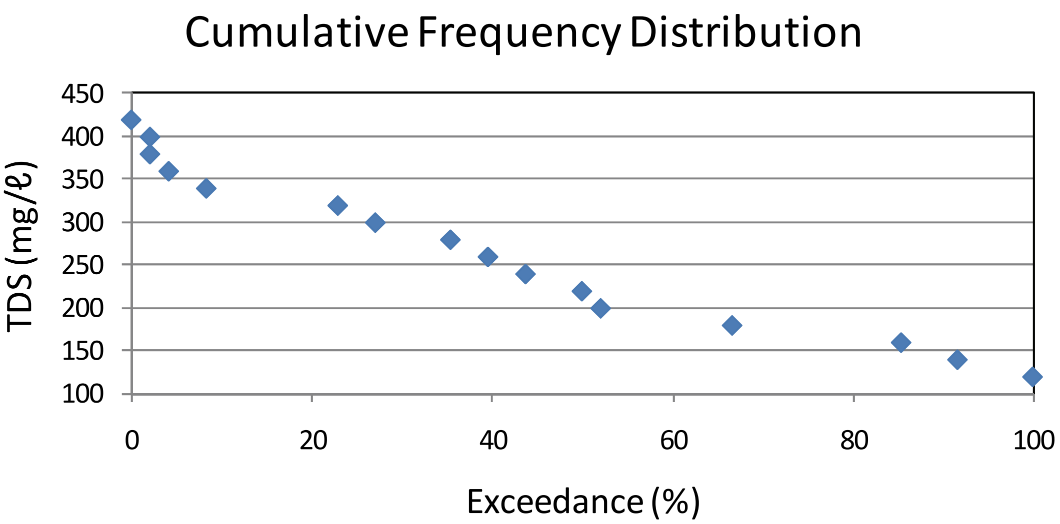


Figure 33: Example cumulative frequency distribution for TDS (mg/ℓ) data

The cumulative frequency distribution shown in **Figure 33** (also called an exceedance diagram, of which another example was given in **Figure 20**) shows what percentage of measured values exceeds any given TDS value. This can be useful for indicating, for example, how many measurements exceeded a water quality guideline.

Percentiles are associated with cumulative frequency distributions. For example, **Figure 33** indicates that about 50% of the values exceed a value between 200 and 250 mg/ℓ. In fact, the median (which is the 50th percentile) is 223.

8.7 BASIC GRAPH INTERPRETATION

The following sections provide a simple reminder of the basics on how to interpret a graph. It is aimed specifically at those less-technical people who perhaps were last taught about graphs in school too many years ago.

8.7.1 Independent and dependent variables

The simplest graphs typically have two axes (**Figure 34**):

- **X-axis**: Conventionally, the X-axis is horizontal and represents the independent variable – the variable whose variability is either (a) not controllable, or (b) not dependent on anything. Typical examples are time (*e.g.* days, months, or years) and distance (*e.g.* km downstream of some point like a river confluence). Variables like time and distance typically change continuously (*i.e.* without interruption). In bar graphs the X variable may be a category like the way water is used (*e.g.* crop irrigation, animal watering, recreation, domestic, industrial process, etc.). Such a variable, by its very nature, does not change continuously.
- **Y-axis**: Conventionally the Y-axis is vertical and represents the dependent variable – the variable of interest that typically changes as the independent variable (the X variable) changes. Any of the usual water quality variables (like pH, calcium concentration, temperature, electrical conductivity, etc.) will typically change either with time or with distance downstream. The dependent variable always changes continuously. It is never split into categories.

