Guidelines for **mapping wetlands** in South Africa

Nancy Job, Namhla Mbona, Anisha Dayaram & Donovan Kotze

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Guidelines for mapping wetlands in South Africa

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TABLE OF CONTENTS

EXECUTIVE SUMMARY vii

ACKNOWLEDGEMENTS viii

1 INTRODUCTION 1
- 1.1 Wetlands and why mapping them is important 1
- 1.2 National Wetland Map 2
- 1.3 Why do we need this manual? 2
- 1.4 What to expect from this manual 4
- 1.5 Who should use this manual? 5
- 1.6 Structure of the manual 6

PART A. BEFORE YOU START – DESIGNING A WETLAND MAPPING PROJECT 7
- A1. Overview of wetland mapping data 7
- A2. Catchment approach, at the scale of quinary catchments 7
- A3. Field or desktop? An approach combining both is strongly recommended 10
- A4. Choosing the appropriate degree of data detail 11
- A5. What data attributes to record 13
- A6. Generic Terms of Reference 16

PART B. BEFORE YOU LEAVE FOR THE FIELD – DESKTOP PREPARATION 18
- B1. Recording information about the project 18
- B2. GIS layers in support of desktop mapping 18
- B3. Approaches to desktop wetland mapping 24
- B4. Desktop mapping of wetland location and extent 25
- B5. Desktop wetland classification 28
- B5.1 Desktop classification of regional setting 29
- B5.2 Desktop classification of landscape unit 32
- B5.3 Desktop classification of hydrogeomorphic (HGM) unit 33
- B6. Desktop assessment of wetland condition 37

PART C. IN THE FIELD 52
- C1. Approaches to in-field mapping 52
- C2. Recording project information 54
- C3. Tools to support in-field mapping 54
- C4. In-field determination of wetland location and extent 57
- C5. In-field wetland classification (HGM unit) 57
- C6. Gathering in-field data on wetland characteristics 58
- C7. In-field assessment of wetland condition 62

PART D. DESKTOP FOLLOW-UP / BACK IN THE OFFICE 64
- D1. Data integration and cleaning 64
- D2. Final review 66
- D3. Assigning confidence levels 66

2 LIST OF REFERENCES 68

APPENDIX A: Metadata example 70

APPENDIX B: How to maintain and use the ARCGIS application for data collection 73

APPENDIX C: Delineating HGM units using Google Earth and QGIS. 79

APPENDIX D: Converting the MS Excel Spreadsheet to a database that can be used within a GIS environment 88

APPENDIX E: Checklist of tasks for mapping projects 90

APPENDIX F: Example field datasheet 92

LIST OF FIGURES

Figure 1: The National Wetland Inventory is the core repository of national wetland information. 3

Figure 2: Components of wetland mapping and inventory data 8

Figure 3: An illustration of quaternary and quinary catchments. 8

Figure 4: An example of planning work within a region of a province, in this case the Mpumalanga Highveld. Mapping work was scheduled one sub-Water Management Area (WMA) at a time. Within each sub-WMA, work was scheduled one quinary catchment at a time (Source: Mbona et al. 2015) 9

Figure 5: Example of an attribute drop-down list in the spreadsheet designed by GeoTerraImage (Pty) Ltd and Wetland Consulting Services (Pty) Ltd for SANBI in 2012. 13

Figure 6: The basic categories for typical inland systems according to the National Classification System (adapted from Ollis et al. 2013) 28

Figure 7: Graphic depiction of hydrogeomorphic wetland types and landscape unit (Ollis et al. 2013). 32

Figure 8: Wetland Level 4A hydrogeomorphic types (note that rivers are not discussed in this document). 35

Figure 9: Map of approximate extent of hydrogeomorphic units where major breaks between different units can be identified 36

Figure 10: Rapid assessment datasheet example. 54

Figure 11: Tools in use: GPS, hard copy maps and a 'home-made' wetland plant ID guide.. 55

Figure 12: Mobile electronic tools: using a tablet with built-in GPS, pre-loaded with desktop mapping and imagery or Google Earth 56

Figure 13: Developing a list of wetland plants 61

Figure 14: Soil information in the field can be collected with a soil auger (left) and matched against colours in a Munsell soil colour chart (right). 61

LIST OF TABLES

Table 1: The different degrees of data detail for a wetland mapping project, showing their spatial extent, attribute details and examples of usage. 12

Table 2: Potential attributes that can be recorded for a wetland mapping project. 14

Table 3: Overall project information attributes, common to all wetlands in a project. 19

Table 4: Examples of existing GIS wetland layers. 20

Table 5: Input GIS layers that provide supporting information for desktop mapping. 21

Table 6: An overview of the merits and limitations of different imagery. 22

Table 7: Attribute information to include about imagery used to support wetland mapping. . . . 23

Table 8: Attributes that relate to desktop (and field) mapping methods. 25

Table 9: Examples of wetlands as identified using spatial imagery. The outer boundaries of the wetland are indicated with dotted lines. 27

Table 10: Attributes available from the SANBI MS Excel spreadsheet (Section A5) that relate to regional setting. 29

Table 11: Attributes from the SANBI MS Excel spreadsheet (Section A5) related to landscape setting of the wetland. 32

Table 12: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to hydrogeomorphic type. 34

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown. 38

Table 14: Possible variables that can be included in models to estimate wetland condition (adapted from Rivers-Moore & Cowden 2012). 44

Table 15: Identifying impacts to wetlands using spatial imagery. 45

Table 17: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to hydrological regime. 58

Table 18: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to wetland characteristics. 59

Table 19: Wetland condition scores (WET-Health, MacFarlane et al. 2009). 63

Table 20: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to a wetland condition assessment. 63

Table 21: Examples of data errors arising from data digitising or modelling. 65

Table 22: Confidence levels assigned to mapped wetland polygons depending on the ground verification and specialist review process. 67

LIST OF ABBREVIATIONS

CD: NGI .....Chief Directorate: National Geospatial Information
CSIR.....Council for Scientific and Industrial Research
DEA .....Department of Environmental Affairs
DWS .....Department of Water and Sanitation
EIA .....Environmental Impact Assessment
ESRI.....Environmental Systems Research Institute
GIS.....Geographic Information System
HGM .....Hydrogeomorphic
NBA.....National Biodiversity Assessment
NFEPA .....National Freshwater Ecosystem Priority Areas
NWI.....National Wetland Inventory
NWM4 .....National Wetland Map 4
PES .....Present Ecological State
QGIS .....Quantum GIS
SANBI.....South African National Biodiversity Institute
ToR.....Terms of Reference
WGS 84 .....World Geodetic System of 1984
WMA.....Water Management Area
WRC .....Water Research Commission
WULA.....Water Use Licence Application

EXECUTIVE SUMMARY

In view of the benefits provided by wetlands, the extensive loss to date and the magnitude of threats to remaining wetlands, there is a definite need for a clear understanding of drivers of wetland loss, cause-and-effect relationships, and of opportunities to secure and restore remaining wetlands. For the purposes of this document, wetland mapping refers primarily to mapping the spatial boundary of a wetland, but may also include mapping spatial features within the wetland, including different wetland disturbance units (e.g. eroded land within the wetland). A wetland inventory refers to assembling information on wetland location, size, type, condition and other important features. Much of this information (notably that relating to location and size) is spatial information derived from maps. Therefore, it can be appreciated that mapping wetlands plays a central role in generating the information that is assembled in a wetland inventory. Knowing where our wetlands are, their diversity, and what pressures they are under, helps to prioritise, rehabilitate and protect the most important wetlands. It also assists in developing appropriate policies, specific awareness messages, and wise-use management guidance. Wetland inventory, including wetland mapping, thus plays a foundational role in any strategic approach to wetland management and conservation.

The National Wetland Inventory is the core repository of national wetland information. It receives and must integrate wetland data from a wide range of sources, typically with different mapping scales, coverage and accuracies, into a single, standardised Geographic Information System (GIS) database and the National Wetland Map. To produce a comprehensive and accurate picture of wetlands for the country, the National Wetland Map requires frequent, full and partial updates, and a clear update protocol.

Given the costs and level of expertise involved, the most feasible and appropriate way of doing this is through incremental updates that take place at more localised scales (e.g. provincial, municipal, sub-catchment or specific project area), funded and conducted by a range of organisations. The protocols in this manual are designed both to improve the ability to capture and record future wetland data in a standardised and unified manner, and to create standardised attributes for existing wetland datasets, in order to facilitate data integration and comparison. This is an important requirement in terms of assisting with the creation of a single, centralised, standard wetland database within the National Wetland Inventory.

The hope is that this manual will contribute to the rapidly expanding community of learning and practice for wetland mapping, through the advantages it provides in terms of standardisation, simplification and potential to contribute to building the National Wetland Inventory.

ACKNOWLEDGEMENTS

Throughout the document, excerpts are drawn from complementary supporting guidelines; in particular the *Classification system for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems* (SANBI Biodiversity Series 22); *WET-Health: a technique for rapidly assessing wetland health* (WRC Report No. TT 340/08) and *A practical field procedure for identification and delineation of wetland and riparian areas* (DWS 2005). Readers are referred to these documents for support when undertaking a mapping project.

The 2012 SANBI mapping guidelines, prepared by Mark Thompson and Stuart Martin of GeoTerraImage (GTI), Gary Marneweck of Wetland Consulting Services (WCS) and Namhla Mbona of the South African National Biodiversity Institute (SANBI), form the foundation of this document. The sections on desktop wetland mapping, wetland catchment mapping, and identifying wetlands using imagery, were originally developed by Anisha Dayaram and Donovan Kotze, as part of a World Wide Fund for Nature (WWF)–Mondi Wetlands Programme initiative.

The idea for this publication came about through WRC project K5/2281, *Supporting better decision making around coal mining in the Mpumalanga Highveld through the development of mapping tools and refinement of spatial data on wetlands*. Development of the document was partly funded through this project, with co-funding from SANBI and WWF–Mondi Wetlands Programme. This document was reviewed by John Dini (SANBI). The initial edits and content contributions by Emily Botts and Aimee Ginsberg and comments of Heidi Nieuwoudt (Department of Environmental Affairs: Working for Wetlands) and Heidi van Deventer (Council for Scientific and Industrial Research (CSIR)) are also gratefully acknowledged.

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1. INTRODUCTION

1.1 Wetlands and why mapping them is important

Wetlands are areas of which the physical, chemical and biological attributes are shaped primarily by the presence of water. Wetlands, therefore, develop in areas where soils are saturated or inundated with water for varying lengths of time and at different frequencies. Wetlands are defined in the National Water Act (No. 36 of 1998) as land:

> *...where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted for life in saturated soil.*

Wetlands that fit this definition, and that have to date been included in the National Wetland Map, cover approximately 2.4% of South Africa's surface area (Driver et al. 2011). Many of these wetlands can be classified as ecological infrastructure, defined as naturally functioning ecosystems that deliver valuable services to people (SANBI 2013). Some wetlands assist in managing the quality and/or quantity of the country's limited water resources. Many have biodiversity significance and are sites of spiritual, recreational and scientific value. With climate change predicted to significantly alter South Africa's rainfall patterns, wetlands will play a more important role than ever before in mitigating the impacts of extreme events like floods and droughts. By providing highly productive opportunities for small-scale cultivation, as well as resources such as grazing, water, fish, fibre and medicine, wetlands continue to underpin the health and livelihoods of many people in South Africa, especially poor rural communities.

Consistent with global trends, high levels of threat to the country's wetlands have been reported. The 2011 National Biodiversity Assessment identified wetlands as the most threatened ecosystem type in South Africa, with 48% of wetland ecosystem types classified as critically endangered, 12% as endangered and 5% as vulnerable[1] (Driver et al. 2011). The National Biodiversity Assessment (NBA) also showed that wetlands are very poorly represented in South African protected areas, with only 11% of wetland ecosystem types well protected and 71% not protected at all.

For the purposes of this document, wetland mapping refers primarily to mapping the spatial boundary of a wetland, but may also include mapping spatial features within the wetland, including different wetland disturbance units (e.g. eroded land within the wetland). A wetland inventory refers to assembling information on wetland location, size, type, condition and other important features. Much of this information (notably that relating to location and size) is spatial information derived from maps. Therefore, it can be appreciated that mapping wetlands plays a central role in generating the information assembled in a wetland inventory. The document is primarily about the mapping of wetlands, but also deals, to some extent, with the collecting of information related to the wetland.

[1] Critically endangered ecosystems are ecosystem types that have very little of their original extent left in natural or near-natural condition. Endangered ecosystems are ecosystem types that are close to becoming critically endangered. Vulnerable ecosystems are ecosystem types that still have the majority of their original extent left in natural or near-natural condition, but have experienced some loss of habitat or deterioration in condition. Full definitions of these categories, including exact thresholds for each, are provided in Driver et al. (2011: 40, 41).

In view of the benefits provided by wetlands, the extent of loss to date, and the magnitude of threats to remaining wetlands, there is a definite need for a clear understanding of drivers of wetland loss, cause-and-effect relationships, and opportunities to secure and restore remaining wetlands. Knowing where our wetlands are, their diversity and what pressures they are under, helps to prioritise, rehabilitate and protect the most important wetlands. It also assists in developing appropriate policies, specific awareness messages, and wise-use management guidance across particular areas. A sound National Wetland Inventory, including a National Wetland Map, thus plays a foundational role in any strategic approach to wetland management and conservation.

The information provided by wetland maps and inventories makes it possible for a range of assessment, planning and decision-making processes to adequately take wetlands into account. These processes include:

- Water resource classification and the determination of Resource Quality Objectives, under the National Water Act.
- Regulatory decision making (e.g. water use licences, mining licences and environmental authorisations).
- Environmental Impact Assessments and Strategic Environmental Assessments.
- Spatial planning instruments (e.g. Spatial Development Frameworks, Environmental Management Frameworks and Land Use Schemes).
- A National Biodiversity Assessment.
- Monitoring and State of Environment reporting.
- Wetland rehabilitation and offset planning.
- Catchment Management Strategies.
- Protected area management plans and expansion strategies.

In short, it is impossible to approach wetland conservation and management in a holistic and systematic way, whether at national, provincial, local or catchment scale, without the baseline information provided by wetland inventories, starting with a good wetland map. This does not imply waiting for perfect data, but rather involves investing in ongoing data improvements while making use of the best available data to develop policy and guidance that is appropriate to regional conditions and wetland characteristics.

Key point

Investing in the mapping of wetlands allows strategic approaches to be taken to wetland conservation and management, and enables assessment, planning and decision-making processes to adequately take wetlands into account.

1.2 National Wetland Map

The National Wetland Inventory, housed within the South African National Biodiversity Institute (SANBI), is the current repository of national spatial information on wetlands. The National Wetland Inventory is the generator of the National Wetland Map, which is the primary wetland input into national planning projects such as the National Freshwater Ecosystem Priority Areas (NFEPA; Nel et al. 2011a) project and the 2011 National Biodiversity Assessment (Driver et al. 2011). A wide range of users also employ the data for a variety of applications, at different scales, including those smaller-scale projects where no higher quality wetland data currently exists (illustrated by the feedback loop in Figure 1). The National Wetland Inventory receives and must integrate wetland data into the National Wetland Map from a wide range of sources, typically with different mapping scales, coverage and accuracies (Figure 1). Data reaching the National Wetland Inventory needs to be consolidated into a single, standardised GIS database. The consolidation of these data requires the data to be in a similar format, with comparable content and attributes.

1.3 Why do we need this manual?

In addition to using the National Wetland Map as an initial input, the NFEPA project made significant improvements and refinements to the availability and quality of wetland data overall.

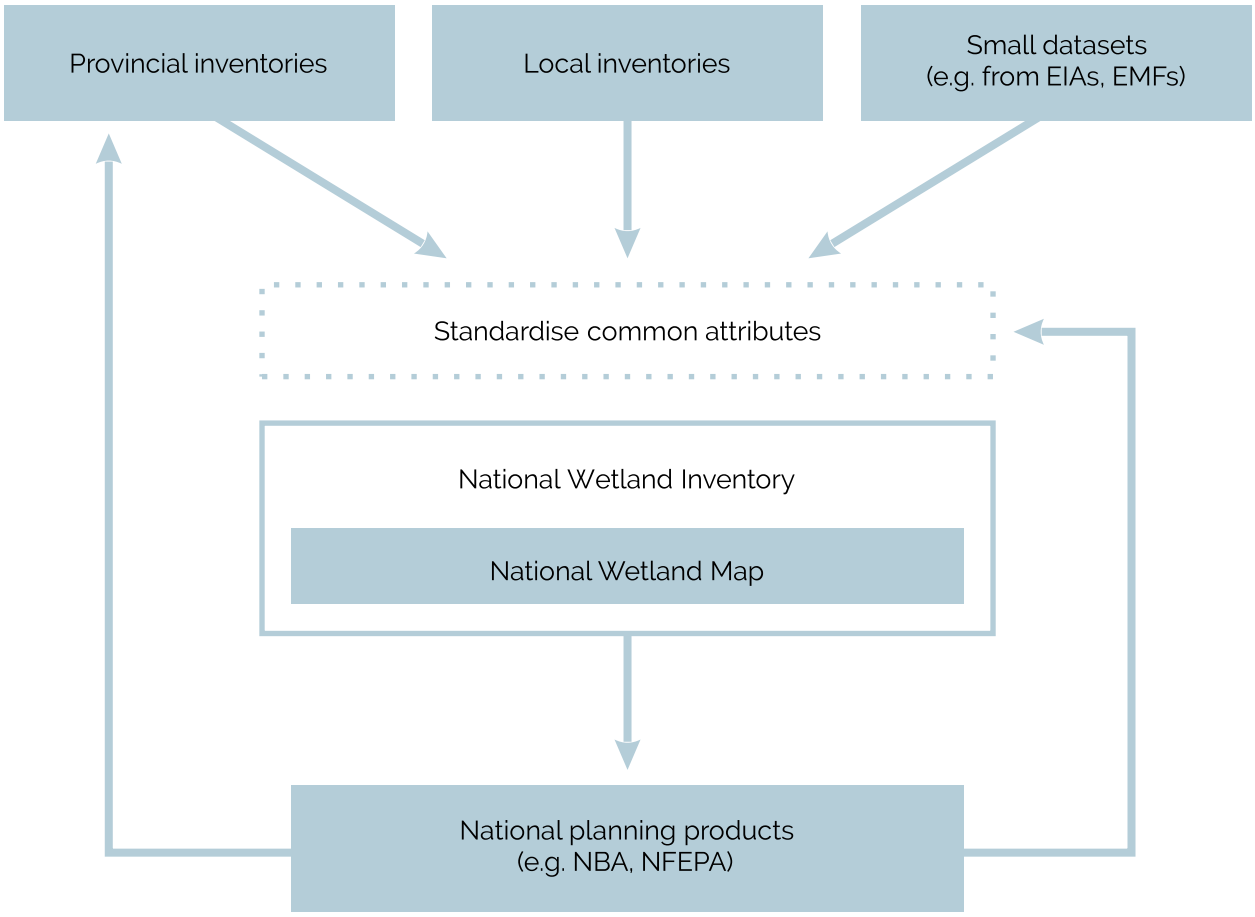


Figure 1: The National Wetland Inventory is the core repository of national wetland information.

However, the national scale of the NFEPA project meant that fine-scale applications of the information remain constrained by data accuracy issues. Recent assessments (e.g. Mbona et al. 2015) have highlighted that the current version (version 4) of the National Wetland Map (referred to as NWM4) is in need of improvement. In priority areas, where wetlands are under pressure and where highly accurate data is needed to support regulatory decision making, further refinement of the wetland data is essential.

The National Wetland Map thus requires more frequent, full and partial updates and a clear update protocol, recognising that the most feasible and appropriate way of doing this is through incremental updates that take place at more localised scales (e.g. municipal, sub–Water Management Area (sub-WMA), provincial or jurisdictional).

Mapping wetlands is often a difficult task. The boundaries of most wetlands are not defined by an abrupt change from wetland to terrestrial habitat. Instead there is normally a gradual transition in soil and vegetation characteristics, linked to declining frequency and duration of saturation of the soil, as one moves away from the centre of the wetland. Finding the point along this moisture gradient at which to draw the boundary can

Key points

- To perform its role as the national repository of spatial wetland information, the National Wetland Inventory receives and must integrate wetland data into the National Wetland Map from a wide range of sources.
- The current version of the National Wetland Map is in urgent need of further improvement.

be a challenging task, especially if the mapping is being done primarily from remote sensing images (e.g. satellite or aerial photos).

Attempting to map wetlands across the entire country is thus a complex and expensive task, and its usefulness is constrained by the level of detail that can be accurately captured at this scale. While the National Wetland Map represents the current best state of knowledge, experience has shown that the methods adopted for mapping wetlands at national scale have at times missed or incorrectly mapped many wetlands. There are considerable challenges to overcome, relating to the quality and completeness of the National Wetland Map, if we want to produce a comprehensive and accurate picture of our wetlands for the country as a whole.

Given the costs and level of expertise involved, options for the systematic re-mapping of wetlands at national scale are extremely limited. Approaches are therefore being pursued that involve incrementally improving and updating the National Wetland Map through more localised initiatives. These are anticipated to generate higher quality data at a finer resolution than would be possible by mapping larger areas. In this way, the improved data produced by localised mapping initiatives can build the national picture one piece at a time.

This approach, of necessity, relies on mapping initiatives at a range of scales, funded and conducted by a range of organisations, as it is beyond the means of any one organisation to undertake this task single-handedly. What SANBI and other key partners in the national mapping of wetlands can do, is to promote an approach to the mapping of wetlands that delivers data as compatible as possible with the National Wetland Inventory, which, as a result, can easily be integrated into the National Wetland Map.

The protocols in this manual are designed to both improve the ability to capture and record future wetland data in a standardised and unified manner; and create standardised attributes for existing wetland datasets to facilitate data integration and comparison. This is an important requirement in terms of assisting with the creation of a single, centralised standard wetland database within the National Wetland Inventory.

Key points

- The inventory needs a central, overarching, regulating body that co-ordinates and manages new data and oversees quality checking of information.
- A national wetland spatial database requires regular updating and improvement to remain robust for use in decision making.
- This will need co-ordination, co-operation and communication between central leadership and multiple mappers across the country, supported by the standardised guidance in this manual.
- The National Wetland Map needs to be multi-scale, able to retain data integrity of the best available fine-scale data, while also benefitting from updates to large-scale datasets.

1.4 What to expect from this manual

This manual supports the generation and management of spatial and attribute data on wetlands at a range of scales, by providing practical guidance for:

1. **Future wetland mapping:** The manual supports future desktop and/or field-based wetland mapping across South Africa, by providing a standardised framework for the capture and organising of wetland data.
2. **Integration of existing data into a single inventory:** This manual helps guide the evaluation of existing wetland data and the creation of standardised attributes for existing wetland datasets to facilitate data integration and comparison.
3. **Quality assurance:** The manual covers quality assurance at various levels, including technical review of common GIS mapping errors, incorporating local expert review, and assigning levels of confidence to the data.

This manual should be seen as complementary to any norms, standards and specific metadata reporting requirements of projects depending on their specific objectives.

This manual does not replace current standards and guidelines for various aspects of wetland identification, delineation, classification and condition assessment. Importantly, this manual alone does not provide all the information needed to become competent in these topics, and it is expected that mappers will familiarise themselves with the key references recommended in this manual. So armed, it is hoped that mappers with different levels of expertise will be encouraged to contribute to the rapidly expanding community of learning and practice for wetland mapping, including contributions to the National Wetland Inventory.

1.5 Who should use this manual?

As already elaborated, improving the quality of wetland inventory data for the country as a whole is a daunting task that is beyond the ability of any single organisation to address individually. Considerable time, financial and human resources are required to do the task justice.

Given the magnitude of the task, the contribution of multiple datasets from multiple sources around the country is required. The South African Spatial Data Infrastructure (SASDI) Act (2003) is an initiative to develop policies and technical standards on the use of geographical data such as maps, aerial and satellite photographs, and surveys. It seeks to facilitate the capture, management, maintenance and integration of spatial data in South Africa under the Committee for Spatial Information (CSI), which identified wetlands as a core dataset. Organisations serving on the CSI, and those that are considered primary generators and users of wetland data, are the logical agents for commissioning or undertaking components of the work. Such organisations include (in no particular order) the Department of Water and Sanitation (DWS), the Department of Environmental Affairs (DEA), the Water Research Commission (WRC), the Council for Scientific and Industrial Research (CSIR) and SANBI at national scale, in collaboration with a range of relevant organisations with similar interests and mandates at provincial, local and catchment scales.

Remote sensing, GIS and wetland specialists will frequently be those advising on and undertaking the task of wetland mapping and data management. While this manual caters for their needs, it also provides an entry point for a broader range of people, who do not necessarily have such expertise, to engage with wetland mapping. Participating in a wetland inventory is an excellent opportunity for learning. The urgent task of generating and improving wetland data across the country will benefit from an expansion in the number of people conducting wetland mapping. It is hoped that it will become more common for a wetland inventory to be undertaken, for example, as part of the compilation of Spatial Development Frameworks and Environmental Management Frameworks, protected area management plans, Catchment Management Strategies or regional conservation stewardship projects, which have traditionally focussed on working with landowners and terrestrial biodiversity, but have not always systematically addressed the wetlands of the region under stewardship. The protocols in this manual are thus aimed at encouraging the incorporation of wetland inventory and mapping into a range of activities where it is currently not present, and will be useful to anyone mapping wetlands on a large or small scale, and any organisation commissioning wetland work.

Key points

- This manual is equally applicable to a wide range of national, provincial, non-governmental and commercial consultancy organisations undertaking wetland mapping.
- Wetland inventory is under-utilised as a strategic management and conservation tool, which this manual hopes to contribute towards changing.

1.6 Structure of the manual

The manual is structured into four parts that correspond to different stages recommended for a wetland mapping project:

PART A: Outlines what to consider before starting a wetland mapping project. This includes choice of scale, degree of detail and aspects of project design.

PART B: Covers the practical preparation that must be undertaken before leaving the office. This often involves preparation of GIS data, desktop digitisation or desktop modelling of wetlands.

PART C: Covers the approach and methods for conducting wetland mapping, and some limited associated data collection, in the field.

PART D: Outlines the follow-up desktop requirements for integrating the data and conducting quality control assessments.

PART A.

BEFORE YOU START – DESIGNING A WETLAND MAPPING PROJECT

This section presents some fundamentals of wetland inventory data and the collection of wetland data to consider before starting on a project.

At the outset of a project, consider what to include when submitting wetland inventory data (Section A1); the benefits of a catchment approach (Section A2); whether field or desktop mapping is appropriate (Section A3); and the type of data to collect (Section A4). This provides the basic guidance for starting your wetland mapping project, including stipulating the appropriate set of information attributes to collect about the wetlands (Section A5). Section A6 provides a standard Terms of Reference for wetland mapping, whether you're doing this yourself or hiring someone else.

A1. Overview of wetland mapping data

The working definition for the phrase 'wetland inventory' produced by the Ramsar Convention on Wetlands (Ramsar Convention Secretariat 2010) reads as 'the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities'.

Mapping typically refers to the collection of the spatial component of information, describing the wetland location and extent. However, for the purposes of this manual a 'wetland mapping project' is understood to include both the spatial component and the collection of information associated with the spatial component, i.e. some wetland inventory elements. This guideline covers both aspects, and it is understood that wetland mapping is a key component of inventory.

Wetland mapping data is captured, either through desktop mapping or a field survey, in a GIS-compatible digital vector format and is typically made up of:

1. The GIS shapefile containing mapped wetland boundaries or points indicating the locations of wetlands on a map.
2. Associated attribute data, which captures a range of features associated with each mapped wetland polygon or point, such as type, condition and importance.
3. A text document containing metadata (i.e. data about data) describing the content, origin and methods, quality, intended purpose and other characteristics of the GIS and attribute data.

Any contributor of wetland data should submit all three components (Figure 2).

These data may be collected at different degrees of detail (see Section A3) and choice of attributes (see Section A5).

A2. Catchment approach, at the scale of quinary catchments

Catchments are important entities to work with for mapping and inventory purposes, as they constitute natural hydrological units. They group areas together that may be interrelated in their ecological

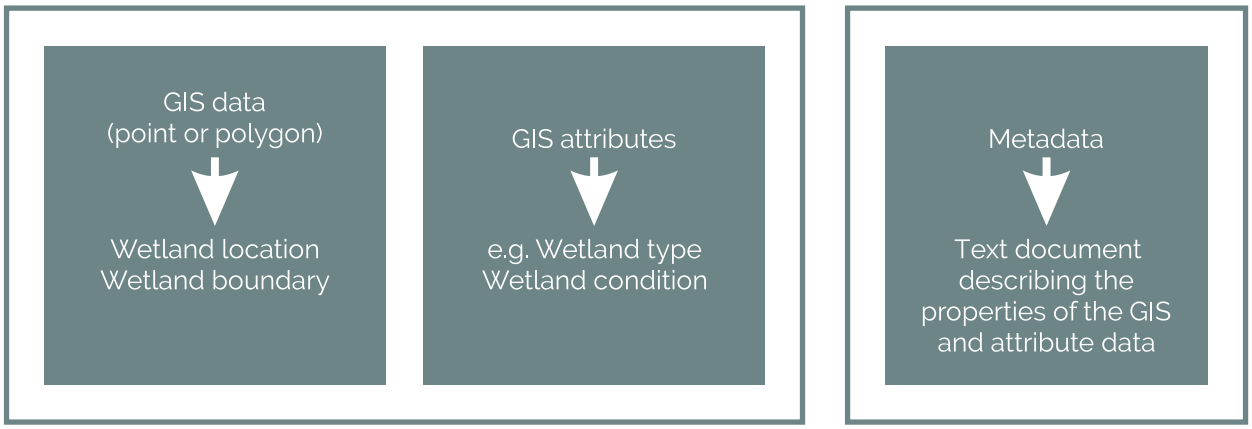


Figure 2: Components of wetland mapping and inventory data.

functioning and affected by common impacts. Activities in one part of a catchment may affect ecosystems downstream through, for example, erosion or more severe flooding due to the cumulative effect of lost wetlands or floodplains.

A catchment is broadly defined as all the land area from mountain ridge to valley floor that is drained by a single river and its tributaries. There is a scaled hierarchy of catchment sizes (WRC 2013). Catchments can be at the scale of one wetland, or one small tributary river, or one large, main river (grouping all the small catchments together). The largest catchment scale is called a primary catchment. This is the full geographic area over which water flows into South Africa's largest rivers. The primary catchment includes all the other smaller rivers, streams and wetlands, which flow into the large river. Primary catchments can be divided into secondary catchments that feed the large river's main tributaries (or second order rivers). These, in turn, can be subdivided into tertiary catchments that contain third order rivers (flowing into second order rivers), and so on.

A common catchment size used in land use planning and catchment management is the quaternary catchment, a fourth order catchment size. Quinary catchments represent fifth order catchments, and are smaller than quaternary catchments. Quinary catchment units are more hydrologically appropriate for the consideration of wetlands than units at the quaternary or

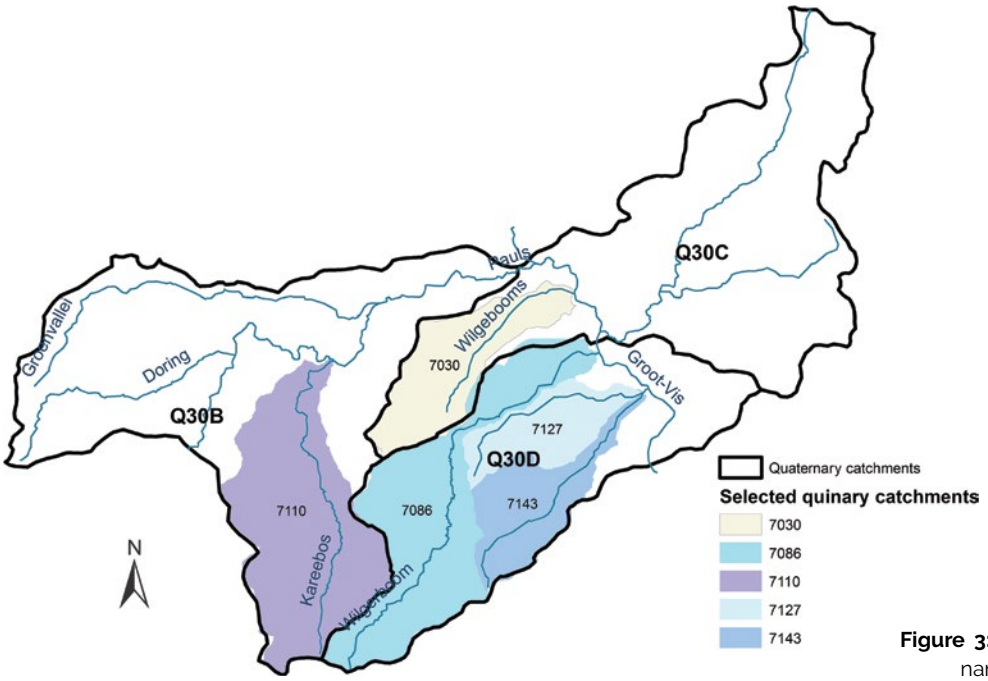


Figure 3: An illustration of quaternary and quinary catchments.

primary catchment-scale (Figure 3). While catchment divisions at the other scales are a reflection of political and management–driven boundaries, the quinary boundaries are currently the best representation of natural units that are hydrogically and biologically meaningful.

Within quaternary catchment Q30B in the above example, it is not necessary to investigate any other quinary catchments to understand the wetland types within quinary catchment 7110 and the impacts on them. Multiple quinaries may also be grouped together to form a logical unit for the management of a particular river and associated wetlands. It makes sense as an aquatic ecosystems manager to calculate hectares and impacts based only within the appropriate quinaries.

A national quinary catchment layer is widely available to the public of South Africa on the SANBI Biodiversity GIS website (http://bgis.sanbi.org), providing the potential for consistency in planning units across the country, province, municipality or local project. The layer was developed as part of the 2011 National Freshwater Ecosystem Priority Areas project (NFEPA) and is labelled 'River FEPAS' for that project. Each quinary has a unique identification number (Figure 3) and these are used nationally to identify catchments that are Freshwater Ecosystem Priority Area (FEPA) catchments and are considered particularly important for freshwater conservation. This manual recommends that the geographical area encompassed by a wetland mapping project be broken into quinary catchment units, and that this delineation guides the workflow of the mapping process. In this way, even a project area of substantial size can be broken into more manageable sections that constitute logical natural units for mapping wetlands and understanding their dynamics.

An example of such an approach is provided in Figure 4, where the Mpumalanga Highveld comprised the project area within which wetlands were to be mapped. This area was broken down into its constituent quinary catchments, and these

Figure 4: An example of planning work within a region of a province, in this case the Mpumalanga Highveld. Mapping work was scheduled one sub-Water Management Area (WMA) at a time. Within each sub-WMA, work was scheduled one quinary catchment at a time (source: Mbona et al. 2015).

were used as the units for planning and undertaking the desktop mapping and field verification. Since the study area encompassed a very large number of quinary catchments, Water Management Areas were also utilised as higher order aggregators to organise work. In cases where there was partial overlap between a quinary catchment and the project area, the quinary was omitted from the project if less than 50% of its area fell within the project area. When the degree of overlap exceeded 50%, the entire quinary was included in the project and the wetlands mapped.

A3. Field or desktop? An approach combining both is strongly recommended

It is important to consider the differences and implications of using either desktop or field-based survey techniques when mapping wetland boundaries, since these can significantly impact on the accuracy at which boundaries can be mapped.

Field survey methods typically generate more accurate wetland boundaries and information on wetland characteristics and condition than desktop methods, because they are based on the direct observation of wetland indicators (hydromorphic soil, hydrophytic plant species and hydrology). Wetland boundaries that have been mapped in the field should be assumed to provide the highest level of positional accuracy (if done correctly), but this approach may be limited in terms of its completeness, i.e. how many wetlands were seen in the field is constrained by time, budget, experience and accessibility. For example, six of the ten wetlands in a catchment may have been mapped very accurately, but four were missed. Those that were missed may represent a unique wetland type, or the only remaining pristine wetlands in the catchment. The time consumed by visiting wetlands individually places severe restrictions on the extent of the area over which an inventory can be conducted using this approach.

Desktop mapping can take the form of desktop modelling techniques (where rules are set as part of a computer programme to automate the mapping of wetlands), or heads-up digitising (manual digitising by a person tracing a mouse over the wetland features from satellite and aerial imagery displayed on the computer). In comparison to field-based mapping, desktop mapping is typically limited by the spatial resolution of the imagery, resulting in comparably lower levels of wetland boundary detail and confidence in the data. However, desktop mapping will generally allow mapping to be done over a wider geographical coverage and with less risk of leaving out significant wetlands. The reasons for this are the broader extent of the imagery being used, its overview capabilities, and the speed at which desktop interpretation can be completed in comparison to fieldwork. Desktop mapping is typically limited to delineating the surface representation of the wetlands in terms of surface features such as vegetation cover characteristics (a combination of form and structure) and open water at the time and date of image acquisition. This can, in some instances, be complemented with an understanding of local topography, geology and pedology, but is still predominantly based on what can be seen and interpreted from imagery.

Given the complementary strengths of both desktop and field mapping of wetlands, it stands to reason that an inventory should make use of both of these methods. Desktop mapping of wetlands is likely to be a key component of any large-scale wetland inventory, as it enables a large area to be covered rapidly and reasonably comprehensively. This allows for a more complete understanding of the variation present in an area. However, desktop mapping cannot provide the level of understanding that a mapper would gain from doing even a limited amount of fieldwork in the area being mapped. Without this knowledge in place, the mapper has a higher risk of misinterpreting the imagery, and drawing inappropriate conclusions that result in errors of omission (wetlands that are not mapped) and errors of commission (non-wetland areas incorrectly mapped as wetlands). It is, therefore, highly recommended that even a limited component of field verification be included to supplement any desktop approach, as this can significantly improve the accuracy of, and hence the level of confidence in, the data. As a minimum, a few strategically chosen sites or sub-catchments should be visited. These sites / sub-catchments should be selected so as to include as much

Key points

- Desktop mapping of wetlands is a key component of large-scale wetland inventory as it provides a rapid and comprehensive cover of an area. This is fundamental to any conservation plan or prioritisation exercise as it allows for a better understanding of the variation of wetland types and impacts present in an area.
- Desktop mapping cannot provide the depth of understanding gained from fieldwork, and without this knowledge in place, a project may draw inappropriate conclusions and have errors in data.
- A well-conceived field-based approach should ideally always include some desktop preparation and follow-up.
- A combined approach is ideal to achieve a moderate to high confidence dataset that covers a usefully large area and takes into consideration the full variation across an area.

as possible of the range of different bioclimatic regions, hydrogeomorphic types and land-uses represented in the area to be mapped.

A combined approach is ideal to achieve a moderate to high confidence dataset that covers a usefully large area and takes into consideration the full variation across the area. This manual recommends a combination of desktop and field-based approaches to achieve a moderate to high confidence inventory.

A4. Choosing the appropriate degree of data detail

It is important that the organisation or manager commissioning the wetland mapping project develops a clear description of the objectives of the project. These objectives will play a key role in determining which are the appropriate mapping techniques to use, and the amount of wetland information (attributes) to record.

The degree of detail recorded for wetland attribute data is best prescribed:

- By the end-users' wetland mapping requirements.
- By the level of expertise of the wetland mapper.

Table 1 illustrates the broad range of potential detail for wetland mapping projects in terms of cartographic mapping scales, size range of wetland features that can be practically mapped, typical data content characteristics, and the most appropriate wetland boundary mapping techniques. Each degree of detail has an optimal mapping area, based on the practicality of generating the prescribed degree of attribute detail over the designated geographical extent.

The broad groups in Table 1 take into consideration the practicality of undertaking a mapping exercise within typical budgetary and time constraints, and as such should be seen as recommendations rather than fixed rules. It is possible to design a wetland mapping project that mixes components from the groups, e.g. intermediate spatial detail with basic level of attribute information.

Key points

- GIS data should always be accompanied by a text metadata document, briefly explaining the project source, methodology, and list of attributes or information the data contains.
- The choice of what degree of detail to use depends on the objectives of a specific project.
- Careful consideration of objectives can save time, such that a project is strategic and follows clear goals. Time, budget and staff availability should then be applied efficiently to get the most value out of time allocated to the project area.

Table 1: The different degrees of data detail for a wetland mapping project, showing their spatial extent, attribute details and examples of usage

	BASIC	INTERMEDIATE	DETAILED
Project requirements	Large mapping area[a] / low spatial detail / low level of attribute information	Medium mapping area / moderate spatial detail / moderate level of attribute information	Small mapping area / high spatial detail / comprehensive attribute information
Mapping scale[b]	1:100 000 to >1:250 000	1:20 000 to 1:100 000	1:5 000 to 1:20 000
Minimum mapping unit[c]	6.25 ha (250 m × 250 m) to >40 ha (635 m × 635 m)	0.5 ha (70 m × 70 m) to 6.25 ha (250 m × 250 m)	<0.01 ha (10 m × 10 m) to 0.5 ha (70 m × 70 m)
Main survey technique	Primarily desktop, however could include basic/rapid field survey	Desktop and field	Primarily field, supported by desktop
Attribute information	Certain basic attributes can be captured: Wetland ID/Name/Size; Source data; Wetland mapping method; Independent verification; Natural/artificial	All attributes under basic plus additional attributes: Regional setting; Landscape unit, Wetland hydrogeomorphic type	All basic and intermediate attributes, plus additional attributes: Wetting regime; Wetland characteristics; Ecological condition; Ecological importance; Ecological reserve
Potential image source[d]	LANDSAT (30/15 m pixel) SPOT4 (20/10 m pixel)	SPOT5 (10/5 m pixel) RAPID EYE (5 m pixel) IKONOS (4/1 m pixel) Orthophotographs (<1 m) Google Earth	GeoEye (1.6/0.4 m pixel) WORLD VIEW (1.8/0.5 m) QUICKBIRD (2.4/0.6 m) Aerial photography (<1 m) Google Earth
Potential applications	Presence/absence. Simple wetland boundary delineation, accuracy levels not adequate for land use decision making	For conservation planning as well as presence/absence, but not suitable for more complex wetland assessment applications	Detailed wetland information required by regulatory processes. Detailed wetland assessment studies
Examples	National Wetland Map version 1	Spatial Development Frameworks (SDFs), Environmental Management Frameworks (EMFs), Conservation Plans, and other spatial planning activities such as town planning	Environmental Impact Assessments (EIAs), Water Use Licence Applications (WULAs), site-specific reserve determinations, site-specific management plans

a) Mapping area refers to the geographical extent of the project area (e.g. farm *versus* national). Spatial detail refers to the completeness with which all the wetlands in the mapping extent have been mapped (e.g. all wetlands or only those > 10 ha). Attribute information refers to the degree of non-spatial wetland detail.
b) Mapping scale refers to the scale at which the wetland data is captured and from which the expected degree of detail can be inferred.
c) Minimum mapping unit refers to the smallest wetland feature that would be represented in the dataset, based on what can be practically identified on the image in terms of spatial resolution and realistically represented visually as a cartographic thematic unit at the specified mapping scale.
d) Potential image source refers to examples of suitable imagery in terms of spatial resolution and geographic coverage. Comparable format imagery may also be used.

A5. What data attributes to record

A suggested template for an attribute table, in the form of an MS Excel spreadsheet, has been prepared by SANBI in support of the National Wetland Inventory to guide standardised collection of wetland inventory data. The spreadsheet has been designed around the structure used by the *National Classification System for Wetlands and Other Aquatic Ecosystems* (Ollis et al. 2013). It allows for the capturing of the most commonly required spatial and attribute data. The spreadsheet is available from the SANBI Biodiversity GIS website (http://bgis.sanbi.org).