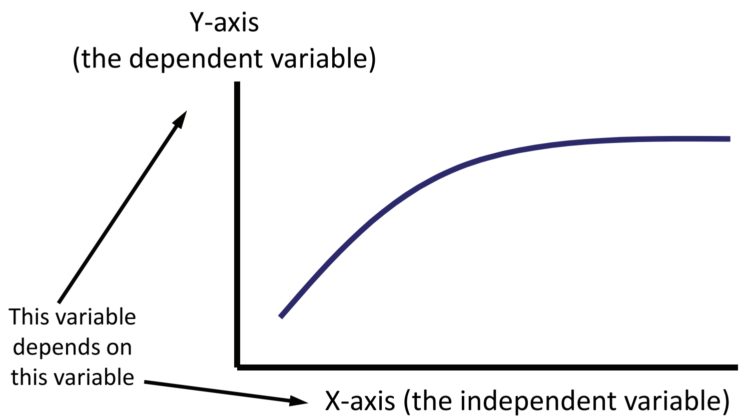


Figure 34: Independent and dependent variables in a graph

Remember that it doesn't make any sense at all to say "distance changes as the pH changes"! This suggests that distance depends on pH. However, we can and do say, for example, "the pH changes with distance downstream" meaning that the value of the pH (the "dependent" variable) will depend on the distance downstream (the "independent" variable).

8.7.2 The slope

The slope of a graph also provides very useful information. The slope is comprised of two components:

1. **The steepness of the graph (Figure 35)**: The steeper the graph the faster the dependent variable is changing.

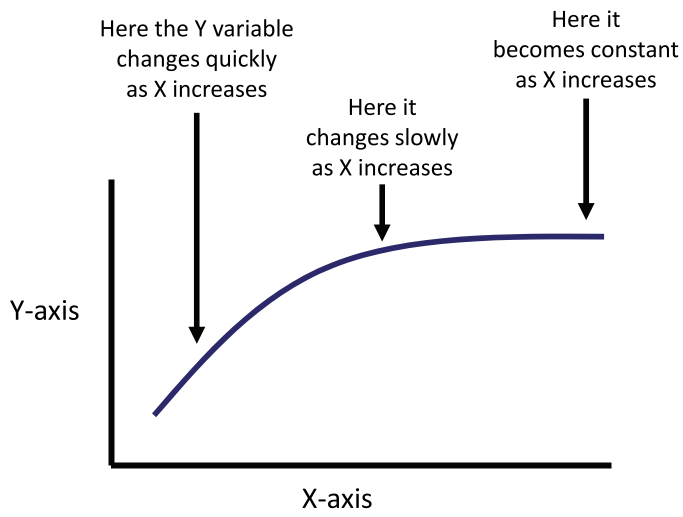


Figure 35: How to interpret the steepness of a graph

2. **Whether it is increasing (*i.e.* has a positive slope) or decreasing (*i.e.* has a negative slope) (Figure 36)**. If it is positive, then the dependent (Y) variable increases as the independent (X) variable increases. If it is negative, then the dependent (Y) variable decreases as the independent (X) variable increases.

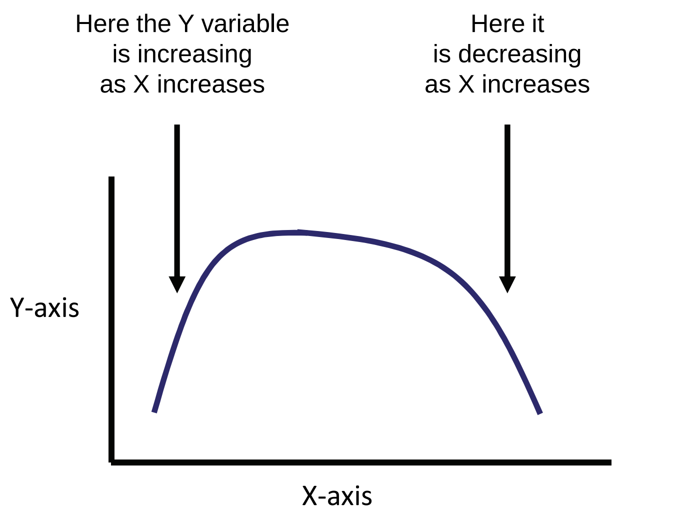


Figure 36: How to interpret a positive and negative slope in a graph

8.7.3 Log scales

Log scales are useful when displaying data that change over many orders of magnitude (hundreds, thousands, or millions). Microbiological data (like *E. coli* measurements) commonly vary in this way.