Data captured by hand in the field can be transferred to the spreadsheet when back in the office, or the spreadsheet could be adapted to digital field tools such as a Trimble©. Once the spreadsheet is populated in MS Excel format it can then be digitally exported into a shapefile attribute table for use within GIS. Instructions for importing the spreadsheet into a GIS are provided in Appendix D. When imported into a GIS, the spreadsheet-based information becomes an attribute table for the wetland boundary data, recording the wetland characteristics of each wetland polygon.

Each row in the spreadsheet should represent a single mapped wetland. For ease of reference, each column in the spreadsheet has a drop-down list that contains the recommended set of descriptors and coding nomenclature (Figure 5). The use of these standardised descriptors will greatly enhance the compatibility between data collected by individual inventory projects and the National Wetland Inventory.

The spreadsheet can also support the preparation of the attributes table section of the metadata report (see Appendix A), providing a standardised format for reporting how a digital wetland map was created and what wetland-related detail the dataset contains.

Table 2 provides a subset of information components (attributes) from the spreadsheet. The spreadsheet also covers rivers and estuaries, which have not been included here.

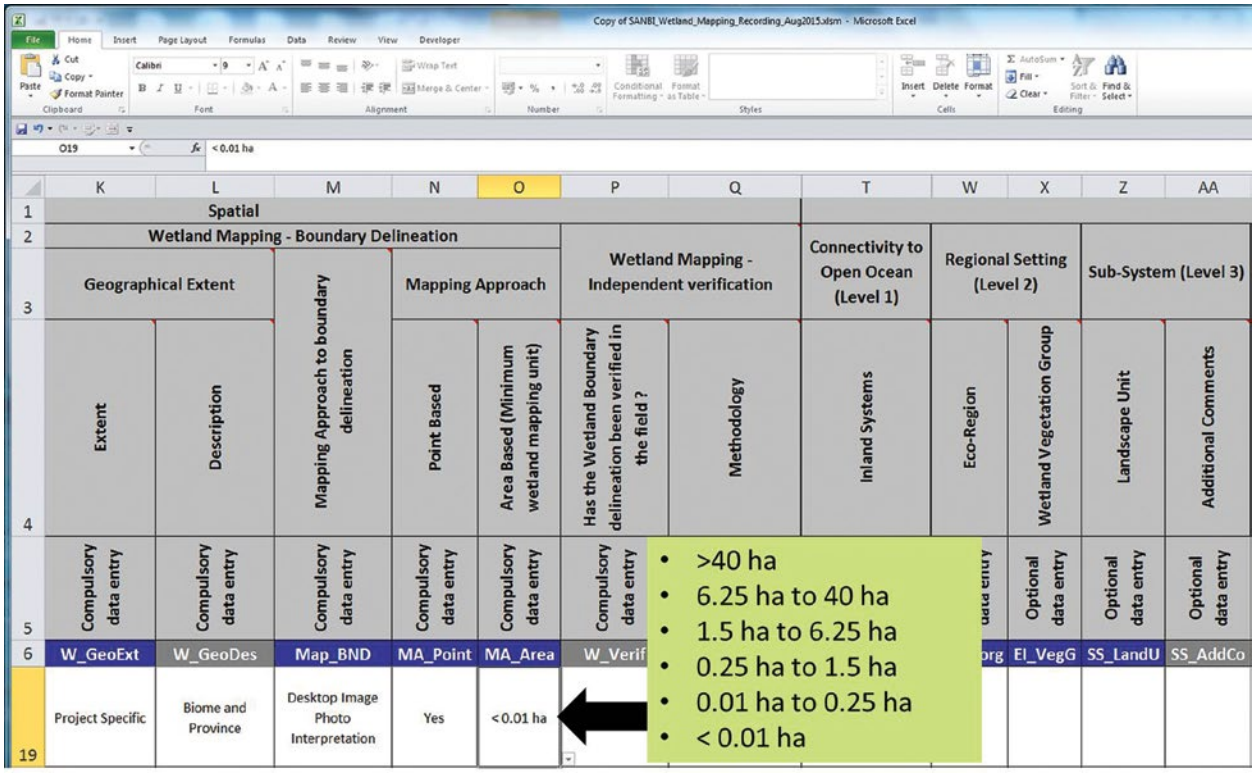


Figure 5: Example of an attribute drop-down list in the spreadsheet designed by GeoTerraImage (Pty) Ltd and Wetland Consulting Services (Pty) Ltd for SANBI in 2012.

Table 2: Potential attributes that can be recorded for a wetland mapping project

CATEGORY	ATTRIBUTE
The following information is common to most basic mapping projects. It is also common across all wetlands in the project, and is useful project information to include in the project metadata report.	
Project information	Project name
	Contact details
Source imagery or field survey technique	Source data
	Positional accuracy
	Acquisition date(s)
Wetland mapping	Project extent
	Extent description
	Date of data/survey
	Mapping approach to boundary delineation
	Minimum wetland mapping unit
Verification	Has wetland boundary delineation been verified (Y/N)
	Approach and level of verification
Some or all of the following data may be collected for wetland inventory. The information differs for each mapped wetland. Categories marked with an asterisk are most commonly collected and considered fundamental to any mapping exercise. Other information can be collected with different degrees of detail, for example, a mapping project can broadly map HGM units or it can delineate them in fine detail, and wetland condition may be estimated or assessed in detail.*	
Wetland	Wetland name*
	Wetland unique ID*
	Wetland size*
Regional setting	DWS eco-region
	NFEPA wetland vegetation group
Landscape (Level 3)	Landscape unit
Wetland HGM type (Level 4)	HGM Unit Level 4A* OR artificial wetland*
	HGM Unit Level 4B (longitudinal zonation)/ HGM Unit Level 4C
Artificial wetland	Artificial wetland type
Hydrological regime (Level 5)	Surface water hydrological regime
	Subsurface water hydrological regime
	Depth class category

It is not expected that all attributes will be collected in every project. The attributes that are collected will depend on the aim of the proposed mapping project (Sections A3, A4 and A5), and the degree of detail required. Different wetland mapping projects often collect different sets of attributes, depending on the purpose of the project and the degree of detail required. For example, a wetland map produced for a site-specific application such as an environmental impact assessment may include many detailed attributes, while the National Wetland Map contains only a small subset of these.

While much of the information collected may understandably be proprietory and confidential, it would be useful for clients and regulators to put

Table 2: Potential attributes that can be recorded for a wetland mapping project (continued)

Wetland characteristics (Level 6)	Geology
	Source data (for geology)
	Vegetation cover type
	Vegetation form
	Plant species list
	Peatland
	Peatland type
	Substratum type
	Salinity
	Acidity/alkalinity
Condition	Present Ecological State (PES)*
	PES Method
Confidence rating	Low, medium or high
The following are additional data that may be recorded during detailed wetland mapping. They are included on the MS Excel spreadsheet that accompanies this manual, but are not discussed further.	
	Protection status
	Ecosystem threat status
	Known or recorded rare or endangered species
	Category of rare or endangered species present
	Populations of unique and/or important species
	Ecological Importance and Sensitivity (EIS) category
	EIS method
	EIS confidence rating
Ecological reserve	Ecological reserve determination undertaken
	Recommended Ecological Category (REC)
General comments	General comments

formal protocols in place to allow for a subset of this data to be submitted to the provincial and/or national custodians of wetland inventory data. This would require agreements at the outset of a project, and within the Terms of Reference, that indicate which information can become available for public use and which is proprietory, and to make provisions for submitting the information to the provincial or national custodians once the project is completed.

Currently, the National Wetland Inventory does not have specific minimum data requirements. This enables it to make use of a wide variety of data sources, which are included in the inventory wherever possible for the sake of increasing coverage and comprehensiveness. However,

preference is given to polygon data and mapping areas larger than a single wetland for which the boundaries have been mapped in the field. As a result, the full set of attribute information collected in smaller-scale projects is often not carried over to the National Wetland Map. For this reason, the data source attribute is important, so users may source more detailed information where it is available.

A6. Generic Terms of Reference

This section presents generic elements that can be used in compiling Terms of Reference for wetland mapping projects. These elements are based on the standardised set of procedures recommended in this manual for both desktop and field-based wetland mapping activities in South Africa.

Note that the generic elements proposed here for Terms of Reference do not replace any pre-existing requirements regarding metadata reporting and/or final project reports, which would normally be expected to accompany such wetland data. These recommendations are compatible with, rather than a replacement of, existing, approved norms and standards for generating and managing spatial data.

Key points

- Basic identifying information for each wetland, as well as information on data source and confidence, allows multi-scale and multi-source data to be combined and compared.
- Develop agreements early in a project regarding which data will be integrated into the national and/or provincial datasets.
- It is important to record the source of the original data where more detailed, fine-scale data has been consolidated into the National Wetland Map. With source information, users can obtain the more detailed, best available information.

The following generic terminology can be incorporated into Terms of Reference as technical specifications when designing and commissioning wetland mapping projects:

- The wetland mapping expert should have a sound knowledge of the most current and appropriate field-based and/or desktop wetland mapping techniques.
- The wetland mapping project must be undertaken according to the protocols and procedures recommended in this manual.
- The MS Excel spreadsheet format as detailed in Section A5 of this manual should be used for collection and presentation of wetland data (the SANBI Wetland Mapping Recording Sheet may be downloaded from http://bgis.sanbi.org/MHwetlands).
- Use of the spreadsheet-based reporting structure implies that as a pre-requisite, the wetland mapping specialist has a comprehensive understanding of this manual, the content and structure of the *National Classification System for Wetlands and Other Aquatic Ecosystems* (Ollis et al. 2013), all associated wetland definitions and the various wetland assessment tools.
- The spreadsheet data must be converted to GIS format to spatially join the attributes recorded in the spreadsheet with the digital wetland boundary data that must also be supplied. The digital map data is to be supplied in GIS shape file coverage format. A single coverage containing all mapped wetland features is to be supplied. All digital GIS data is to be supplied in geographic format (WGS84, WGS84) in addition to any other map projection format.
- A catchment approach to organising work flows and datasets is strongly recommended. To produce a moderate to high confidence inventory of all the wetlands in a catchment, the following key tasks are recommended:
  - Identify project catchment(s).
  - Consolidate best available data and/or generate new data with remote sensing or desktop image interpretation.
  - Undertake a detailed site assessment or verification of a subset of sites in the field.

- Complete a drive-through of the project area for verification of as many sites as feasible.
- Complete desktop mapping of the project area, applying knowledge gathered from the field.
- Allocate sufficient time for a final review by appropriate competent specialists, e.g. GIS technical review, wetland specialist review, stakeholder review.

PART B.
BEFORE YOU LEAVE FOR THE FIELD – DESKTOP PREPARATION

Desktop preparation is essential for any wetland mapping project, even if the mapping approach is largely field based. This section provides guidance on the use of GIS for desktop identification and delineation of wetlands and features that influence components of wetland condition (hydrology, vegetation and geomorphology). Section B1 outlines the data that needs to be collected for every project regardless of the mapping approach used. GIS layers that can support desktop mapping and imagery are introduced in Section B2. Sections B3 and B4 review the two main desktop mapping approaches (desktop modelling and heads-up digitising) and apply them to the mapping of wetland boundaries. Decisions also need to be made about how much additional information to collect about the wetlands. Section B5 introduces classification of wetland types including classification of regional wetland type (Section B5.1), classification of landscape unit (Section B5.2), and classification of hydrogeomorphic type (Section B5.3). The remaining section discusses the assessment of wetland condition (Section B6).

B1. Recording information about the project

Section A5 (Table 2) introduced an extended set of attributes that could be collected for a wetland mapping project, and introduced the MS Excel spreadsheet developed to support the collection of attribute information. Throughout the remainder of this manual, components of the spreadsheet are represented in tables (Tables 3, 7, 8, 10, 11, 12, 17, 18 and 19) and accompanied by supporting explanatory text.

The first section of Table 2 (and the MS Excel spreadsheet) is repeated in Table 3 below. Table 3 addresses attribute fields that are typically applicable to the entire project dataset. This information may also be recorded in the dataset's metadata in the section of the metadata document, which summarises general information about the project (Appendix A).

Information about the source of the data is an important attribute to record. This could include the unique name applied to the project as defined by the client or the wetland mapper / wetland mapping service provider (e.g. St Lucia Wetlands), and the contact details for the source of the data. This is useful information when multiple datasets are combined, allowing future users of the data to know which wetlands were mapped and reviewed by a specialist, which were modelled and which, for example, came from analyses of maps from the Chief Directorate: National Geospatial Information (CD: NGI). For projects that have adopted a catchment approach, project extent information is the place to record this and also to provide the catchment names or codes.

B2. GIS layers in support of desktop mapping

Collating best available GIS wetland data

A single source of consolidated GIS data on wetlands is an invaluable resource to users in a region. Multiple wetland data layers that

Table 3: Overall project information attributes, common to all wetlands in a project

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Project name	PrjName	The unique name applied to the project (e.g. St Lucia Wetlands)	Freehand text (maximum of 20 characters)
Contact details	Contact	Wetlands mapping service provider responsible for this project (e.g. Wetlands Consulting)	Freehand text (maximum of 20 characters)
Project geographical extent/catchment	PrjExt	Definition of the type of project mapping area (e.g. Cadastre)	National Provincial District Local municipality Cadastre (erven) Cadastre (farm portion, parent farm) Catchment Sub-catchment Quaternary catchment Sub-quaternary catchment Water management area Project specific
Geographical extent description / catchment code	ExtDes	Description of the extent as expressed by the appropriate code	If cadastre is used, the SG 21 Digit code must be provided, e.g. T0IQ00990000012300001 In the case of a hydrological catchment, use DWS official codes or NFEPA quinary codes Freehand text

have inconsistencies between them can lead to confusion and conflicts in decision making. Integration of all the best available data helps to avoid duplication of effort or the use of less accurate information where better information exists. The integration process requires consensus, supporting justifications of choices made, or expert review of what is the most accurate data. Thus, the consolidation of available wetland GIS data into a single layer, and the identification and resolution of conflicts between the layers, is an important desktop preparation task and is a key contribution the wetland inventory process can make to effective decision making and conservation management in a region. It would be important to be able to interrogate the metadata and, for example, based on the data field 'approach and level of verification' (Table 2) generate a map showing the degree to which, for different parts of a study area, the map has been verified and whether the approach used was field or desktop verification.

It is essential that the layers contributing to the new updated layer (Table 4) be mentioned in the metadata document that accompanies the GIS dataset (see Appendix A). They should also be referenced in the attributes of the polygons that have been incorporated, especially where they have not been changed, for example, polygons that are high confidence and have been carried over in their original form. This would be

Table 4: Examples of existing GIS wetland layers

DATA LAYER	SOURCE	NOTES
NFEPA wetland dataset	NFEPA project	Provides wetland Freshwater Ecosystem Priority Areas (FEPAs), hydrogeomorphic and regional type, condition and presence of important taxa
Working for Wetlands data	Working for Wetlands	High confidence specialist-mapped wetlands prepared for the Working for Wetlands Programme
Specialist-mapped wetlands	Multiple sources	High confidence specialist-mapped wetlands e.g. 'Mfolozi catchment wetland inventory'
Inland water features: Pans	CD: NGI	Pans data from the topographic maps will help with identifying depressions
Inland water features: Artificial wetlands	CD: NGI	Several different artificial wetlands are identified in this data and will help with identifying whether a newly digitised wetland has previously been identified as a dam or other artificial wetland type
Inland water features: Marshes	CD: NGI	As with pans and dams above, this is very useful moderate to high confidence data

referenced under 'project name' and 'contact details' attributes outlined in Section B1. Large inventory projects are thus likely to reflect multiple project names in their 'project name' attribute column. In this way, the source of the data is acknowledged and can be followed up for any extra information that may not have been able to be carried over from the original dataset.

Inventory work is often an ongoing process, benefitting from access to existing wetland datasets covering a study area. Currently, it is often difficult to access best available data. Forward planning, where agreements are built into the initial stage of commissioning of development projects could change this, so that, for example, spatial datasets with basic attributes become public data while certain information is withheld as intellectual property or to protect client information. Maintaining and strengthening relationships with wetland specialists in a region is one mechanism for facilitating access to supplementary data. Protocols need to be in place to accept this data and reconcile it with the new wetlands map created through a project. This requires both GIS expertise to incorporate additional data and align the attributes, and wetland expertise to make appropriate decisions on adjustments and further review the data to ensure it has not been inadvertently altered during incorporation.

GIS layers that can support the mapping process

Several non-wetland data layers are useful to have at hand when conducting desktop mapping.

Key points

- The tasks of consolidating GIS data into as few as possible layers and identifying and resolving conflicts are critical to the usefulness of a mapping project. Stakeholders may otherwise continue to be faced with multiple and differing data layers and may choose to build yet another new layer.
- Consider strategic ways to build agreements into the Terms of Reference and initial stage of commissioning of development projects so that, for example, a spatial dataset with basic attributes becomes public data while other information is agreed to be withheld as intellectual property or to protect client information.
- Acknowledge the source of the data in both the attributes and the metadata, so that more detailed available information can be followed up where it is available.

Table 5: Input GIS layers that provide supporting information for desktop mapping

DATA LAYER	SOURCE	NOTES
All data layers mentioned in Table 4 can assist in identifying new wetlands and in ensuring that what has already been mapped is not overlooked		
Layers to help identify catchment boundaries		
Quinary catchments (River FEPAs)	NFEPA project	Identifies entire sub-quaternary catchments associated with river reaches. Current best available hydrological boundary.
Quaternary catchments	Department of Water and Sanitation	Quaternary catchments are the most commonly used hydrological unit.
Water Management Areas (WMAs)	Department of Water and Sanitation	19 Water Management Area administrative and management units for water resource management.
Non-wetland layers useful to support the identification of wetlands		
1:50 000 rivers data	Chief Directorate: National Geospatial Information (CD: NGI)	Currently the most accurate spatial cover for rivers. It draws the eye to many of the potential areas in a landscape where wetlands may be present.
5 m or 20 m interval contours and 1:10 000 or 1:50 000 spot heights	CD: NGI	Contour lines help to identify watersheds and drainage, showing the flow of water in the landscape.
Layers to help the identification of landscape position		
Landforms layer	Multiple sources	Landforms help identify wetland landscape position.
Digital elevation models	Multiple sources	Digital Elevation Models (DEM) support modelling of wetland presence and type.
Layers to help the identification of regional wetland type		
WetVegGroup	Nel et al. 2011a	Wetland Vegetation Group was applied for NFEPA and the NBA (Nel et al. 2011a; Driver et al. 2011).
DWS Level 1 eco-regions	Kleynhans et al. 2005	The Department of Water and Sanitation has defined Level I eco-regions for aquatic ecosystems (Kleynhans et al. 2005).

These data layers provide important context for wetland mapping. As mentioned above in Section A2, catchments are highly useful hydrological units for wetland mapping, and several existing data sources can help to define the boundaries of catchments (Table 5). Data layers providing useful topographical information and drainage context include contour lines and 1:50 000 river lines, both of which are very useful to support the identification of wetlands and the classification of hydrogeomorphic types, as they help the mapper to understand the flow of water through the catchment. It is helpful to have these data layers loaded into your GIS project window when doing desktop-based wetland delineation.

These GIS layers can be obtained from:

- SANBI Biodiversity GIS (BGIS) website: http://bgis.sanbi.org

Key points

- Make use of multiple data sources to assist with determining water movement and catchments.
- Without the aid of catchment boundary lines, it is a common problem to mistakenly overlap catchment boundaries while mapping.
- Having the catchment boundaries, contour lines and 1:50 000 river lines in place compels the mapper to understand the landscape context, and, in so doing, assists in interpreting the imagery correctly.

- National Geospatial Information: http://www.ngi.gov.za/; Van der Sterr Building, Mowbray, Western Cape; and SalesPta@drdlr.gov.za; 24 Helen Josephs, 708 Capitol Towers, Pretoria (Tel. no.: +27 12 312 9606/9604)
- DWS website: https://dwa.gov.za

Spatial imagery

The method of wetland boundary delineation is largely dependent on the degree of detail required. There are, however, preferred methods if mapping accuracy is paramount and external factors such as time and cost are less important. In determining which boundary delineation method to use, it is important to consider whether:

- The method of boundary delineation is appropriate to end-user accuracy requirements.
- The method is correctly recorded and captured in the attribute spreadsheet.
- End-users (and wetland mapping specialists) are fully aware of the implications and limitations of such techniques when using the wetland data in future analyses.

Table 6: An overview of the merits and limitations of different imagery

	GOOGLE EARTH*	OTHER SATELLITE IMAGERY**	AERIAL IMAGERY***
Limitations	Limited by acquisition date, seasonality and location accuracy of the imagery (errors of several metres). No access to true multispectral imagery. Limited functionality of the Google Earth software.	Resolution and mapping scale dictates the degree of mapping detail e.g. in a large-scale mapping project a wetland may be allocated as 'valley-bottom' wetland or may not have any information about wetland HGM type, while at a finer scale it may be divided into 'valley-bottom' and several side 'seep' wetlands.	Limited by the acquisition date and seasonality of the available aerial imagery. Typically acquired in sub-optimal seasonal conditions for wetland mapping. No access to true multispectral imagery. Many of the available imagery are not ortho-rectified.
Applicability	Project or sub-catchment scale mapping. This is a simple desktop image interpretation mapping process. Historical imagery is available for at least the last ten years.	Sub-catchment to national scale mapping. Multispectral image format facilitates extraction of greater wetland information. Supports comprehensive desktop mapping and modelling process with incorporation of complementary data.	Project, sub-catchment or catchment-scale mapping. Can be used either in a simple desktop image interpretation mapping process or as a comprehensive desktop mapping and modelling process. Very useful historical imagery to at least 1945.
Area coverage	Omission errors are typically limited due to the ease of accessing the required image coverage.	Access to a significantly wider archive of available imagery.	Depends on the availability of suitable date coverage.

NB: It is assumed that imagery has been geo-corrected to an appropriate high level of precision.