Figure 37 shows how a log scale displays the same numbers very differently from a normal (linear) scale. The actual numbers are Site A: 540, Site B: 10380, Site C: 170 and Site D: 4570 counts/100 mℓ. On a normal scale (left bar graph) small numbers have such a short bar that their actual values are not obvious. However, the sizes of the bars do communicate the correct relative sizes of the values.

On the other hand, on a log scale (right bar graph) the actual values are now clearer. However, their relative sizes are now not apparent. For example, the value at Site C is not about half of that at Site B (as seems apparent from the graph).

Note that each horizontal line on the log scale graph increases by a factor of ten from one horizontal line to the next.

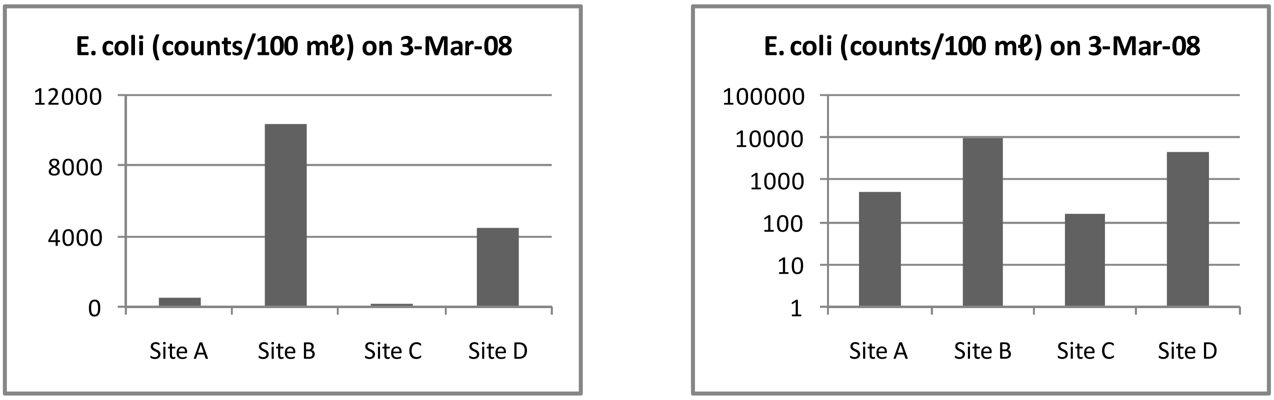


Figure 37: Comparison of normal and logarithm axes

CHAPTER 9: REFERENCES & FURTHER READING

ASARAVALA A (2007). Email Do's and Don'ts . http://www.techsoup.org/learningcenter/internet/page6175.cfm.

ASHTON PJ (2007). *Writing Scientific Papers*. Seminar. January 2007. Skukuza, Kruger National Park. South Africa.

BACK W and FREEZE RA (Eds.) (1983). *Chemical Hydrogeology*. Hutchinson Ross Publishing Company. Benchmark Papers in Geology. ISBN 0-87933-440-1. Volume 73.

BONNAO M (2004). Conquering the Short Story. Online: http://www.fmwriters.com/Visionback/Vision21/ Themeconquering.htm.

BROCH ES and YAKE W (1969). A modification of Maucha's ionic diagram to include ionic concentrations. *Limnology and Oceanography*. **14**: 933–935.

CCME (2001). *Canadian Environmental Quality Guidelines. Update 6.0.* Canadian Council of Ministers of the Environment.

CLARKE KC (1997). *Getting started with Geographic Information Systems*. 2nd edition. Prentice Hall, New Jersey.

CLEVELAND WS (1984). Graphs in Scientific Publications. *The American Statistician.* **38**(4): 261-269.

DWAF (2003). *A Guide to Conduct Water Quality Catchment Assessment Studies: In Support of the Water Quality Management Component of a Catchment Management Strategy*. MS 8.3. 1st Edn. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (1996a). *South African Water Quality Guidelines for Fresh Waters. Volumes 1-8*, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (1996b). *South African Water Quality Guidelines for Coastal Marine Waters. Volumes 1-4*, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2005). *National Toxicity Monitoring Programme (NTMP) for Surface Waters Phase 2: Prototype Implementation Manual*. By K Murray, Heath RGM, Slabbert JL, Haasbroek B, Strydom C and Matji PM. Report No.: N0000REQ0605 ISBN No.: 0-621-36403-7. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2006a). *Resource Directed Management of Water Quality: Volume 1.2: Policy*. Edition 1. Water Resource Planning Systems Series, Sub-Series No. WQP 1.4.2. ISBN No. 0-621-36788-5. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2006b). *Resource Directed Management of Water Quality: Volume 2.1: Strategy*. Water Resource Planning Systems Series, Subseries No. WQP 1.5.2. Edition 1. ISBN No. 0-621-36790-7. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2006c). *Resource Directed Management of Water Quality: Management Instruments. Volume 4.3: Guideline on Monitoring & Auditing for Resource Directed Management of Water Quality*. Edition 2. Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.3. ISBN N0. 0-621-36796-6. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (2006d). *Integrated water quality management plan for the Vaal river system: Task 2: Water Quality Status Assessment of the Vaal River System*. Directorate National Water Resources Planning. Department of Water Affairs and Forestry. Pretoria. South Africa.

DWAF (2008). *Development of SA Risk-Based Water Quality Guidelines: Phase 1 Needs Assessment & Philosophy*. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF, DoH and WRC (1998). *Quality of Domestic Water Supplies, Volume 1: Assessment Guide*, Second Edition. Water Research Commission No.: TT 101/98. Department of Water Affairs and Forestry, Department of Health and the Water Research Commission. Pretoria, South Africa.

EA (2008). *General Quality Assessment of rivers: chemistry*. Environmental Protection. Online: www.environment-agency.gov.uk/commondata/acrobat/chemistry.pdf.

FREEZE RA and CHERRY JA (1979). *Groundwater*. Prentice-Hall, Inc., New Jersey.

MATTESS JC (1982). *The properties of groundwater*. Translated by John C. Harvey. John Wiley & Sons. ISBN 0-471-08513-8.

HEM JD (1985). *Study and Interpretation of the Chemical Characteristics of Natural Water*. 3rd Edition. United States Geological Survey Water - Supply Paper 2254 (Library of Congress Catalog-Card No. 85-600603).

HOHLS BC, SILBERBAUER MJ, KÜHN AL, KEMPSTER PL AND VAN GINKEL CE (2002) *National Water Resource Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in SA . The Big Picture.* Report No. N/0000/REQ0801. ISBN No. 0-621-32935-5. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

HOLTZHAUSEN L (Ed.) (2006). *"A little gift" and other short stories*. Water Research Commission. ISBN No. 1-77005-413-8. Pretoria, South Africa.

KALLICK-WAKKER I (1994). Science Icons: The Visualization of Scientific Truths. *Leonardo*. 27(4): 309-315.

KAMPHERBEEK J (2002). 100 Dos and Don'ts in Web Design. Styleguide by SpiderPro. Version 1.1. Online: http://www.spiderpro.com/ebooks/styleguide.pdf.

KENNEDY M (2006). *Introducing Geographic Information Systems with ArcGIS*. John Wiley & Sons. New Jersey.

KLEYNHANS CJ, LOUW MD. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 329/08.

KULHAVY RW and STOCK WA (1996). How Cognitive Maps are Learned and Remembered. *Annals of the Association of American Geographers*. 86(1): 123-145.

LOHSE G, WALKER N, BIOLSI K and RUETER H (1991). Classifying graphical information. *Behaviour & Information Technology*. **10**(5): 419-436.

LOYD JW and HEATHCOTE JA (1985). *Natural inorganic hydrochemistry in relation to groundwater: An introduction*. ISBN 0-19-854422-7. Clarendon Press, Oxford.

MATTHEWS JR, BOWEN JM and MATTHEWS RW (1996). Successful scientific writing. A step-by-step guide for the biological and medical sciences. Cambridge University Press, Cambridge, United Kingdom.

MAUCHA R (1932). Hydrochemische metoden in der limnologie (Hydrochemical methods in limnology) (in German). *Binnengewasser*. **12**, 1-173.

MORGAN D (2005). Dos and don'ts of technical writing. *Institute of Electrical and Electronics Engineers Potentials*. August/September, 22-25.