** In South Africa, Google Earth imagery is typically a combination of 2.5 m true colour SPOT 5 imagery, true colour 50 cm Ground Sampling Distance aerial imagery and/or sub-metre true colour GeoEye and WorldView (QuickBird) satellite imagery.*

***In South Africa, SPOT 5 multispectral imagery is currently readily available for all government-funded wetland mapping initiatives. These datasets have been recorded annually from 2006/2007 onward and provide a level of ad hoc seasonality. Imagery such as QuickBird, WorldView* and *GeoEye require a significant purchase cost, while SPOT 5 tile mosaics datasets must not be confused with the SPOT 5 image data. The SPOT 5 image dataset is a true multispectral image format. The SPOT 5 tile mosaics are composites of one or more image acquisition dates. Tile mosaics have high mapping accuracy, which is compromised by the lack of multispectral information and the multiple acquisition dates within one dataset.*

****This data is freely available from the Chief Directorate: National Geospatial Information. It is supplied as 50 cm Ground Sampling Distance orthophotography in a digital format and is suitable for analysis in digital image processing or GIS software packages and has very high location accuracy.*

These factors also apply to the choice of appropriate imagery for desktop image interpretation. For example, it may be inappropriate to use Google Earth imagery on desktop or a recreational grade Global Positioning Systems (GPS) in the field for an engineering or land use development-based application that requires a high degree of accuracy, as the location accuracy of the wetland boundaries may be out by several metres (± 10–15 m is possible).

The merits and limitations of different sources of spatial imagery are outlined in Table 6. In general, desktop wetland mapping will improve as better imagery becomes available.

When using spatial imagery for desktop image interpretation of wetland boundaries, it is necessary to provide the details of the imagery used, for example, positional accuracy of spatial data is normally seen as the first indication of the reliability of the dataset. Positional accuracy is either supplied with the data or is calculated by the image analyst. There is typically a limited amount of metadata information available relating to the positional accuracy of Google Earth, thus a project mapped with Google Earth may have variable accuracy.

The attributes relevant to desktop image interpretation are given in Table 7. These reflect the attributes on the MS Excel spreadsheet described

Table 7: Attribute information to include about imagery used to support wetland mapping

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Data source	Data	This specifies either the source imagery or the field survey technique that has been used to capture the wetlands boundary (e.g. SPOT 4 (20 m)). It is furthermore important to indicate which are panchromatic (pan) or multispectral (ms) when reporting on imagery used	• Landsat ETM (15 m) • SPOT 4 (20 m) • SPOT 4 (10 m) • SPOT 5 (10 m) • SPOT 5 (5 m) • SPOT 5 (2.5 m) • RapidEye (5 m) • Worldview 1 & 2 (0.5 m) • Worldview 1 & 2 (2 m) • QuickBird (2.5 m) • QuickBird (0.6 m) • GeoEye 1 (2 m) • GeoEye 1 (0.5 m) • Ikonos (4 m) • Ikonos (1 m) • CD: NGI – Aerial Photography (0.5 m) • Google Earth • Field GPS: Recreational Grade (>15 m) • Field GPS: Mapping Grade
Positional accuracy	Acc	Positional accuracy is either supplied with the data or is calculated by the image analyst	• Mapping Grade GPS • Recreational GPS • CD: NGI Aerial Photo • Ortho Correction Imagery • Geo Correction Imagery • Unknown
Acquisition dates	Dates	The acquisition date of the imagery or the date of the field survey. In case where only the year is known, months are coded as '00'. In cases where multiple image or field survey dates are applicable, then the dates are separated by a comma	• Image – MM/YYYY • Image – 00/YYYY • Image – MM/YYYY, MM/YYYY • Field Survey – MM/YYYY • Field Survey – 00/YYYY • Field Survey – MM/YYYY, MM/YYYY

in Section A5. Table 7 also includes a section to record information about the field survey, with respect to the positional accuracy of the data. Recreational GPS equipment used in the field cannot be compared with high precision mapping grade equipment – this is useful to remember if such equipment has been used for a project.

Most imagery datasets and many GIS layers are organised according to the grouping of 1:50 000 topographic map tiles either into latitude–longitude grids or sub-grids (AA, AB etc.). Map tiles divide the geographic area into a grid of a certain size. Spatial imagery and other underlying data are often available as individual map tiles, to allow ease of dissemination. As a result, a useful way to organise wetland mapping work is according to the set of tiles making up a catchment, i.e. map a complete catchment, one tile at a time.

B3. Approaches to desktop wetland mapping

The aim of desktop wetland mapping is typically either to digitise new wetlands or to correct wetlands that were incorrectly or only partially mapped. It is recommended that all field mapping projects invest in some level of desktop mapping to best prepare for the field component. Thus, desktop mapping is a key component of any wetland inventory and it is commonly undertaken through one of the following two broad approaches:

Desktop modelling: Modelling refers to prediction of wetland occurrence based on a range of variables, rather than confirmation of actual occurrence. For the purpose of this document, remote sensing–derived image classification is included in this section. Modelling of wetland presence and other wetland characteristics is becoming increasingly popular, with much current research being conducted into optimal approaches. Given the constantly changing nature of GIS technology and tools, it is not practical to provide detailed desktop modelling guidance in this manual, other than a brief overview and acknowledgement of its contribution as an important component in an overall wetland inventory strategy. Some key points related to this approach are that:

- Modelling works best for large-scale areas (e.g. the National Wetland Map), but lacks human eye interpretation.
- Modelling returns only what the computer programme has been calibrated to do, which is highly dependent on the input data and the modelling rules that are set. However, for example with images with a red-edge and/or narrow SWIR bands, it can at times offer better separation between species compared to the human eye.

Desktop 'heads-up' digitising: Delineating wetland boundaries can be achieved through desktop image interpretation using onscreen digitising over raster imagery within GIS software. New wetlands can be digitised using a combination of available imagery supported by other existing GIS layers (see Section B2). It is ideal to use multiple imagery sources (e.g. SPOT, Google Earth, orthophoto) and various imagery dates. Desktop 'heads-up' digitising relies on the wetland-related expertise of the individual conducting the mapping. It can take time for the wetland mapper to become experienced in identifying wetlands from an image. Once the mapper has practised mapping wetlands, and spent time visiting wetlands in the field, image interpretation becomes quicker and easier.

There are several information attributes that relate to desktop mapping methods and verification (Table 8). These attributes allow future users to understand the desktop mapping methods used, their properties and limitations. The attributes are grouped into those related to the nature of the wetland mapping itself (i.e. the approach used) and the means of verification. Field mapping methods are also referred to in

Key points

- It is important to compare different types of imagery available for mapping and assess their applicability and limitations.
- GIS data and imagery is frequently grouped according to 1:50 000 topographic map tiles and this can be a useful way to schedule mapping within catchments.

Table 8: Attributes that relate to desktop (and field) mapping methods

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Mapping approach to wetland boundary delineation	Map_Meth	The approach to wetland boundary mapping.	• Desktop Image Classification / Modelling • Desktop Image Photo Interpretation • Field Observation (no augering) • Field Observation with augering
Point based	Point	Is the wetland location defined as a point based on either image or field-based mapping approaches?	• Yes • No
Area based (Minimum wetland mapping unit)	Map_Unit	This is the expected minimum wetland mapping unit, expressed in hectares. It is the smallest wetland feature that would be represented in the dataset, based on what can be practically identified on the image.	• > 40 ha • 0.25 ha to 1.5 ha • 6.25 ha to 40 ha • 0.25 ha to 1.5 ha • 1.5 ha to 6.25 ha • 0.01 ha to 0.25 ha • < 0.01 ha
Has the wetland boundary delineation been validated in the field?	Verif	Has an independent assessment of wetland boundary mapping been undertaken to confirm mapping accuracy and completeness across the project area?	• Yes • No
Methodology	Verif_Meth	Method used to independently verify the wetland boundaries. This may either be an alternative desktop approach or a more comprehensive in-field survey.	• Desktop comparison to independent wetland data • Desktop comparison to independent image data • In-field validation: Field observation with point augering (Recreational GPS) • In-field validation: Field observation with transect augering (Recreational GPS) • In-field validation: Field observation with point augering (Mapping GPS) • In-field validation: Field observation with transect augering (Mapping GPS) • None

Table 8, but these are discussed further in Part C of this guideline.

Independent verification of the mapped wetland boundary is important for confirming mapping accuracy and completeness across the project area. Methods used to independently verify and validate the wetland boundaries may either be an alternative desktop approach or a more comprehensive in-field survey (Table 8). Level of wetland experience, and level of local knowledge, should also be taken into account during verification.

B4. Desktop mapping of wetland location and extent

Whichever approach is used for image interpretation (either modelling or 'heads-up' digitising), one has to be able to recognise wetlands in the landscape. This section covers some basic guidance on how to do so. The first step is to distinguish

Key points

- Desktop modelling is a critical tool for achieving coverage at provincial and national scale.
- The major limitations of desktop mapping are problems of wetland mapping accuracy and detection.
- Desktop mapping is an important preparatory task, but should be part of a larger strategy that includes field verification.

between the wetlands and surrounding terrestrial ecosystems.

Modelling of wetland location and extent

Wetland modelling takes into account environmental variables such as slope, sinks/depressions and flow accumulation calculated from GIS data. One primary input into wetland modelling is a DEM, which shows the topography of the land surface. Other types of modelling can include supervised and unsupervised automated image classification of spatial imagery. Early versions of the National Wetlands Map (Beta Version) were modelled using a 90 m DEM and Landsat imagery. This was able to provide a national dataset in terms of coverage, but was limited to wetlands greater than 1 ha, with poor boundary delineation accuracy and no associated wetland attribute information (SANBI 2012).

Hiestermann and Rivers-Moore (2015) have recently demonstrated that predictive models based on ancillary data have the potential to improve the accuracy of wetland mapping in South Africa. Ancillary data, which can be in the form of a variety of environmental variables (e.g. rainfall, evaporation, geology, slope, elevation, flow accumulation and soil characteristics), has been widely used in probabilistic/predictive models (including Bayesian networks and logistic regression) to generate probabilities of wetland occurrence. The accuracy of these predictions can then be tested with real data. For KwaZulu-Natal, areas with a high probability of wetland occurrence in the final model outputs of Hiestermann and Rivers-Moore (2015) correlated well with known wetland systems and wetland-rich areas in KwaZulu-Natal.

Desktop 'heads-up' digitising of wetland location and extent

Desktop digitising of wetlands using GIS software relies on the ability of the wetland scientist to operate the software and to recognise wetland features on available imagery. This can often prove difficult to a person with limited GIS experience, as well as to the GIS practitioner with a limited wetland science background. Recognising key landscape features associated with wetlands may prove challenging if one does not have an understanding of what drives the emergence and persistence of wetlands in the landscape and has not been exposed to the full range of examples in the field.

The first step in wetland mapping is recognising where the wetland and non-wetland areas are on the imagery (Table 9). On satellite and orthophoto imagery, wetlands often appear different in colour and texture from surrounding non-wetland areas. Wetlands are most often found in low-lying positions in the landscape as channelled or unchannelled valley-bottoms, or in seepage areas at higher positions. There is often connectivity between seeps and valley-bottom wetland areas. Wetlands are sometimes found at the tops of mountains, generally on plateaus. However, this is less common. Wetlands appear slightly differently in different parts of the country, as the soil and vegetation differs in colour and texture. The quality and timing of the imagery itself also adds variation to the appearance of wetlands, with wet season and multi-season imagery often proving particularly useful. Below are a few screen shots that highlight different examples of the way in which wetlands and wetland types appear on desktop imagery.

Desktop mapping of wetland extent is aided by:

- Visible patches of open water.
- Visible signs of the presence of patterns indicative of periodic soil saturation and indicator plant communities/species (i.e. vegetation colour, pattern and texture) (Table 9).

Table 9: Examples of wetlands as identified using spatial imagery. The outer boundaries of the wetland are indicated with dotted lines

WETLAND EXAMPLES	DESCRIPTION
	Wetlands can often appear darker than the surrounding non-wetland (picture left) and have a coarser-textured appearance as a result of the particular vegetation growing in the wetland. The darkness of the vegetation may be more as a result of characteristics of the vegetation than the soils, although both are likely to have an influence. In addition, the direct presence of moisture in the upper soil horizon would also add to the darkness, provided that it was not obscured by the vegetation. (Co-ordinates: 27˚24'08.43"S, 30˚31'36.23"E)
	Palmiet (*Prionium serratum*) can often appear lighter in colour than the surrounding landscape (pictured left). These wetlands are largely confined to the Western Cape and the coastal hinterland of northern Transkei (Eastern Cape). Common reed (*Phragmites australis*) may also often appear light in colour, particularly if the image is from towards the end of the growing season. (Co-ordinates: 33˚38'44.00"S, 19˚21'19.77"E)
	Wetlands often appear greener than the surrounding landscape. However, care must be taken not to mistake irrigated irregularly shaped fields such as golf courses (pictured left) as wetlands since these can also appear as bright green features in the landscape. Bunkers are slightly visible as circular sand patches along the course. (Co-ordinates: 33˚37'27.82"S, 19˚26'38.15"E)
	Wetlands are often difficult to farm and will often appear as unfarmed areas in a highly transformed agricultural landscape. However, in some landscapes, most of the wetland may be transformed to agricultural land. (Co-ordinates: 29˚04'21.08"S, 30˚42'44.38"E)

Other clues to locating wetlands in the landscape include:

- Contour lines that indicate catchments/watersheds, as well as slopes, valleys and depressions (see Section B2).
- River lines, which indicate the direction of water flow as well as highlighting potential areas to look for wetlands (see Section B2).

The remaining sections in PART B focus on information that can be used to characterise wetlands in a mapping project.

B5. Desktop wetland classification

Wetlands encompass tremendous geomorphological and hydrological diversity, but also have many fundamental features in common. Wetland classification refers to 'the process of grouping wetlands into similar types according to their biophysical characteristics and the way in which they function' (Ollis et al. 2013).

The *National Classification System* distinguishes between marine, estuarine and inland aquatic ecosystems. Both rivers and wetlands are included in inland systems (see Figure 6); however, this inventory manual deals only with wetlands.

A comprehensive manual has been published to guide users to implement the *National Classification System for Wetlands and Other Aquatic Ecosystems User Manual: Inland Systems* (hereafter *National Classification System*) (Ollis et al. 2013), and it should be the primary reference when applying wetland classification. It is strongly recommended that inexperienced wetland mappers read the full explanations of the wetland types before their first attempt to apply the classification system, especially at its finer levels, to the wetlands being mapped. The following section contains excerpts from the *National Classification System*, but is not intended to replace it.

Regional setting (Level 2) is discussed in Section B5.1, landscape unit (Level 3) in Section B5.2 and HGM unit (Level 4) in Section B5.3. These three components can also be addressed in the field, and are discussed once again in the field mapping sections of this manual, namely Sections C4 and C6.

The remaining two columns of Figure 6 (Hydrological Regime – Level 5, and descriptors/wetland characteristics – Level 6) are best assessed in the field (with the exception of the

WETLAND CONTEXT		FUNCTIONAL WETLAND UNIT		WETLAND CHARACTERISTICS
LEVEL 2: REGIONAL SETTING	LEVEL 3: LANDSCAPE UNIT	LEVEL 4: HYDRO-GEOMORPHIC UNIT	LEVEL 5: HYDROLOGICAL REGIME	LEVEL 6: DESCRIPTORS
DWA Level 1 Ecoregions OR NFEPA WetVeg Groups OR Other spatial framework	Valley floor	Floodplain wetland	Period and depth of inundation Period of saturation	Natural vs. artificial Salinity pH Substratum type Vegetation cover type Geology
	Slope	Channelled valley-bottom wetland		
	Plain	Unchannelled valley-bottom wetland		
	Bench (hilltop/saddle/shelf)	Depression		
		Seep		
		Wetland flat		

Figure 6: The basic categories for typical inland systems according to the National Classification System (adapted from Ollis et al. 2013).

DWS Level 1 eco-regions (Kleynhans et al. 2005) are based on broad-scale patterns of physiography, climate, geology, soils and vegetation, and have been commonly used to categorise the regional setting for rivers in the country. There are 31 Level 1 eco-regions.

The GIS layer of wetland vegetation groups (WetVegGroup; Nel et al. 2011a), which characterises the regional context within which wetlands occur, can be used to classify regional wetland groups. Each wetland functional unit can be assigned the wetland vegetation group that occupies the majority of its area. The vegetation groups make finer distinctions than the DWS eco-regions (131 classes compared with only 31). It is therefore anticipated that the vegetation groups may have applicability to a more detailed level than the eco-regions.

As with desktop modelling, regional setting is an emerging area of research. There are also other spatial frameworks available for the country, such as DWS Level 2 eco-regions, peatland eco-regions, land types (Land Type Survey Staff 1984) and geomorphic provinces (Partridge et al. 2010). Section C6 encourages the field collection of data on wetland characteristics to promote observations of regional differences and to promote the collection of much primary data, ultimately to feed into large-scale research, which is able to detect and defend regional differences, such as the National Wetland Vegetation database (Sieben et al. 2014).

natural/artificial and geology descriptors under Level 6, which can be assessed either on desktop or in the field) and are discussed in Section C8.

B5.1 Desktop classification of regional setting

Regional setting refers to the grouping of wetlands into different eco-regions or regional groups (Level 2 of the classification). This part of the manual deals with determining regional setting from a desktop perspective. It is further explored in Section C6 from a field perspective. For desktop mapping, wetland regional setting can be modelled or estimated using existing identified regional boundaries. Two methods to determine regional setting are currently specifically recommended in the National Classification System: the DWS eco-regions (Kleynhans et al. 2005) and the wetland vegetation groups of the NFEPA project (Nel et al. 2011a) (see text box above). The acquisition of either or both of these layers (see Table 5 in Section B2) will enable the mapped wetland to be assigned to a particular regional setting. Both of these approaches are provided for in the attribute spreadsheet (Table 10 and Section A5).

Table 10: Attributes available from the SANBI MS Excel spreadsheet (Section A5) that relate to regional setting

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION
Eco-region	L1_Ecoregn	At Level 2 of the classification system, inland systems are grouped according to DWS Level I eco-regions for aquatic ecosystems (Kleynhans et al. 2005).
DROP-DOWN OPTIONS		
• Bushveld Basin (BB) • Drought Corridor (DC) • Eastern Coastal Belt (ECB) • Eastern Escarpment Mountains (EEM) • Ghaap Plateau (GP)		• Great Escarpment Mountains (GEM) • Great Karoo (GK) • Highveld (H) • Lebombo Uplands (LU) • Limpopo Plain (LP)

Table 10: Attributes available from the SANBI MS Excel spreadsheet (Section A5) that relate to regional setting (continued)

DROP-DOWN OPTIONS (continued)

- Lowveld (L)
- Nama Karoo (NK)
- Namaqua Highlands (NH)
- Natal Coastal Plain (NCP)
- North Eastern Coastal Belt (NECB)
- North Eastern Highlands (NEH)
- North Eastern Uplands (NEU)
- Northern Escarpment Mountains (NEM)
- Northern Plateau (NP)
- Orange River Gorge (ORG)
- South Eastern Coastal Belt (SECB)
- South Eastern Uplands (SEU)
- South Western Coastal Belt (SWCB)
- Southern Coastal Belt (SCB)
- Southern Folded Mountains (SFM)
- Southern Kalahari (SK)
- Soutpansberg (S)
- Waterberg (W)
- Western Bankenveld (WB)
- Western Coastal Belt (WCB)
- Western Folded Mountains (WFM)

Wetland vegetation group	WetVegGroup	An alternative option for Level 2 is Wetland Vegetation Group. This was applied for NFEPA and the NBA (Nel et al. 2011a; Driver et al. 2011).

DROP-DOWN OPTIONS

- Albany Thicket Bontveld
- Albany Thicket Escarpment
- Albany Thicket Valley
- Central Bushveld Group 1
- Central Bushveld Group 2
- Central Bushveld Group 3
- Central Bushveld Group 4
- Central Bushveld Group 5
- Central Bushveld Group 6
- Central Bushveld Group 7
- Central Bushveld Group 8
- Central Bushveld Group 9
- Drakensberg Grassland Group 1
- Drakensberg Grassland Group 2
- Drakensberg Grassland Group 3
- Drakensberg Grassland Group 4
- Drakensberg Grassland Group 5
- Dry Highveld Grassland Group 1
- Dry Highveld Grassland Group 2
- Dry Highveld Grassland Group 3
- Dry Highveld Grassland Group 4
- Dry Highveld Grassland Group 5
- East Coast Alluvium Renosterveld
- East Coast Granite Renosterveld
- East Coast Shale Renosterveld
- East Coast Silcrete Renosterveld
- Eastern Fynbos–Renosterveld Conglomerate Fynbos
- Eastern Fynbos–Renosterveld Granite Fynbos
- Eastern Fynbos–Renosterveld Quartzite Fynbos
- Eastern Fynbos–Renosterveld Sand Fynbos
- Eastern Fynbos–Renosterveld Sandstone Fynbos
- Eastern Fynbos–Renosterveld Shale Band Vegetation
- Eastern Fynbos–Renosterveld Shale Fynbos
- Eastern Fynbos–Renosterveld Shale Renosterveld
- Eastern Kalahari Bushveld Group 1
- Eastern Kalahari Bushveld Group 2
- Eastern Kalahari Bushveld Group 3
- Eastern Kalahari Bushveld Group 4
- Eastern Kalahari Bushveld Group 5
- Eastern Kalahari Bushveld Group 6
- Gariep Desert
- Indian Ocean Coastal Belt Group 1
- Indian Ocean Coastal Belt Group 2
- Indian Ocean Coastal Belt Group 3
- Indian Ocean Coastal Belt Group 4
- Kalahari Duneveld
- Karoo Dolerite Renosterveld
- Karoo Shale Renosterveld
- Knersvlakte
- Lower Nama Karoo
- Lowveld Group 1
- Lowveld Group 10
- Lowveld Group 11
- Lowveld Group 2
- Lowveld Group 3
- Lowveld Group 4
- Lowveld Group 5
- Lowveld Group 6
- Lowveld Group 7
- Lowveld Group 8
- Lowveld Group 9
- Mesic Highveld Grassland Group 1
- Mesic Highveld Grassland Group 10
- Mesic Highveld Grassland Group 11
- Mesic Highveld Grassland Group 2
- Mesic Highveld Grassland Group 3
- Mesic Highveld Grassland Group 4
- Mesic Highveld Grassland Group 5
- Mesic Highveld Grassland Group 6
- Mesic Highveld Grassland Group 7
- Mesic Highveld Grassland Group 8
- Mesic Highveld Grassland Group 9

Table 10: Attributes available from the SANBI MS Excel spreadsheet (Section A5) that relate to regional setting (continued)

DROP-DOWN OPTIONS (continued)

- Mopane Group 1
- Mopane Group 2
- Mopane Group 3
- Mopane Group 4
- Nama Karoo Bushmanland
- Namaqualand Cape Shrublands Granite Fynbos
- Namaqualand Cape Shrublands Granite Renosterveld
- Namaqualand Cape Shrublands Quartzite Fynbos
- Namaqualand Hardeveld
- Namaqualand Sandveld
- Northwest Quartzite Fynbos
- Northwest Sand Fynbos
- Northwest Sandstone Fynbos
- Northwest Shale Band Vegetation
- Northwest Shale Fynbos
- Rainshadow Valley Karoo
- Richtersveld
- South Coast Limestone Fynbos
- South Coast Sand Fynbos
- South Strandveld Western Strandveld
- Southern Namib Desert
- Southern Sandstone Fynbos
- Southern Shale Band Vegetation
- Southern Shale Fynbos
- Southern Silcrete Fynbos
- Southwest Alluvium Fynbos
- Southwest Ferricrete Fynbos
- Southwest Granite Fynbos
- Southwest Quartzite Fynbos
- Southwest Sand Fynbos
- Southwest Sandstone Fynbos
- Southwest Shale Band Vegetation
- Southwest Shale Fynbos
- Sub-Escarpment Grassland Group 1
- Sub-Escarpment Grassland Group 2
- Sub-Escarpment Grassland Group 3
- Sub-Escarpment Grassland Group 4
- Sub-Escarpment Grassland Group 5
- Sub-Escarpment Grassland Group 6
- Sub-Escarpment Grassland Group 7
- Sub-Escarpment Grassland Group 8
- Sub-Escarpment Grassland Group 9
- Sub-Escarpment Savanna
- Swamp Forest
- Trans-Escarpment Succulent Karoo
- Upper Nama Karoo
- West Coast Alluvium Renosterveld
- West Coast Granite Renosterveld
- West Coast Shale Renosterveld
- West Coast Silcrete Renosterveld
- Western Fynbos–Renosterveld Conglomerate Fynbos
- Western Fynbos–Renosterveld Limestone Renosterveld
- Western Fynbos–Renosterveld Quartzite Fynbos
- Western Fynbos–Renosterveld Sandstone Fynbos
- Western Fynbos–Renosterveld Shale Band Vegetation
- Western Fynbos–Renosterveld Shale Fynbos
- Western Fynbos–Renosterveld Shale Renosterveld
- Western Strandveld

Table 11: Attributes from the SANBI MS Excel spreadsheet (Section A5) related to landscape setting of the wetland

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Landscape unit	SS_LandU	A distinction is made between four landscape units in inland systems on the basis of the landscape setting	• Slope (S) • Valley floor (VF) • Plain (P) • Bench (hilltop, saddle, shelf) (B)

B5.2 Desktop classification of landscape unit

Level 3 of the classification hierarchy involves the identification of units of the landscape where a wetland occurs. A distinction is made between four landscape units based on the landscape setting (i.e. topographical position) within which the wetland is situated (Table 11; Figure 7):

- Slope: an inclined stretch of ground that is not part of a valley floor, which is typically located on the side of a mountain, hill or valley.
- Valley floor: the typically gently sloping, lowest surface of a valley.
- Plain: an extensive area of low relief characterised by relatively level, gently undulating or uniformly sloping land.
- Bench (hilltop/saddle/shelf): an area of mostly level or nearly level high ground.

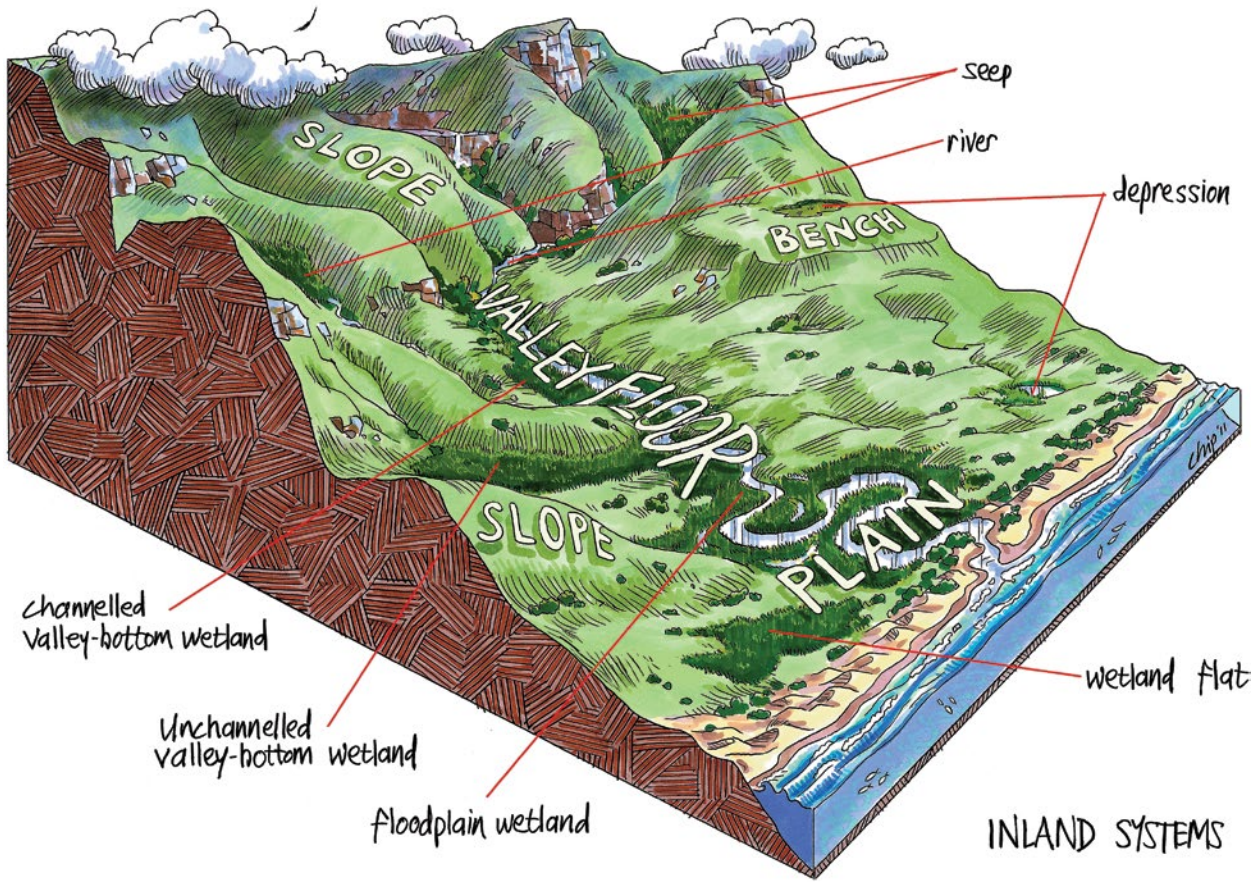


Figure 7: Graphic depiction of hydrogeomorphic wetland types and landscape unit (Ollis et al. 2013).

For more detail regarding the descriptions of the landscape units, see Ollis et al. (2013).

For desktop mapping, wetland landscape setting can be modelled or estimated using a Digital Elevation Model (DEM) (Van Deventer et al. 2014).

B5.3 Desktop classification of hydrogeomorphic (HGM) unit

The hydrogeomorphic unit at Level 4 is the focal point of the *National Classification System*. Wetland systems can be grouped according to broadly similar hydrologic processes (the way in which water moves into, through and out of the wetland systems) and geomorphic factors (such as the position of the wetland in the landscape, landscape shape and processes active in this location) (Figure 7). This is named the hydrogeomorphic (HGM) approach to classifying wetlands (Brinson 1993) and has been adapted for South Africa (Ellery et al. 2009; Ollis et al. 2013).

As the HGM unit is the focal point of wetland classification, comprehensive attribute information is collected on HGM type (Table 12). Seven HGM units are recognised at Level 4A (Figure 8). With the addition of artificial wetland, these eight options are recorded under the attribute 'HGM unit Level 4A' (Table 12). Table 12 also details how the HGM unit may be further divided into three groups (4A, 4B and 4C), which refer to increasing levels of detail.

To aid identification of, and distinction between, the different HGM types, extensive text has been prepared in support of each type, and a dichotomous key has been developed. These are available in the *National Classification System* (Ollis et al. 2013) document. Figure 8 is excerpted from the document and provides illustrations of each HGM unit at Level 4A.

A further challenge in desktop mapping is that a single wetland may in fact consist of several *different* hydrogeomorphic units and it is not

Table 12: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to hydrogeomorphic type

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
HGM unit Level 4A	HGML4A	Seven HGM units (plus artificial systems) are distinguished for inland systems (note that channel/ rivers are not discussed further in this manual).	• River • Floodplain wetland • Channelled valley-bottom wetland • Unchannelled valley-bottom wetland • Depression/pan • Flat • Seep • Artificial wetland (see following row for types)
Artificial wetland type	Artificial	There are many categories of artificial wetland.	• Canal • In-channel dam • Off-channel dam • Open reservoir • Excavation • Waste water treatment works • Stormwater pond • Irrigated land • Salt works • Aquaculture pond • Other
HGM unit Level 4B (longitudinal zonation)	HGML4B	At Level 4B of the classification system, certain of the primary HGM units can further be divided into sub-categories based on longitudinal geomorphological zonation or localised landform.	For valley-bottom and floodplain wetlands only specify: • Valley-bottom flat • Valley-bottom depression • Floodplain flat • Floodplain depression • Unknown
HGM unit Level 4C	HGML4C	At Level 4C of the classification system, depressions and hillslope seeps are further categorised according to their outflow drainage.	For depressions and seeps only specify: • Depression (exhoreic with channelled inflow) • Depression (endorheic with channelled inflow) • Depression (endorheic without channelled inflow) • Seep with channelled outflow • Seep without channelled outflow • Unknown

always feasible to divide the wetlands into units when undertaking large-scale mapping projects. Figure 9 illustrates a wetland consisting of a floodplain that is linked to channelled valley-bottom, with a seep and an unchannelled valley-bottom wetland.

The boundary between one unit and another may be unclear and to locate the boundary in a sensible manner, users will need to read the descriptions of the types in the *National Wetland Classification System* carefully. It is useful to remember that the transition is often, but not always, associated with a change in slope. For example, a transition from seep to valley-bottom, as in Figure 9, is usually associated with a decrease in slope.

Most mapping projects will stop at Level 4A, listing the seven HGM types (artificial wetlands

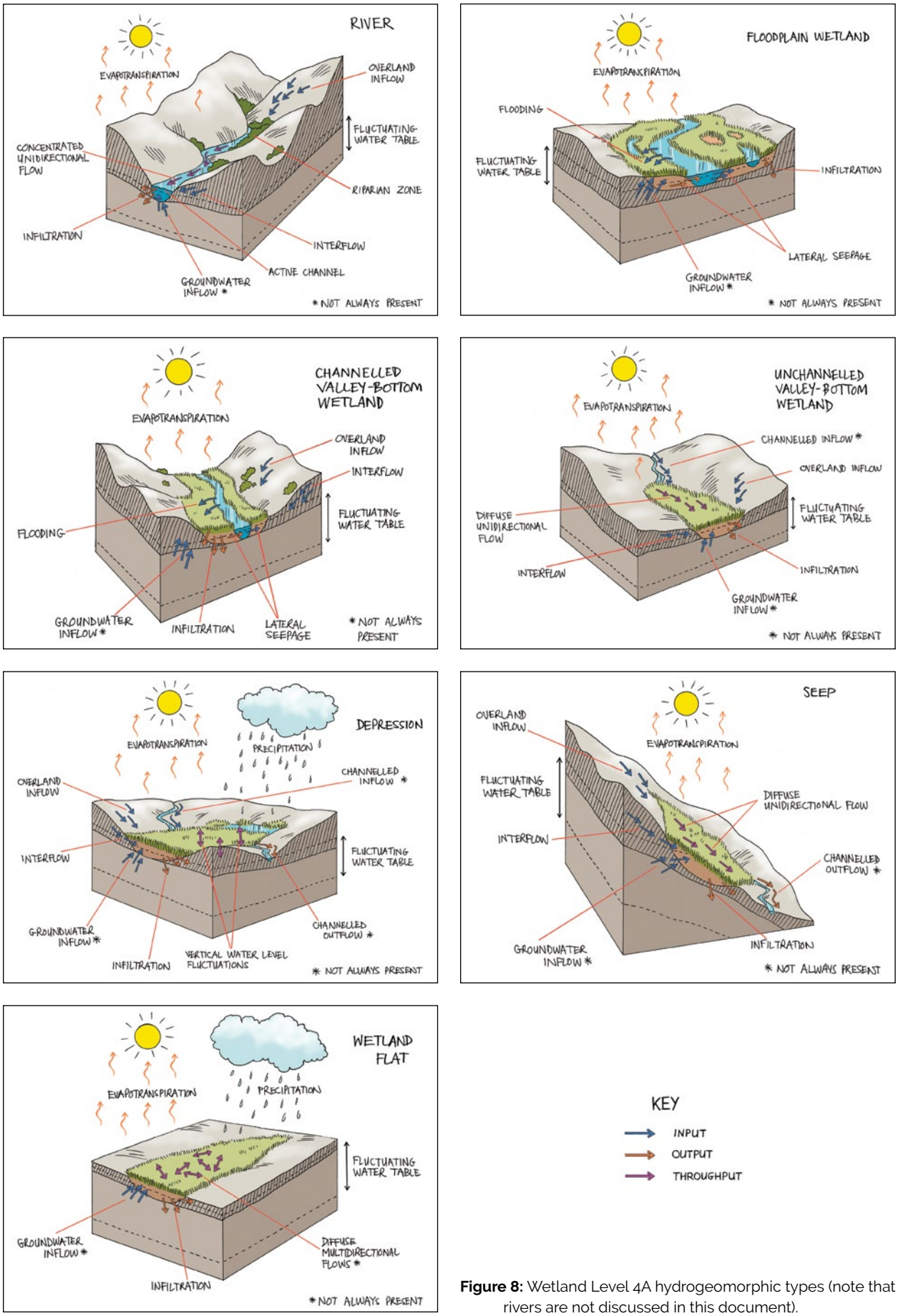


Figure 8: Wetland Level 4A hydrogeomorphic types (note that rivers are not discussed in this document).

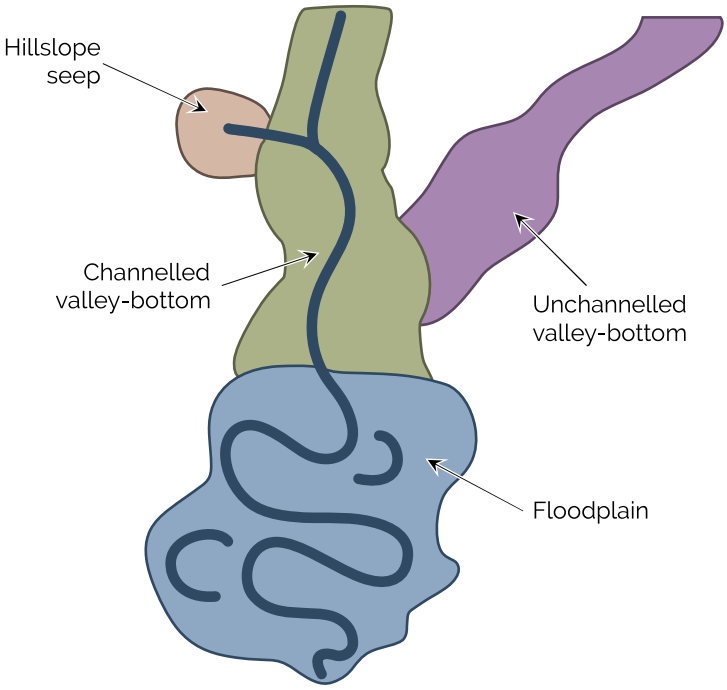


Figure 9: Map of approximate extent of hydrogeomorphic units where major breaks between different units can be identified.

are the eighth HGM type, but are treated separately). Limiting the determination of HGM type to Level 4A is sensible for projects being undertaken only through desktop mapping. This is because it is difficult to classify down to Levels 4B and 4C with confidence through desktop mapping, and it is advised not to apply these levels unless they can be assigned with confidence. A higher confidence dataset with fewer categories is much more desirable than many categories that are low confidence.

Where there is limited field knowledge of an area and poor quality imagery, it might even be recommended to consolidate the Level 4A HGM types further. For example, mapping valley-bottom wetlands as a group, rather than dividing them into unchannelled and channelled.

Flats wetlands are also very difficult to confirm on desktop, and it may be better to assign them to another HGM type if confidence is low, using the available guidance to allocate them to the next class they most closely resemble, for example, depression.

It is also common that extensive areas are mapped solely as valley-bottom wetlands when, in fact, these areas are often flanked by extensive seepage areas. The time and/or budget allocated to a project may not be sufficient to allow these seeps to be mapped as separate HGM units. This presents a challenge for consideration when data of multiple scales are combined.

Classifying HGM type through desktop modelling

Modelling of wetland HGM type is in the early stages and to date there has not yet been any one computer-generated method that has successfully and consistently identified HGM types. There is much room for future development on this topic.

The modelling undertaken in the development of the National Wetland Map 4 is an example of wetland modelling of HGM type (Van Deventer et al. 2016). The four steps used to develop attribute information for classifying the GIS layer of the National Wetland Map 3, and which resulted in the National Wetland Map 4, are outlined in Van Deventer et al. (2016). The steps produced GIS with attribute information for Levels 1–4 of the *National Classification System*. At Level 1 of the classification system, inland wetlands were extracted from the NWM3, excluding estuarine systems. The regional setting (Level 2) and the landscape unit (Level 3) were attributed to the wetlands in intermediary steps, whereas the HGM type (Level 4A) provided the final wetland ecosystem types.

These methods are described in detail in Van Deventer et al. (2016) and in the NFEPA technical manual (Nel et al. 2011b).

Recognising HGM units on spatial imagery for heads-up digitising

This section of the manual highlights examples of the different wetland features that one would use to determine HGM unit during desktop preparation as they would appear on spatial imagery (Table 13). An effort was made to outline various ways in which these features may appear on the imagery. However, these examples are by no means exhaustive. In many instances, the feature in question is highlighted by a red polygon for emphasis. These polygons are by no means final wetland delineations. They are merely tools to guide the reader of this manual, by highlighting relevant features. The co-ordinates of each feature are given below the description, so that the reader can view the images further, should they wish to explore the feature and its characteristics in greater detail.

B6. Desktop assessment of wetland condition

Once the wetland location and extent has been mapped (Section B4) and the wetland has been classified according to regional and landscape setting and HGM type (Section B5), one of the most useful further sets of information to gather is wetland condition.

The WET-Health Manual (MacFarlane et al. 2009) provides detailed methodology and explanatory text in support of assessing wetland condition. It is strongly recommended that inexperienced wetland mappers read the WET-Health Manual and take advantage of training that is offered on the application of the method before their first attempt to ascribe a condition score to a wetland.

Key points

- Wetland systems can be classified into hydrogeomorphic types with broadly similar hydrologic and geomorphic factors.
- HGM types are the focus of the *National Classification System* for wetlands (Ollis et al. 2013), which has detailed supporting information to help distinguish between HGM types.
- Many wetland systems occur as mosaics of more than one HGM type.

Wetland condition is ideally best determined by a wetland specialist during a site visit. However, given constraints in data collection across large areas, and known relationships between condition and catchment-scale predictors, models can become useful in informing regional planning and policy decisions. Thus, desktop modelling of wetland condition or the use of spatial image interpretation of wetland condition are both options for large-scale mapping projects with limited budget for field assessment.

Desktop modelling of wetland condition

In the absence of field survey data for wetland condition, an index of relative condition may be derived through modelling. A number of methods of differing complexity are available to model wetland condition. While no particular approach is recommended, it is advisable to consider approaches that have been used successfully. These methods are likely to change over time as innovative new methods are developed and the underlying data is improved.

A basic method can be based on the approach taken by the NFEPA project (Nel et al. 2011b). In

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown

FLOODPLAIN WETLAND

Floodplain wetlands occur on mostly flat or gently sloping land adjacent to and formed by an alluvial river channel. They are typically characterised by a suite of geomorphological features associated with river-derived depositional processes, including point bars, scroll bars, oxbow lakes and levees (see Ollis et al. 2013 for guidance on recognising these features).

For typical floodplain wetlands, oxbow lakes will be visible as U- or C-shaped water bodies disconnected from the main channel (pictured left).

(Co-ordinates: 30˚18'02.85"S, 28˚38'13.44"E)

In some instances, the oxbow lakes may appear as oddly shaped water bodies (not the typical U-shape) associated with, but still disconnected from, the channel.

(Co-ordinates: 26˚19'03.15"S, 30˚28'33.42"E)

CHANNELLED VALLEY-BOTTOM WETLANDS

Channelled valley-bottom wetlands are characterised by their location on valley floors, the absence of characteristic floodplain features and the presence of a river channel flowing through the wetland. Dominant water inputs are from the river channel flooding, subsurface flow or overland flow.

Channelled valley-bottom wetlands with visible channels are easily identified on the imagery as a wetland with a stream or river passing through it. The wetlands associated with this HGM unit will often appear as wetter, greener vegetation on one or both sides of the stream.