MURRAY K, DU PREEZ M, TAYLOR MB, MEYER R, PARSONS R, VAN WYK E, KÜHN A, VAN NIEKERK H, EHLERS MM (2003a). *National Microbial Monitoring Programme for groundwater: Prototype Implementation Manual*. Water Research Commission Report No. TT 312/07, Pretoria, South Africa.

MURRAY K, SLABBERT L AND MOLOI B (2003b). *Needs assessment and development framework for a tested implementation plan for the initialisation and execution of a National Toxicants Monitoring Programme (NTMP)*. Department of Water Affairs and Forestry, Pretoria, South Africa.

MURRAY K, DABROWSKI J, HILL L, DU PREEZ M, KADIAKA M, STRYDOM W (2009). Communicating water quality data and information: Research report. Water Research Commission Report No. 1755/1/09. Pretoria. South Africa.

PALMER T, BEROLD R, MULLER N AND SCHERMAN P (2002). *Some, for all, forever. Water ecosystems and people*. Water Research Commission Report No. TT 176/02. Pretoria, South Africa.

QEPA (2008). Assessing water quality. Queensland Environmental Protection Agency. Online: http://www.epa.qld.gov.au/environmental_management/water/water_quality_monitoring/assessing_water_quality/water_quality_data/.

RAND GM and PETROCELLI SR (1995). *Fundamentals of Aquatic Toxicology*. Hemisphere Pub. Corp. Washington.

RICHARDS S, BARKER P, BANERJI A, LAMONT C and MANJI K (1994). *The Use of Metaphors in Iconic Interface Design*. On-line: http://www.intellectbooks.com/iconic/metaphor/metaphor.htm.

ROBINSON AH, MORRISON JL, MUEHRCKE PC, KIMERLING AJ and GUPTILL SC (1995). *Elements of Cartography*. 6th edition. John Wily & Sons. New York.

SANS 241 (2006). *Drinking Water Specification*, Edition 6.1. South African National Standard 241. Pretoria.

SAX NI (1974). *Industrial Pollution*. Van Nostrand Reinhold Company. New York.

SCHNOTZ W (2002). Towards an Integrated View of Learning from Text and Visual Displays. *Educational Psychology Review* 14(1): 101-120.

SILBERBAUER MJ and King JM (1991). The water chemistry of selected wetlands in the south-western Cape Province, South Africa. *Southern African Journal of Aquatic Science*. **17**: 82–88.

SLABBERT JL, OOSTHUIZEN J, VENTER EA, HILL E, DU PREEZ M and PRETORIUS PJ (1998). *Development of Guidelines for Toxicity Bioassaying of Drinking and Environmental Waters In South Africa*. Water Research Commission Report No. 453/1/98, Pretoria, South Africa.

SMARTDRAW (2007). *Creating Persuasive Charts: Visualizing data with charts*. On-line: http://www.smartdraw.com.

STANDARD METHODS (1998). *Standard Methods for the Examination of Water and Wastewater*. 20th Ed., Eds. Eaton AD , Clesceri LS and Greenberg AE. American Public Health Association, Washington, DC, USA.

TEER-TOMASELLI R and DE VILLIERS C (1998). *Radio: Theatre of the mind*. In: Mass Media: Towards the Millennium. The South African Handbook of Mass Communication. AS de Beer (Ed.). Second edition. Van Schaik. Pretoria.

TODD DK (1980). *Groundwater Hydrology*. Second Edition. John Wiley & Sons. ISBN 0-471-87616-X.

TRUSS L (2003). *Eats, Shoots & Leaves: The Zero Tolerance Approach to Punctuation*. Profile Books. London.

URL1: http://www.web-source.net/internet_marketing/23193.html.

URL2: http://www.web-source.net/internet_marketing/23193.html.

VEKIRI I (2002). What is the Value of Graphical Displays in Learning? *Educational Psychology Review* **14**(3); 261-312.

WORLD BANK (1999). *Pollution Prevention and Abatement Handbook 1998: Toward Cleaner Production*. World Bank Group. Washington DC.