(Co-ordinates: 34˚14'16.35"S, 19˚13'01.39"E)

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown (continued)

UNCHANNELLED VALLEY-BOTTOM WETLANDS

Unchannelled valley-bottom wetlands are similar to channelled valley-bottom wetlands, but without associated river channels. They are typically located on valley floors, have an absence of distinct channel banks, and a prevalence of diffuse flows. Water inputs are typically from an upstream channel and seepage from adjacent valley side slopes. There is generally a net accumulation of sediment. Channelled valley-bottoms sometimes appear unchannelled on the imagery when vegetation grows over a narrow stream and this can lead to an inaccurate desktop classification of an HGM unit. Therefore, for accurate assessments it is recommended that a field investigation follows, although this is not always feasible.

Unchannelled valley-bottoms will have no clear stream on spatial imagery. This often requires clear imagery and requires the user to zoom in to examine more closely, as channels can often be narrow and difficult to find. The absence of linear riparian vegetation following a stream is a good indicator that the wetland is unchannelled.

(Co-ordinates: 22˚49'05.23"S, 30˚31'45.94"E)

Unchannelled valley-bottoms can sometimes have short sections of natural channel within them. Artificial drainage channels may also be present. However, these drains can be differentiated from a natural channel as they generally appear straight (see Table 15). Natural channels usually terminate before the end of the largely unchannelled wetland, as can be seen on the left, whereas an artificial drainage channel will often continue to the end of the unchannelled wetland so as to effectively drain water out of the area.

(Co-ordinates: 22˚45'12.13"S, 30˚33'09.74"E)

Valley-bottoms often appear unchannelled when the canopies of overhanging vegetation prevent a clear view of the channel. In these cases field verification is necessary to determine whether a channel is present beneath the tree canopy.

(Co-ordinates: 29˚26'25.18"S, 30˚03'42.58"E)

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown (continued)

SEEP WETLAND

Seeps are located on gently to steeply sloping land and are dominated by the colluvial (gravity-driven), unidirectional movement of water and material downslope. Seeps are often located on the side slopes of a valley. Water inputs are primarily via subsurface flows from an upslope direction. Seeps are often associated with diffuse overland flow during and after rainfall events. It is important to note that a seep can share a boundary with a distinct river channel and feed into the channel via diffuse surface flow or subsurface flow.

The most effective way to identify a seep is by looking at the topography. Overlaying a contours layer (shown in purple) over the imagery can be useful for this exercise. In the picture, the darker vegetation indicates a wetland and the curved contour lines indicate that this wetland is on a slope, i.e. a seep.

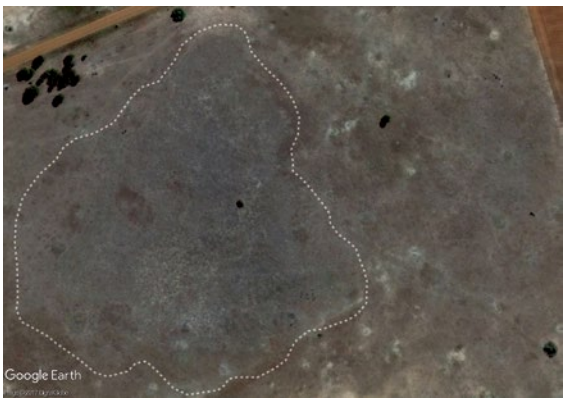
(Co-ordinates: 28˚24'00.56"S, 29˚41'57.87"E)

Seeps can often have several smaller seeps leading into them before the main seep flows into the stream.

(Co-ordinates: 26˚38'50.94"S, 31˚09'42.59"E)

WETLAND FLAT

A wetland flat is a level or near-level wetland area that is not fed by water from a river channel, and which is typically situated on a plain or a bench. The primary source of water for a wetland flat is generally precipitation, with the exception of wetland flats situated on a coastal plain where groundwater may rise to or near the ground surface. Horizontal water movements within the wetland are typically weak and multi-directional. Closed elevation contours are not evident around the edge of a wetland flat; however, multiple small-ponded areas that form depressional micro-features are considered part of a wetland flat.



Wetland flats often appear as irregularly shaped wetland areas that are not linked to a stream. They are often level or near-level areas where waterlogging occurs and can be differentiated from depressions by their lack of defined margins.

(Co-ordinates: 26˚51'03.98"S, 25˚35'41.99"E)

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown (continued)

DEPRESSION WETLAND

A depression wetland is an inland aquatic ecosystem with closed or near-closed elevation contours, which increases in depth from the perimeter to a central area of greatest depth, and within which water typically accumulates. Dominant water sources are precipitation, groundwater discharge, interflow and (diffuse or concentrated) overflow. Depressions may be flat-bottomed or round-bottomed, and may have any combination of inlets and outlets or lack them completely. An important point to note when delineating depressions is that the extent of the wetland goes beyond the body of water that may be present within the deeper parts of the depression.

Depressions will often (but not always) contain water in the deeper part of the depression during the wet season. They will appear as spherical or kidney-shaped wetland bodies with defined edges. Deeper depressions often do not have vegetation in the deep parts of the wetland. In this wetland, the water body terminates visibly; however, the extent of the wetland goes beyond the water's reflected surface and will often appear as a halo around the edges of the depression.

(Co-ordinates: 26˚25'21.33"S, 30˚11'50.30"E)

Depressions can often be vegetated. However, a clear rounded shape is still evident. In the picture the wetland area extends beyond the shores of the pan and is visible as slightly darker than the surrounding non-wetland.

(Co-ordinates: 26˚23'11.85"S, 30˚12'22.96"E)

Shallow depressions may be infrequently inundated and will therefore not always reflect water on the satellite imagery. However, the oval-shaped depression is generally still visible.

(Co-ordinates: 26˚17'23.37"S, 30˚10'14.52"E)

Table 13: Recognising hydrogeomorphic units from spatial imagery. The outer boundaries of the wetlands are indicated in dotted lines. For images that are zoomed into the wetland, no boundaries are shown (continued)

DEPRESSION WETLAND	
	Depressions which have been dammed will still often appear rounded but with one or more straight edges. (Co-ordinates: 26°20'27.33"S, 30°14'29.88"E)
	Salt pans will often appear dry and reflect as white areas on image mosaics. (Co-ordinates: 26°20'27.33"S, 30°14'29.88"E)
	Depressions are sometimes associated with a seep (pictured left). In these instances the seep must be delineated as part of the wetland along with the pan. However, it must be assigned as a different HGM unit. (Co-ordinates: 26°15'21.42"S, 30°10'22.28"E)

this method, the percentage of natural land cover in and around the wetland is used as a surrogate measure of wetland condition. To model wetland condition the percentage of natural land cover can be calculated within four areas: the wetland itself, and the wetland surrounded by GIS buffers of 50, 100 and 500 m from the delineated wetland polygon. The lowest extent of these four percentages can be considered a guide to the condition category of the wetland. For example, if the extent of natural vegetation within the wetland itself and the wetland's buffer of 50, 100 and 500 m was 81%, 65%, 32% and 35% respectively then the lowest extent of 32% is taken as the guide to the condition category of the wetland. The following rules can be used:

- Non-riverine wetlands are considered in good, moderately modified or heavily modified condition if the minimum percentage natural land cover is ≥ 75%, 25–75% or < 25% respectively. These wetlands are coded 'AB', 'C' and 'Z' respectively.
- Riverine wetlands associated with a heavily modified NFEPA river (i.e. in a 'D', 'E' or 'F' ecological category) should be assigned the condition category of that river irrespective of the surrounding natural land cover.
- Wetlands associated with natural or only moderately modified NFEPA rivers (i.e. in an 'A', 'B' or 'C' ecological category) are assigned a condition based on the minimum percentage natural land cover rule used for non-riverine wetlands, because the surrounding land use is more likely to be a driver of ecosystem degradation than the moderate condition of the associated river.
- Several riverine wetlands are associated with rivers too small to be included in the NFEPA rivers network GIS layer. In these instances, the river condition was unknown and the wetland was assigned a condition based on the natural land cover rule alone.
- All dams identified by the digitisers were coded as 'Dam'.

The approach used by NFEPA for a national-scale assessment could be refined for assessment at a finer scale, e.g. within a selected catchment. Further investigation into the weighting of the different buffers is warranted. An example is distinguishing within wetland vegetation as having a much greater impact on the wetland and thus warranting a different treatment to varying widths of vegetation outside of the wetland. A second example is the consideration that the greater the width of the buffer, the lower the potential impact will be as the distances between the sources of the impacts and the wetland increase. A further refinement could be to distinguish between different land cover types. The general assumption made in the NFEPA model is that all non-natural land covers impact equally upon wetlands, but certain non-natural land covers (e.g. mines) are likely to impact much more on wetlands than other land uses. Thus, land covers/land uses could be scored according to their relative impacts, e.g. as done by Malan et al. (2013) for scoring water quality impacts on wetlands by land uses in a wetland's catchment. A more recent desktop method (Kotze 2015) has been developed, which has close links with the WET-Health method. The rationale underlying the new method is that different land cover types (e.g. commercial annual crops) tend to be associated with particular impacts on wetlands, and thus by rapidly identifying which land cover types occur in a wetland and its catchment, and determining how extensive these land cover types are, inferences can be drawn about the magnitude of impact on the ecological condition of the wetland. The operator of the method is presented with a comprehensive list of land cover types to which typical impact intensity scores have been pre-assigned based on the scientific literature, expert judgement and peer-review. The primary task of the operator is to identify the extent of any of these types present, from which an overall magnitude of impact is automatically generated.

Alternative methods may use a larger number of existing variables to model wetland condition. These variables can either be proxies for wetland condition or known drivers of deteriorating wetland condition. Rivers-Moore and Cowden (2012) developed an approach to assess wetland condition per wetland type to facilitate the prioritising of conservation actions at a regional level. Condition data for seep, floodplain and valley-bottom (channelled and unchannelled) HGM units was combined with data for 21 potential explanatory variables for land cover, infrastructure and catchment physiography (Table 14). In their analysis, per cent natural vegetation, road density, population density and altitude, together with anthropogenic land use (cultivation

and forestry plantation area) were found to be important predictors of wetland condition, and differed per HGM type. The study of Rivers-Moore and Cowden (2012) focussed specifically on KwaZulu-Natal and was based on a sample of 463 HGM units in the province for which ecological condition was assessed in the field. While there appears to be potential to refine and extend the model of Rivers-Moore and Cowden (2012) for application at a national level, this will require a much larger dataset, which covers a wider spatial area.

Recognising impacts to wetlands using spatial imagery in heads-up digitising

Spatial imagery can be used to identify features that impact on wetland hydrology, vegetation and geomorphology (Table 15). This can assist in assigning a condition category to a wetland. For information relating to the in-field assessment of wetland condition and condition categories, please refer to Section C7.

Table 14: Possible variables that can be included in models to estimate wetland condition (adapted from Rivers-Moore & Cowden 2012)

VARIABLE	UNITS	DESCRIPTION
Stream order	Stream order number	Calculated by assigning the highest stream order to occur in each quaternary catchment
Population density	People/km²	Population density per catchment
Road	Number	Wetlands falling within a 1 000 m buffer of a main road
Rail	Number	Wetlands falling within 1 000 m buffer of a main rail
Slope	Degrees	Slope of pixel on which wetland centroid located, calculated from a 90 m elevation image
Altitude	m amsl	Altitude where wetland centroid located, as well as modal altitude per catchment using a 90 m image
Plantation	%	Forestry plantation (includes clear-felled areas)
Sugarcane	%	Sugarcane (commercial and emerging farmer)
Dense settlement	%	Built-up dense settlement
Low settlement	%	Low density settlement
Agriculture dry	%	Agricultural cultivation (dryland)
Agriculture irrigated	%	Agricultural cultivation (irrigated)
Natural	%	Natural land classes
Degraded	%	Degraded land classes
Dams	%	All inland dams
Dams – No	Number	Number of dams per quaternary catchment (1:50 000 scale)
Basin length	Km	Straight distance from basin outlet to farthest point on drainage divide
Drainage shape	Ratio	Area divided by the square of basin length
Relief ratio	Ratio	Difference in altitude divided by basin length
Drainage density	km²	Density of rivers per quaternary catchment (1:50 000 scale)
Road density	km²	Density of roads per quaternary catchment (1:50 000 scale, no footpaths)

Table 15: Identifying impacts to wetlands using spatial imagery

DAMS	
	Dams are one of the easiest wetland impact features to identify. They impact hydrology, geomorphology and vegetation, and often result in the complete loss of native vegetation under flooding too deep to support emergent vegetation. Dams are created when a wall is constructed across the direction of water flow in a stream and/or wetland. Walls usually appear as hard linear features (left) with a body of water upstream. (Co-ordinates: 27˚05'26.46"S, 30˚26'48.11"E).
	Dams can also have curved walls (left) which appear as regular semi-circular features. (Co-ordinates: 27˚06'42.92"S, 30˚29'36.02"E).
	Seepage below the dam wall can have significant impacts on hydrology and vegetation within this portion of a wetland. (Co-ordinates: 29˚07'37.86"S, 30˚33'26.35"E).
ARTIFICIAL DRAINAGE CHANNELS	
	Artificial drains can sometimes result from straightening (and often enlarging) of the stream channel. In this situation (pictured left) the drain can be differentiated from the natural channel by the change from a sinuous channel to a more straightened/ angular pattern, particularly the right angle highlighted by the red outline (left). Artificial drains can directly impact geomorphology and hydrology and indirectly affect wetland vegetation. (Co-ordinates: 25˚45'58.35"S, 29˚31'39.22"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

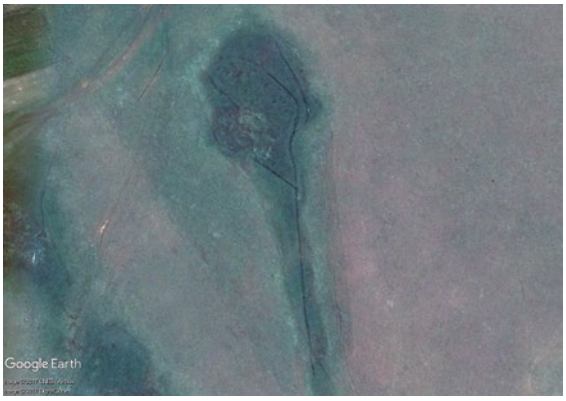
ARTIFICIAL DRAINAGE CHANNELS (continued)	
	Artificial drains can also be located so that they feed into the stream channel as indicated within the red polygon. (Co-ordinates: 25˚34'28.21"S, 29˚53'06.58"E).
	Artificial drains can also have several side drains extending from the main drain. (Co-ordinates: 29˚31'56.27"S, 29˚51'58.17"E).
	Artificial drains are not always associated with a channel and can often be found within unchannelled valley-bottom wetlands. (Co-ordinates: 27˚29'46.43"S, 30˚25'20.21"E).
	Artificial drainage may sometimes be undertaken using ridge-and-furrow methods, which are visible as repeated dark (furrow) and light (ridge) lines. In the image on the left ridges and furrows are clearly visible leading into a main artificial drainage channel in the lower right side of the image. (Co-ordinates: 29˚31'42.24"S, 29˚52'04.46"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

FEATURES WHICH RESEMBLE DRAINS	
	Fence lines can often resemble artificial drains. However, fence lines can be differentiated from drains as they will often extend beyond the extent of the wetland (left). (Co-ordinates: 27˚27'03.44"S, 30˚30'37.36"E).
	Pivot irrigation structures can also be mistaken for artificial drains; however, these structures will often terminate at the edge of the circular field. (Co-ordinates: 27˚08'48.56"S, 30˚22'35.40"E).
IMPACTS OF PAST AND PRESENT AGRICULTURE	
	Agricultural fields that extend into wetlands can often be recognised by a change in the colour of the soil between the non-wetland areas (generally browner and lighter) and the wetland areas (generally greyer and darker). However, once the cultivated soil becomes covered with a crop, it is often impossible to distinguish wetland from non-wetland, especially when the crop is irrigated, requiring greater dependence on ground-truthing. (Co-ordinates: 26˚19'56.45"S, 26˚48'43.14"E).
	Agricultural fields can also be situated around depressions. In the picture linear plough lines are clearly visible. (Co-ordinates: 27˚31'18.59"S, 30˚30'46.15"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

IMPACTS OF PAST AND PRESENT AGRICULTURE (continued)	
	Fields used for small-scale cultivation are often irregular-shaped and collectively take on a patchwork appearance. However, they can be easily differentiated from natural wetland vegetation by their geometric patterns (pictured left). It is often difficult to differentiate recently used fields from old lands. This difficulty can be solved by using historical imagery in Google Earth or by speaking to the land-user(s) about land use history. (Co-ordinates: 28°55'19.92"S, 31°13'25.88"E).
	Old fields are often difficult to recognise. However, faint linear patterns can often still be detected through the wetland (pictured left). (Co-ordinates: 27°34'00.02"S, 30°27'42.62"E).
	Sometimes wetlands can be dried out through construction of a berm around the periphery so that the interior of the wetland can be cultivated. In this example the drain is more clearly visible than the associated berm. The berm (which was ground-truthed) was over a metre wide and half a metre high and yet was still not clearly visible on imagery, thus highlighting the need to zoom in to the wetland significantly before features such as berms can be detected. (Co-ordinates: 27°26'22.00"S, 30°30'31.71"E).
IMPACTS OF PLANTATION FORESTRY	
	Wetlands within plantations are often identified as the open spaces between plantations on the imagery. Forestry management best practice suggests a 20 m buffer around wetlands. However, caution must still be exercised when delineating and other wetland features described earlier must be used to confirm that the unplanted area is wetland, since there is some variation in the width of the buffer. Also, areas which are not wetland may also be unplanted as they are unsuitable for tree growth or for other environmental reasons. (Co-ordinates: 29°03'36.60"S, 30°46'55.24"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

IMPACTS OF PLANTATION FORESTRY (continued)

Plantation trees are sometimes planted within seeps, thus reducing the amount of water flowing into the lower reaches of the wetland. This practice was more frequent before the introduction of mandatory buffer zones around wetlands in plantation forestry. In the image to the left (above) much of the margins of the seep has been planted, although some of the central portion appears to have been left unplanted. A more recent image of the same seep (left below) shows how the plantation has been pulled back from inside the wetland. It is important to note that in seeps, which tend to be small and readily dried out by plantation trees within and surrounding them, plantation trees will often grow as well or sometimes even better in the seep than in the surrounding area.

(Co-ordinates: 25˚47'54.85"S, 30˚47'13.82"E).

In some wetland areas with plantation trees, the trees do not grow well under the waterlogged conditions in the wetland, and therefore these areas can be identified by short, sparsely growing/patchy stands.

(Co-ordinates: 29˚12'12.57"S, 30˚35'27.38"E).

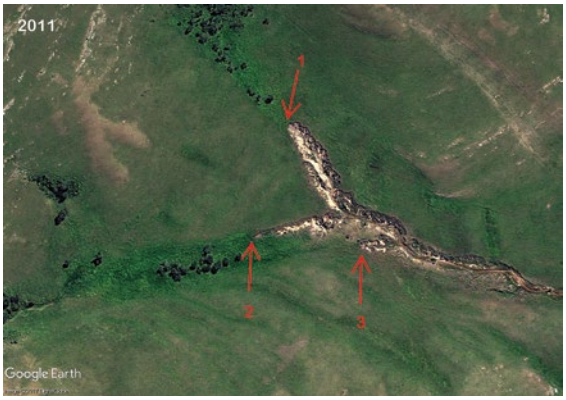
IMPACTS OF EROSION

Over time, the erosion gullies occupying only a small portion of a wetland can become more visible on the imagery as the head cuts of the gully advance through a much larger portion of the wetland. Historical imagery can be used to determine how actively a head cut has advanced over time. The imagery to the left indicates where the three head cuts are located in the wetland in 2004.

(Co-ordinates: 31˚12'01.48"S, 29˚53'47.73"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

IMPACTS OF EROSION (continued)



The imagery to the left indicates where the head cuts are located in the wetland in 2011. In comparison to 2004 it can be seen that all three head cuts have advanced further into the wetland, particularly head cuts 1 and 2.

(Co-ordinates: 31˚12'01.48"S, 29˚53'47.73"E).

The imagery to the left indicates where the head cuts are located in the wetland in 2016. In comparison to 2011 it can be seen that all three head cuts have continued to advance, but Head Cut 2 to a lesser degree than head cuts 1 and 3. A much larger proportion of the wetland is now eroded than in 2004.

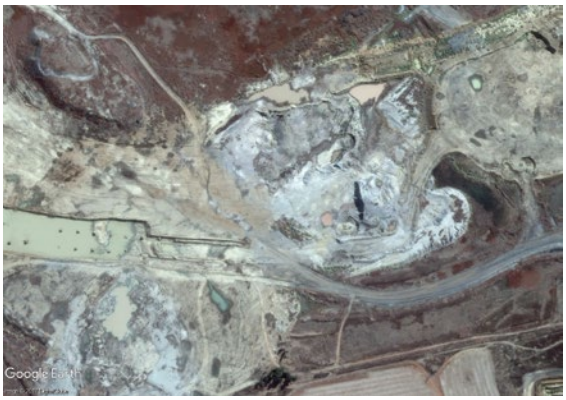
(Co-ordinates: 31˚12'01.48"S, 29˚53'47.73"E).

OTHER IMPACTS

Infrastructure refers to built infrastructure such as roads, dams and other artificial structures, which totally replace existing habitat and influence water flow within the wetland. Historical imagery can be useful in highlighting areas that have been impacted by infrastructure as well as the potential changes that have occurred after construction. The picture to the left (above) shows a wetland as it appeared in 2004 while the picture below it shows the same wetland in 2016 after infrastructure has been developed.

(Co-ordinates: 25˚28'10.90"S, 30˚57'31.67"E).

Table 15: Identifying impacts to wetlands using spatial imagery (continued)

OTHER IMPACTS (continued)	
	Animal pathways within the wetland, sometimes supporting standing water, can appear to be artificial drains or side channels. However, the criss-crossing nature of these pathways (pictured left) is generally an indication of animal movement rather than channels formed by natural water movement. Nevertheless, it should be noted that over time some pathways may develop into eroded channels or gullies. (Co-ordinates: 22˚11'35.62"S, 29˚13'44.29"E).
	Excavation can occur through small- or large-scale mining (e.g. for sand or coal) when wetland soils are removed out of the wetland. Inflows to the wetland are often also severely affected. (Co-ordinates: 26˚10'16.45"S, 28˚42'53.12"E).

Key points

- The outputs of modelled wetland data must be clear, logical and able to be integrated into other datasets, even if this means field verification. An investment in a modelled dataset that needs to be replaced entirely by field-derived data is a false economy, hence the strong recommendation that some measure of field verification be incorporated into a modelling project.
- If a model is used, then its underlying strengths, limitations and assumptions need to be understood and accounted for when applying the model.
- Modelling methods improve as the data input (seasonality / time series data; DEMs) improves and as new tools become available.
- As mentioned in Section A4, the ideal approach is to conduct both desktop mapping (whether that be through image interpretation or modelling) and field verification in one project. The field team can thus have input into any challenges in rule-setting before assumptions become entrenched.

PART C.
IN THE FIELD

Field surveys allow for the ground-truthing and verification of desktop-mapped wetlands, which significantly increases the level of confidence in the representation of the extent and types on a map for those wetlands visited, and for the dataset as a whole.

This section of the manual introduces field components of a mapping project. These include combining detailed and basic (rapid) levels of field data collection (Section C1), what data to collect (Section C2), tools to aid mapping in the field (Section C3), identification of wetland boundaries in the field (Section C4), assessing HGM wetland types (Section C5), and using field observations to identify wetland characteristics (Section C6) and wetland condition (Section C7).

The best way to learn field mapping is together with an experienced wetland ecologist, who would then also be able to explain the choice of a particular approach to suit a specific occasion. Each individual will likely have developed their own set of adjusted techniques and efficiencies and will continue to slightly adapt them to meet the requirements of each specific project. It is not realistic or desirable to attempt to capture this into a few pages. What follows is thus simply an overview, with the hope of encouraging new mappers and providing an introduction to the key tasks.

C1. Approaches to in-field mapping

Wetlands mapped as part of an Environmental Impact Assessment play a role in the long-term collection of high confidence wetland data for the country. The ideal approach to a wetlands mapping project, recommended by this guideline, is to comprehensively cover entire catchments. The size of the catchment(s) can be small, appropriate to the resources available for being able to map it comprehensively within a project. Working from a catchment perspective improves the chance of encountering the full range of wetland types within an area. Necessitating the mapping of an entire catchment prevents the tendency to visit only the most well-known and accessible wetlands, which may result in missing the presence of certain wetlands or wetland types (if the goal is to prioritise amongst wetlands or to capture the range of biodiversity present in an area), or may lead to an insecure wetland rehabilitation investment (if there are severe upstream rehabilitation needs that are missed).

For this reason, the overall scale of a mapping project should be informed by the choice of a catchment or sub-catchment size that can be completed within the scope of the project. This is influenced both by the experience levels of the field mapper and how much existing information is already available or has been generated during the desktop preparation phase.

To efficiently map entire catchments might also mean that it is necessary to collect a minimum subset of data on many wetlands, rather than more detailed data on only a few wetlands. To achieve this, a combination of approaches is recommended, namely, an investment in desktop preparation and project planning as outlined in the previous section, detailed field assessment of selected wetlands, and rapid field assessment of as many further wetlands in the catchment as possible, followed by the desktop application of the knowledge gained from these field assessments to all remaining wetlands in the

catchment. The recommended field approach is broadly summarised below:

- Detailed site assessment (high confidence) of representative wetlands. This entails attempting to visit representative examples of the full range of wetland types and wetland condition classes in the catchment. Detailed wetland assessments may include sample plots to document typical vegetation, soil and hydrology characteristics and to aid in determining the approximate location of the wetland boundary. The level of detail ranges according to the level of assessment, for example, a full set of assessments associated with an EIA, or a full WET-Health assessment, or simply the type of sample plots suggested above. Similarly, the level of confidence in the results will vary, for example according to the expertise of the assessor, the time available, and whether the entire wetland or only part of the wetland was visited. All of this should be described in the project methods and metadata, for the data to be best interpreted by others.
- Rapid 'windscreen' survey (moderate to low confidence) for the remaining accessible wetlands in the catchment. Rapid wetland assessments are made by observing site characteristics from adjacent vantage points or adjacent properties where access is permitted, in some cases, with the aid of binoculars. Again, the level of detail of a rapid survey can range, from looking at the wetland from a vehicle (even this is a useful confirmation that presence of the wetland was verified) to a very rapid walk through the wetland or part of the wetland or a rapid look at the soil using a soil auger.

During the field visit it is important to attempt to access and see as much of the wetland system as possible. Much time will be taken in the travelling between wetlands. Therefore, it is important to take into account travelling time and most efficient routes when selecting which wetlands to visit in the field. A combined approach is ideal, where a set of reasonably accessible wetlands are selected, representing the diversity of HGM types known to occur in the study area, for the most detailed assessment. This can then be supplemented by very rapid assessments of some of the remaining wetlands – for example those passed while accessing the sites that require more detailed assessments.

As mentioned above, for sections of wetlands that were not visited, visible or accessible in the field, wetland determinations will need to be completed by desktop analysis of imagery and other existing data, as well as by drawing on the experience gained during the rapid and detailed field work at other wetlands in the same catchment and from other experts' (including landowners') experience. This is discussed further in Section D2.

C2. Recording project information

Although the field datasheet is introduced in this section of the document, the best time to prepare a field datasheet is at the outset of a project (see Section A5 and Table 2), aligning it with the proposed goals of the project and also with the wetland attributes collected in GIS during the desktop phase. Datasheets are designed to capture the wetland characteristics, which become attribute data attached to polygon data. They make provision for recording wetland type, condition and any other information prescribed to meet the stated goals of a specific project. For an example of a datasheet, see Figure 10 and Appendix F.

Some or all of the data listed in Table 2 (Section A5) may be collected in the field for a wetland mapping project. Categories marked with an asterisk (*) are most commonly collected. Other information can be collected with different degrees of detail. A mapping project can broadly map HGM units (for example, assigning all wetlands along valley floors to be valley-bottom wetlands, while at a fine scale there would be multiple small seeps feeding the valley-bottom wetlands) or it can delineate them in fine detail. Similarly, wetland condition may be estimated or assessed in detail.

Datasheets must always have a column for GPS co-ordinates, to link the attribute information to the spatial polygon data. A general rule to keep in mind when mapping is to allocate a unique number to each wetland being mapped and to use that number across all the information gathered in different tools. Examples of a range of possible tools are discussed in Section C2.

Key points

- Datasheets record the characteristics of the visited wetlands and become attribute data attached to polygon data.
- The best time to prepare a datasheet is at the outset of a project, aligning it with the proposed goals of the project.
- Datasheets can be completed digitally on a mobile device, or by hand on a print-out.

Unique numbers can also be adjusted to reflect the quinary catchment where the wetland is found, or to group those wetlands that are hydrologically linked and thus are likely all affected by an impact.

Basic data collection could be as simple as a wetland identification number, a GPS point and a note on rapid condition scores for vegetation and hydrology, such as the example below (Figure 10). This example comprises a series of rows filling an A4 page and headings prompting the type of information to collect relating to wetland HGM type, condition of vegetation and hydrology, and a list of observed plants. An example of a more detailed datasheet has been included in Appendix F.

C3. Tools to support in-field mapping

Time in the field is very valuable and there may only be one opportunity to visit a particular

WET ID/gps	Boundary adjusted?	HGM	Veg	Hydro	Dominant plants	Notes

Figure 10: Rapid assessment datasheet example.

wetland, especially for large-scale inventory projects and in cases where it is necessary to travel very far or cross difficult terrain to get to a wetland, or if special permission is needed to access the wetland. Investing time in adequate desktop preparation and an organised approach to the field data collection are therefore critical and allow you to maximise your time in the field. This could include setting aside time to review the spatial data well before going to the field and preparing a list or map of issues to investigate or verify based on desktop preparation. Keep to this plan as much as possible once in the field, to make the best use of time available.

The following describes a few tools to aid mapping in the field, some of which are illustrated in use in Figure 11:

GPS and camera: A GPS is an important tool for field visits. It can be used to collect spatial co-ordinates of a wetland in point format. The co-ordinates can be taken anywhere in the wetland if the purpose is for the attributes gathered in the field to be linked to the point. The GPS can also be used to adjust the wetland boundary that was mapped on desktop by recording selected points by walking around the wetland in the field. A high accuracy GPS such as a Trimble is necessary if fine-scale mapping accuracy of a wetland boundary is important. A camera is also a useful tool to capture the general look of the wetland. It is important to photograph species found in the wetland while they are fresh as some plants will dry out later, making them more difficult to identify. Many modern cameras have a built-in GPS and vice versa.

List of anticipated local wetland plant species: Familiarise yourself with species common to the area with a hard copy or digital field guide, or by preparing your own digital or print field guide file of expected species for the area (see also Section C6 below). This can then be added to with photographs and notes on the common species you encounter during your field work.

Datasheets: Datasheets and spatial GIS layers that have been brought over from desktop mapping can be brought into the field either as hard copy paper printouts or in electronic format. Data gathered in the field can similarly be captured digitally on mobile devices, or onto

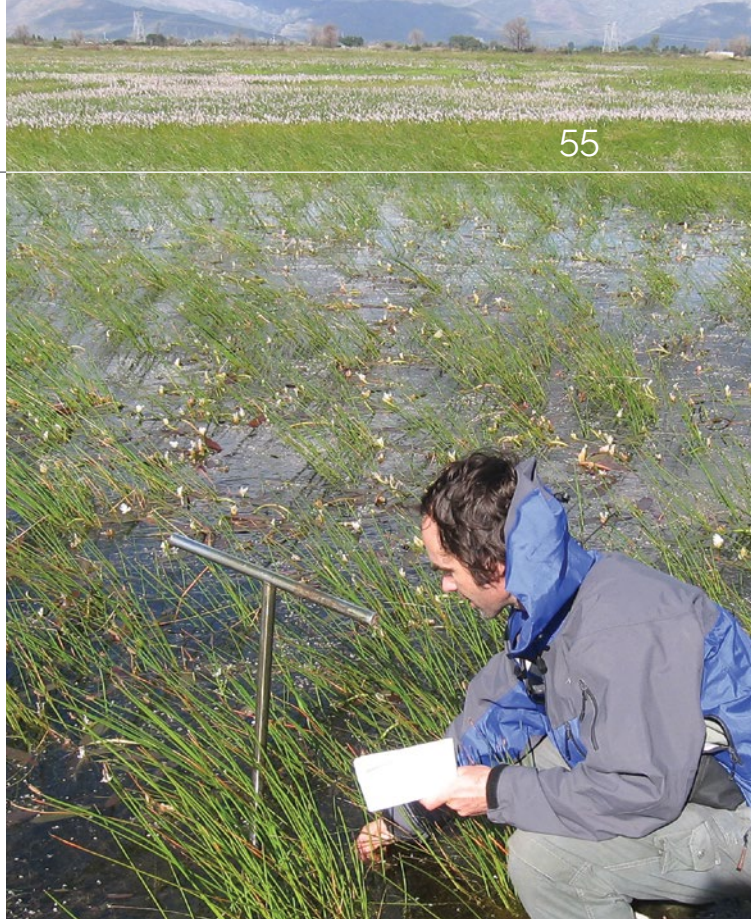


Figure 11: Tools in use: GPS, hard copy maps and a 'home-made' wetland plant ID guide.

a hard copy datasheet and map printouts. If using mobile devices, the MS Excel spreadsheet described in Section A5 can be adapted for the appropriate degree of detail and loaded onto a mobile device.

Maps: Hard copy print maps should be prepared using the highest possible resolution imagery overlaid with the desktop digitised wetland data. Boundary changes as a result of in-field verification and refinement can be drawn directly onto the map. A supporting set of topographic maps for the area are also extremely useful. Topographic data are available digitally from CD: NGI and can also be overlaid with desktop mapping when preparing the field maps. A challenge with hard copy maps is that they can be difficult to orientate and navigate with in the field, and expensive to print if the inventory covers a large area. They need to be zoomed in sufficiently to be able to identify details. If topographic information is not available, it is helpful to show the north arrow, and to add other GIS information such as contours and 1:50 000 river lines to help highlight potential wetland areas in the catchment as well as main roads to help navigate. It is important to add just enough data to the image to be helpful without making the map too complicated to be useful. If there are multiple map sheets, it is helpful to overlap the edges and mark notable features so it can be easily seen how one map sheet joins to the next.

Applications like ArcGIS mobile can be used to collect data in the field. They use the built-in GPS of the device to locate the current position. Polygons can be drawn while standing in the field (Figure 12). The application has imagery as a background. The data is collected as polygons drawn with a linked attribute table, and is stored in the 'cloud' using an internet connection. Unfortunately there are parts of South Africa that have poor or no cell phone reception; this is a disadvantage of using GIS apps. See Appendix B on

Figure 12: Mobile electronic tools: using a tablet with built-in GPS, pre-loaded with desktop mapping and imagery or Google Earth.

Key points

- A number of tools are available to support wetland mapping in the field.
- Tools have advantages and disadvantages, and choice of tools should be made for each project based on these factors.
- Make sure you have interpreted maps well before going to the field, know what you want to verify, know where you have encountered problems during desktop mapping, and then stick to your plan to make best use of your time.

how to setup the data capturing for ESRI ArcGIS mobile version.

Other: Binoculars, a soil auger and soil colour chart (Section C6, Figure 13 and 14) are further useful tools to support the field investigations.

C4. In-field determination of wetland location and extent

Field site visits provide the opportunity to verify and refine the wetland boundary (outside edge of the wetland) that should already have been estimated using desktop mapping approaches. In the field, the wetland boundary and extent can be verified and refined by looking for the presence of water or saturated soils, soil characteristics and wetland plant species.

The *Manual for the identification and delineation of wetlands and riparian areas* (DWAF 2005) provides a useful introduction on what to look for to confirm the presence of a wetland and its boundary. The release of an updated manual is anticipated in the near future. The South African Wetland Society (2014) identified a short list of issues an update to the manual could usefully address, including: more guidance in terms of field procedure and minimum reporting requirements for delineation, guidance for dealing with difficult situations, guidance to account for the regional context of the wetland, review of certain specific indicators and review of the wetland indicator status of individual plant species.

Wetland verification can be guided by the Department of Water and Sanitation's *Manual for the identification and delineation of wetlands and riparian areas* (DWAF 2005).

C5. In-field wetland classification (HGM unit)

Identification of wetland HGM types has been introduced in Section B5, and can be supported by the National Classification System. For those new to identifying wetland HGM types, it is strongly recommended to make use of the definitions provided in the supporting documents to consistently recognise a wetland type and to be able to state with confidence, in a methodology report, the set of criteria used to recognise, for example, seep wetlands or a wetland flat, in the field.

Hydrology

Mappers should be alert in the field for dry-looking areas that may, in fact, be wetland. This can be confirmed by investigating the vegetation and soils. Wetlands are not always inundated (they may have no visible water on the surface); yet digging into the soil may reveal saturated soil or free water in the soil pit very close to the ground surface. Wetlands are also not always wet all year round, soils may be dry for several months of the year in some wetlands, and this can also vary from year to year (these are often important and vulnerable wetlands).

Wetland HGM types are closely related to different sources of water driving the different types of wetland, and the manner in which water moves through and leaves the wetland. Detailed level mapping projects may go further

Table 17: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to hydrological regime

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Surface Water Hydrological Regime	SurfH	At Level 5A, inundation and saturation periodicity are the major discriminating factors for wetland HGM units.	• Permanently inundated • Seasonally inundated • Intermittently inundated • Never inundated • Unknown
Subsurface Water Hydrological Regime	SubsH	Saturation is considered within the upper 0.5 m of the soil surface (commonly accepted depth considered for wetland delineation purposes (see DWAF 2005)).	• Permanently saturated • Seasonally saturated • Intermittent saturated • Unknown
Depth Class Category	DepthH	Two depth class categories have been included to classify the (maximum) depth of inundation for permanently inundated systems.	• Limnetic (≥ 2 m maximum depth at low water) • Littoral (< 2 m maximum depth at low water)

and describe more specifically the hydrology of a wetland, including the hydrological regime, wetland wetness zones and impacts to wetland hydrology. Attributes listed in the MS Excel spreadsheet described in Section A5 relating to hydrological regime are shown in Table 17.

C6. Gathering in-field data on wetland characteristics

Regional setting is discussed in Section B5.1 above. This refers to estimation or modelling of anticipated regional differences in wetlands. Neither the DWS eco-regions (Kleynhans et al. 2005) nor the wetland vegetation groups of the NFEPA project (Nel et al. 2011a) have been formally tested with respect to how well they represent the biotic diversity of South African wetlands. There is a need to undertake such a test based on field data from many wetlands across the country through a dedicated initiative beyond the scope of these guidelines, such as, for example, the WRC National Wetland Vegetation Database Project (Sieben et al. 2014), which has sampled wetlands with a consistent methodology across South Africa.

Although definitive regional wetland types can only be set in the appropriate manner and scale referred to above, gathering of information on wetland characteristics is nevertheless an opportunity to record, through direct observations, the variety of wetlands found across a particular inventory study area. The more wetlands observed, the easier it will be to notice key characteristics and to start to group wetlands together that seem similar. Through the course of a study it may become apparent that a particular wetland group is affected by common impacts, or is particularly sensitive to certain impacts, and in this way appropriate and specific management advice can be generated. Table 18 presents the type of characteristics that may be collected for a detailed wetland inventory.

Recognising and describing wetland plants

The presence of wetland plants is one way of identifying a wetland. Wetland plants are those plants adapted to, or tolerant of, saturated soils.

Over the course of a wetland inventory project, it is very useful to develop a list of the wetland plants found within the study area. This list could include:

- Indicator plants – can include those that are known to always occur in wetlands and indicate the presence of a wetland or a regional wetland type. The presence of certain plant species can

Table 18: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to wetland characteristics

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Geology	Geolo	The geological types associated with a wetland can be recorded as an optional descriptor by obtaining the Lithostratigraphic Units from the relevant 1:250 000 scale geological map(s).	Freehand text (maximum of 20 characters).
Source Data (for Geology)	GeoDa	Indicate the source data for the geology. For example whether it was derived from a report (which should be referenced) or a map such as the 1:250 000 scale geological maps (map reference should be indicated).	Freehand text (maximum of 20 characters).
Vegetation Cover Type	VegCover	A distinction can be made between vegetated and unvegetated wetlands.	• Vegetated • Unvegetated
Vegetation Form	VegForm	In the case of non-swamp forests, the vegetation status category of 'plantation' has been included instead of 'crop' (at sublevel C), as it is a more appropriate term.	• Aquatic floating • Aquatic rooted • Aquatic algal mat • Herbaceous grasses • Herbaceous herbs/ forbs • Herbaceous sedges/ rushes • Herbaceous reeds • Herbaceous restios • Herbaceous palmiet • Herbaceous geophytes • Shrubs/thicket • Forest swamp forest • Forest non-swamp forest
Plant Species	Plants	Record dominant or indicator species names or refer to the relevant report.	• Comprehensive plant species list available • Basic plant species list available • No plant species list available • Species names
Peatland?	Peat	Indicating whether or not the particular HGM unit or wetland component is a peatland (substratum type is comprised of peat or partly of peat).	• Yes • No • Unknown
Peatland Type	Peat_type	Note you can indicate more than one category.	• Bog • Fen • Papyrus swamp • Swamp forest • Dolomitic eye • Valley-bottom • Dome • Other
Substratum Type	SubsT	Substratum type.	• Boulders • Cobbles

Table 18: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to wetland characteristics (continued)

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Substratum Type	SubsT	Substratum type.	• Pebbles/gravel • Sand • Bedrock • Silt/mud • Peat • Salt crust • Clay • Loam • Other
Salinity	Salin	• Fresh (salinity < 2.0 g/l or ec < ± 300mS/m) • Brackish (salinity 2.0–12.0 g/l or ec < ± 300–1 800 mS/m) • Hypersaline (salinity 12.0–40.0 g/l or ec < ± 1 800–6 000 mS/m) • Saline (salinity > 40 g/l or ec > ± 6 000 mS/m)	• Fresh • Brack • HyperS • Saline
Acidity/ Alkalinity	pH	• Acid (pH < 6) (Ac) • Circum-Neutral (pH = 6–8) (Ci-Ne) • Alkaline (pH > 8) (Al)	• Acid • Circum-neutral • Alkaline

also indicate healthy or impacted wetland condition.

- Dominant plants – which can help to characterise the wetland and distinguish regional wetland types that are present in the study area.

Through this listing exercise, it is helpful to collect photographs in the field to build up a photographic herbarium for the study area. It is also useful to develop an abbreviation system to refer to common plants, for example using the first two letters of the genus and first two letters of the species, which can then be used as shorthand for filling out datasheet in the field. An example of this is presented in the datasheet in Appendix F.

Developing a set of personal notes on the characteristics of wetland plants can assist in identifying them in the field (Figure 13). Some important aspects to look at include:

- Root form (clump or tuft-forming, rhizomes, stolons or fibrous roots).
- Habitat (permanently wet, seasonally saturated, sand, highly organic soil, salty estuarine area, steep slope, rocky area, etc.).
- Distinguishing features (hairy ligule or stem, opposite or alternate leaves, etc.).
- Frequency that the plant occurs at in wetlands (plants that are always found (>99%) in wetland are called obligate, plants that are frequently found (67–99%) in wetlands are called facultative wetland plants, while those found in wetlands 34–66% of the time are simply called facultative (Reed 1988)).

The categories of occurrence by Reed (1988) have been adapted for South Africa and the process of allocating South African wetland plant species to these categories is underway. A preliminary indication is given in *Easy identification of some South African wetland plants* by Van Ginkel et al. (2011). However, many wetland species are not covered in this manual. In these cases, a reliable reference text should be consulted for the habitat preferences of the plant.

Recognising and describing wetland soils

Soils are often a definitive indicator used by experienced wetland scientists to confirm the presence of a wetland and understand more about its functioning. Hydromorphic soils result from a high water table that causes saturation at or near the surface, leading to anaerobic

Figure 13: Developing a list of wetland plants.

- There are a number of aids for identifying wetland plants, including the WRC field guide *Easy identification of some South African wetland plants* (Van Ginkel et al. 2011).
- The online species identification fora, iSpot (http://www.ispot.org) and iNaturalist (http://www.inaturalist.org) can be a valuable interactive way to identify plants.
- For an updated South African Red List status of species, visit http://redlist.sanbi.org/.

conditions developing in the top 50 cm of the soil. Most soils saturated for a long duration develop a characteristic morphology. These are described in more detail in the *Manual for the identification and delineation of wetlands and riparian areas* (DWAF 2005). Soils are investigated in the field by extracting samples with a soil auger, recording their colour against the standardised colours of the Munsell chart (Figure 14), identifying whether the soil is organic (such as for peat wetlands) or mineral, and, in the case of mineral soils, describing their texture.

Colour is one of the most important aspects of soil morphology for identifying hydromorphic soils, and a standard colour chart is therefore

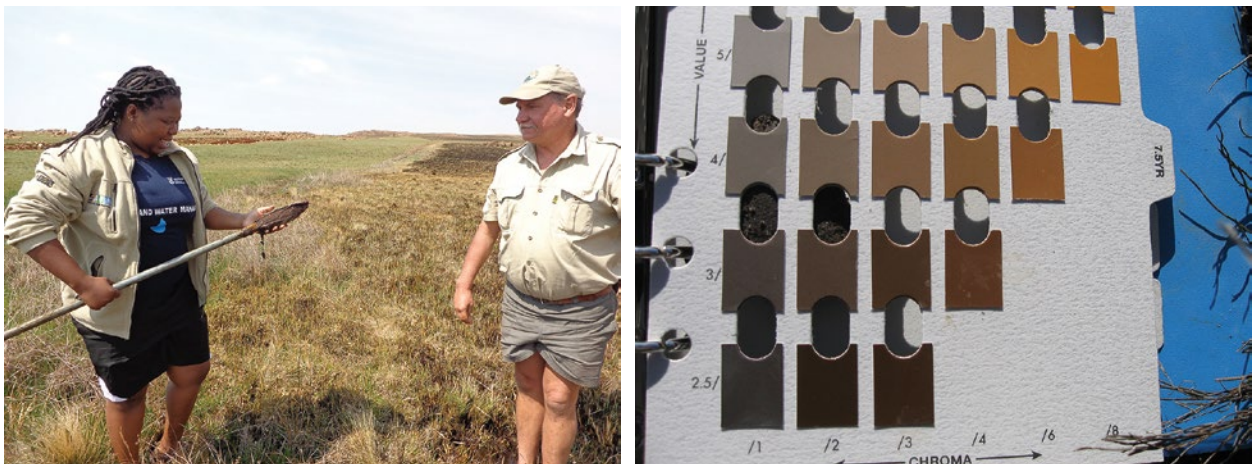


Figure 14: Soil information in the field can be collected with a soil auger (left) and matched against colours in a Munsell soil colour chart (right).

essential to be able to carry this out as consistently as possible. Soil texture is described by the relative amounts of clay, silt and sand in the soil. Soil texture is the primary factor determining the hydraulic conductivity of the soil, i.e. how readily water moves through the soil. This affects how the wetland functions and how human modifications affect the wetland, e.g. artificial drainage channels are likely to have a higher impact on subsurface drainage in sandy soils than in clayey soils. Information on soil texture as well as soil depth, e.g. 'deep sand' or 'a layer of dense clay' or 'bedrock within 1 m' can help indicate the hydrology of the wetland (see previous section), i.e. whether the wetland is permanently, seasonally or temporarily wet. A good initial place to read more on these topics is the *WET-Health* and *National Wetland Classification* manuals referred to elsewhere in this document.

C7. In-field assessment of wetland condition

The health of a wetland refers to the extent to which human impacts have caused the wetland to differ from its natural reference condition. Wetland health profoundly affects the value of a wetland with regards to biodiversity and for providing ecosystem services. Wetland health may be complex to assess and is generally best carried out by examining health in terms of different sub-components (e.g. hydrology, geomorphology, vegetation).

In the field, it is important to get a sense of the disturbance units present within the wetland. Disturbance units represent different levels of disturbance and differing land-uses, e.g. natural / cultivated / dominated by invasive alien trees, within the wetland.

Health assessments need to be of an acceptable standard and be comparable from different sources. Thus, it is critical that any health assessment be conducted by an assessor with prior training and adequate field experience using an appropriate method (e.g. WET-Health). If the wetland is to be assigned a health class based on professional judgement alone, then it is critical that the assessor has a high level of expertise as well as knowledge of the wetlands in the region being assessed.

The *WET-Health Manual* (MacFarlane et al. 2009) provides detailed explanation of assessing wetland condition, which is carried out according to three main sub-components, namely geomorphology, hydrology and vegetation. The latter two are described briefly below.

- **Hydrology condition score:** To arrive at a hydrology integrity score, consider the potential water source(s) to the wetland (rain/stream/hillslope/groundwater/open water). Are they natural or altered? List the key impacts on the datasheet. Consider areas of plantation, cultivation, hardened surfaces in the wetland catchment to gauge impacts to water input to the wetland. Consider relative area (%) within the wetland affected by drainage channels and erosion gullies, modifications to stream channels, deep flooding by dams or other changes in natural hydroperiod, reduced surface roughness (dense vegetation slows and spreads water and allows sediment to drop out), on-site water use such as by alien invasive vegetation or plantations within the wetland, infilling or depositional features. Map all dams and other artificial wetlands. Assign an overall hydrology integrity score on a scale of 0 (critically altered) to 10 (natural condition, unimpacted) (Table 19).
- **Vegetation condition score:** First list specific impacts to vegetation. The datasheet has a list of common impacts. Take into consideration the relative area (%) of the wetland affected when assigning a score, as well as historical land use and fire history where known, and assign an overall vegetation integrity score for the unit (Table 19).

In addition to the score of the A–F above, the MS Excel spreadsheet makes provision for recording further information about the wetland condition assessment (Figure 5; Table 20).

A full explanation of assessing wetland condition can be found in the *WET-Health Manual* (MacFarlane et al. 2009). WET-Health has a table of typical scores according to common impacts to wetland disturbance unit types.

Table 19: Wetland condition scores (WET-Health, MacFarlane et al. 2009)

INTEGRITY	IMPACT	DESCRIPTION	PES
9.1–10.0	0–0.9	No discernible modifications, natural.	A
8.1–9.0	1.0–1.9	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged.	B
6.1–8.0	2.0–3.9	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	C
4.1–6.0	4.0–5.9	Largely modified and impact clearly detrimental. For example, 50% hydrological integrity lost, alien and weedy species equal indigenous species.	D
2.1–4.0	6.0–7.9	Extensive loss of natural habitat, biota and basic ecosystem services. For example, vegetation composition substantially altered, although some characteristic species may remain.	E
0–2.0	8.0–10.0	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	F

Table 20: Attributes from the SANBI MS Excel spreadsheet (Section A5) relating to a wetland condition assessment

MS EXCEL SPREADSHEET HEADING	GIS ATTRIBUTE HEADING	EXPLANATION	DROP-DOWN OPTIONS
Present Ecological State (PES)	Con_PES	A PES assessment is normally undertaken as part of an EIA or WULA process. If these data are available, then record the PES rating score or category derived from the assessment.	• A • B • C • D • E • F • Unknown (U)
Trajectory of change	Con_TrajC	This can be recorded as an optional descriptor by indicating the trajectory of change class.	• Improve markedly (IM) • Improve (I) • Remain stable (RS) • Deterioration slight (DSl) • Deterioration substantial (DSb) • Unknown (U)
PES method	Con_Meth	A PES assessment is normally conducted via one of five possible methods, which in turn indicate the degree of detail at which the study was undertaken.	• Wetland Reserve Method (DWAF 1999) • WIHI for Valley-Bottom Wetlands (DWAF 2007) • WET-Health (MacFarlane et al. 2009) • Revised Wetland Reserve method (DWA 2011) • Other (indicate in additional comments)
PES confidence rating	Con_ConR	The PES assessment generally produces a confidence score that indicates the level of confidence the assessor had in the data used to derive the PES.	• 1 • 2 • 3 • 4 • 5
Additional comments	Con_AddCo	A comment column is provided for more details regarding the condition of the system or method used.	Freehand text (maximum of 20 characters)

PART D.
DESKTOP FOLLOW-UP / BACK IN THE OFFICE

Part D of this manual describes the final tasks of integrating the information collected in the field into the final GIS and attribute data. Cleaning of the data, especially when integrating multiple sets of data into an inventory, or if the mapper is a wetland- rather than a GIS specialist, is an essential follow-up task (Section D1). A final review is an important step in further verifying the data collected and improving data confidence. Allocating sufficient time for wetland expert review of the final product is particularly important and is often overlooked in modelled datasets (Section D2). Finally, it is useful to assign a confidence level to the data and this is discussed in Section D3.

D1. Data integration and cleaning

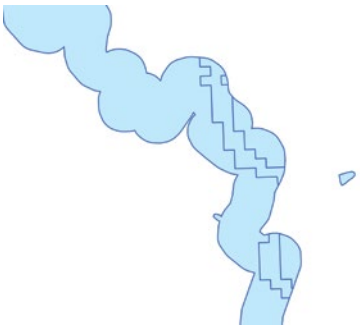
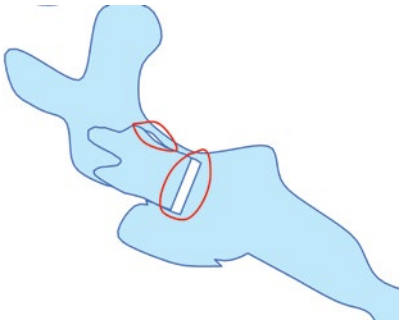
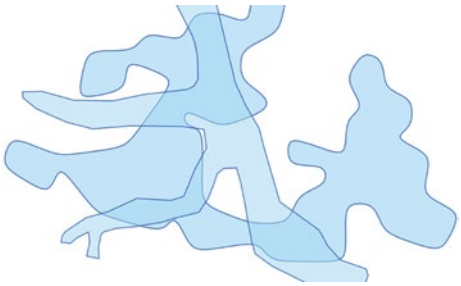
Once each quinary catchment has been visited and datasheets filled out, it is necessary to correct the wetland and HGM boundaries in GIS and convert the datasheet information into attributes. The data collected in the field can first be captured into an MS Excel spreadsheet (described further in Section A5). The spreadsheet can then be turned into a shapefile in GIS (see Appendix D) and then linked as a set of attributes to the polygon layer using spatial location. The data from ArcGIS mobile can be downloaded and added into GIS as a shapefile to assist with boundary correction and assignment of attributes (Appendix B).

Integrating all the data captured through desktop and/or field methods into a single dataset must then be undertaken. An individual with experience in GIS should be in control of collating the various data layers to create the final GIS product and of cleaning of the dataset. Data cleaning requires meticulous attention to detail and should be conducted according to a strict GIS protocol. Guidance is available on the basic GIS topology rules (e.g. www.help.arcgis.com topology rules poster) and wetland mappers should ensure that they are familiar with this topic before embarking on a GIS mapping project.

If there are various data capturers, and a number of different datasets that have been integrated, data errors may have entered the dataset. Keeping a lookout for these issues will be particularly important if attempting a system of mapping updates drawn from multiple sources, citizen science initiatives or incremental additions from tablet-based applications. Some of the common errors (Table 21) that arise from haphazard data capture include multipart polygons, which create difficulties if this data is to be used for any further GIS analyses and which may lead to double counting or other false statistics. Data is also typically checked for the presence of 'slivers'.

The attribute table should also be reviewed for gaps – where no information has been assigned to a polygon. Attribute data inconsistencies such as typing errors or spelling a common attribute in several different ways, should also be corrected at this point. This is also the time to make sure that data recorded in the field, including new attribute data, has been correctly assigned to the appropriate polygon. Certain tasks of filling an attribute table may be automated. Wetland knowledge is often useful during this final review phase, as automation rules need to be set carefully so

Table 21: Examples of data errors arising from data digitising or modelling

CLEANING THE DATA OF DIGITISING AND MODELLING ERRORS	
	Large-scale modelled datasets will often require further steps to clean the data into sensible wetland units for a wetland inventory. In this example (left) modelled outcomes have resulted in geometric edges that need correcting.
	Topology errors need to be found and corrected. In this example (left) no snapping tolerances were set, nor was the autocomplete tool (in ArcGIS or QGIS) applied, resulting in poorly matched polygon edges.
	A choice needs to be made of which dataset will take precedence when multiple datasets are combined. In this example a choice must be made between the two overlapping wetlands, using an appropriate method such as wetland expertise, local knowledge and/or field verification to decide on the more accurate of the two. Use the clip command in ArcGIS to resolve.
	Overlapping polygons are particularly important to look out for when datasets are combined from separate catchment mapping efforts. In this example, wetlands of each colour represent separate mapping exercises from three different catchments. The overlapping areas must be reviewed and corrected so that there is only one polygon.
	It is often very useful to map wetland boundaries using Google Earth, especially for people not comfortable using GIS, but with wetland expertise to contribute. However, Google Earth has very limited editing capabilities and it is common to receive data with poorly matched polygon edges. A solution is to capture in Google Earth then bring into QGIS to clean the topology.

that a computer can assist in speeding up the task, but not generate meaningless data, which would undermine the product. Time allocated for wetland expert review of the final output is particularly important for modelled datasets and an often overlooked opportunity.

D2. Final review

The final review of the integrated dataset is a very important stage of a wetland mapping project. Once the ground-truthing is complete for a sub-catchment, and the findings incorporated into an updated GIS dataset, a review of the wetlands in every quinary catchment should be conducted. At this scale, it is much easier to compare and contrast amongst the wetlands, which improves the review confidence and calibration of results. This should be undertaken one final time to identify any remaining data errors.

The updated shapefile should be reviewed over spatial imagery or Google Earth imagery by the core team. Knowledge gained by the team during the field mapping, along with assistance from a local expert and other stakeholders who know the area can be valuable at this review stage. This final review can be used to improve the confidence rating of the mapped wetlands (see Section D3).

The review can also include one final check to ensure that the digitising team did not miss the following desktop preparation steps (Section B2) by including them again in a rapid review:

- Check for any NFEPA polygons that were missed by the new mapping, verify if they are wetlands, and, if so, include into the new mapping.
- Use CD: NGI dataset, specifically the mapped artificial wetlands, to a) check if any new mapping inadvertently mapped a known dam as wetland, and b) verify mapped dams and allocate these as high confidence.
- Use CD: NGI dataset, specifically the perennial and non-perennial pans, to a) check if any known depressions were inadvertently missed in the new mapping, and b) verify any corresponding mapped polygons to be depression HGM type and allocate these as high confidence.
- Make use of wetland polygons mapped by wetland specialists to a) align boundary of new mapping with specialist mapping, and b) adjust any corresponding mapped polygons to be the same HGM types as the specialist mapping – allocate these as high confidence.

D3. Assigning confidence levels

Assigning confidence levels to wetland data has important implications in terms of the certainty with which users can apply the data. Based on feedback from wetland specialists, the requirement for data source and confidence information is a recurring recommendation. These users would like to know which wetlands were mapped and reviewed by a specialist, which were modelled, and which came from other sources.

In addition to including source information as a GIS attribute, each wetland can be assigned a level of mapping confidence. At its simplest, this could be divided into three categories, namely high, medium and low (Table 22).

Key points

- Final tasks in a wetland mapping project include integrating all the data captured into a single dataset and reviewing the dataset.
- Multiple data capturers, or modelling processes, can result in common GIS data errors that need to be found and corrected.
- Data users must be able to ascertain and trust the quality of the data.
- Data quality can be improved by conducting a thorough review of the dataset with reference to specialists or existing high confidence datasets.

Table 22: Confidence levels assigned to mapped wetland polygons depending on the ground verification and specialist review process

CONFIDENCE LEVEL	DESCRIPTION
High	Wetland delineation reviewed by at least one wetland specialist and either ground-truthed or verified using existing high confidence datasets.
Moderate	Wetlands mapped at desktop level but outputs reviewed by at least one wetland specialist.
Low	Wetlands mapped at desktop level, but outputs not reviewed by an expert.

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Appendix A:
Metadata example

FILE NAME: Mpumalanga Highveld Wetlands		
Full Path		
Description (detailed)	This layer codes Mpumalanga Highveld Wetlands. The delineations were based on tracking wetlands on SPOT 5 imagery within the Mpumalanga Highveld boundary supported by Google Earth, 1:50 000 contour lines, 1:50 000 river lines, Exigent data and NFEPA wetlands. The project focusses on updating previously mapped wetlands in three major steps, which are desktop digitising, field ground-truthing and reviewing of mapped data.	
Copyright holder	SANBI	
Data origin	Desktop mapping of Mpumalanga Highveld	
Capture source	SANBI	
Scale digitised at	1:6 000	
Date captured	August 2013 to September 2014	
Data copyright	No	
To be distributed	Yes	

DATA INFORMATION AND METADATA INFORMATION		
Owner organisation	SANBI	
Contact person	Namhla Mbona	Siyabulela Benard Memani
Position of contact person	Freshwater Biodiversity Planner – Ecological Infrastructure	GIS Technician – Ecological Infrastructure
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Contact number	+27 (0)12 843 5294	+27 (0)12 843 5123
Contact e-mail	n.mbona@sanbi.org.za	s.memani@sanbi.org.za

LEGEND PROPERTIES	
Legend title	Mpumalanga Highveld Wetlands
Feature type	Polygon
Scale parameters	

PROJECTION	
Projection name	GCS_WGS_1984
Central meridian	25
Upper parallel	-33
Lower parallel	-24

DATUM	
Name	WGS_1984
Semi-major axis	0
Semi-minor axis	0
Inverse flattening	0

DETAILED NOTES

Purpose:

To ground-truth and refine the current data layers of the extent, distribution, condition and type of freshwater ecosystems in the Mpumalanga Highveld coal belt, to support informed and consistent decision making by regulators in relation to the water–biodiversity–energy nexus. To incorporate these revised data layers into the atlas of high-risk freshwater ecosystems and guidelines for wetland offsets, which is currently being developed by SANBI to improve the scientific robustness of these tools. To support the uptake and development of the necessary capacity to apply the data, atlas and guidelines by regulators and the coal mining industry in their planning and decision-making processes.

Methods:

Highveld grasslands boundary was chosen as the study area for the project supported by the catchment quinaries. SPOT 5 imagery was used as the base imagery for digitising reference. The HGM unit was identified at the desktop digitising stage and confirmed in the field. More data were collected from the field, reviewed back in the office, and incorporated in the layer attribute table. Reviewing was also aligned with polygon boundary adjustment where necessary to produce a good product. The data are captured in vector format during the desktop stage and then ground-truthed and reviewed. At each of these stages, data on wetland boundaries, type and condition were collected. Four Water Management Areas within the Mpumalanga Highveld were targeted by the project. Training and capacity building on wetland delineation was conducted during the course of the project. The primary result was an updated spatial dataset for the wetlands of the Mpumalanga Highveld. Additional analysis was conducted on this dataset to determine changes to ecosystem threat status, protection level and Freshwater Ecosystem Priority Areas (FEPAs) arising from refinement of the wetland data.

Available documentation:

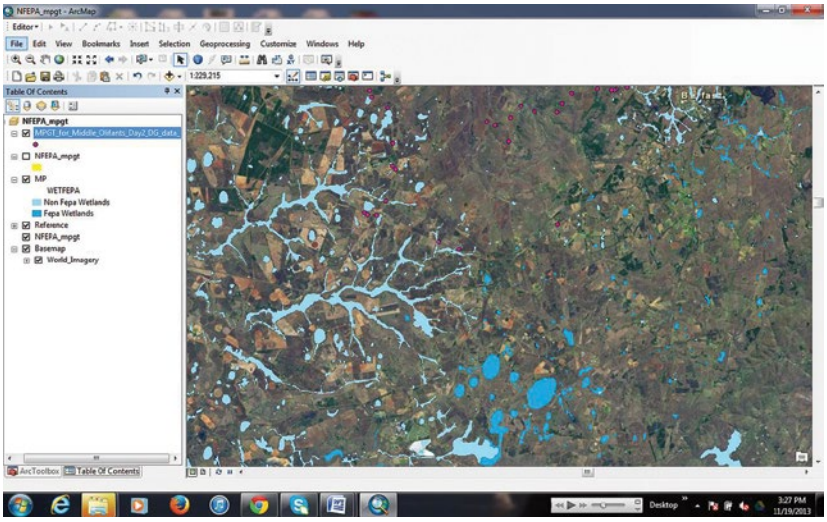
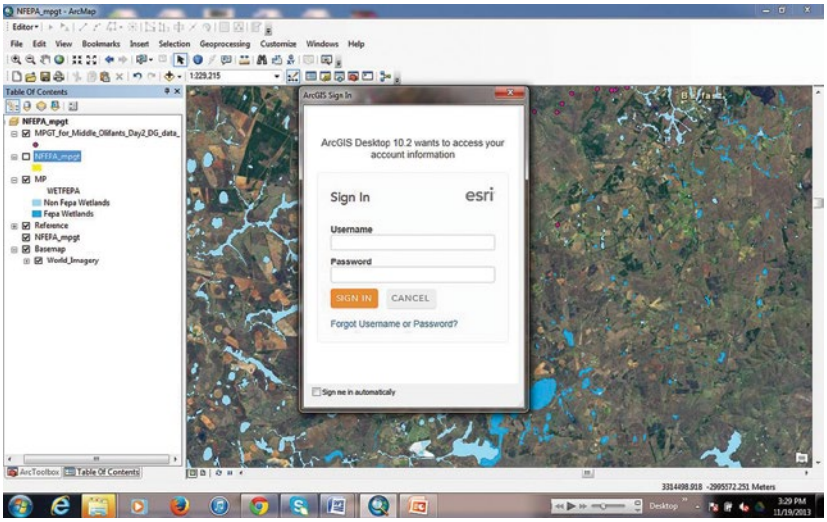
Final report to be issued at a later stage.

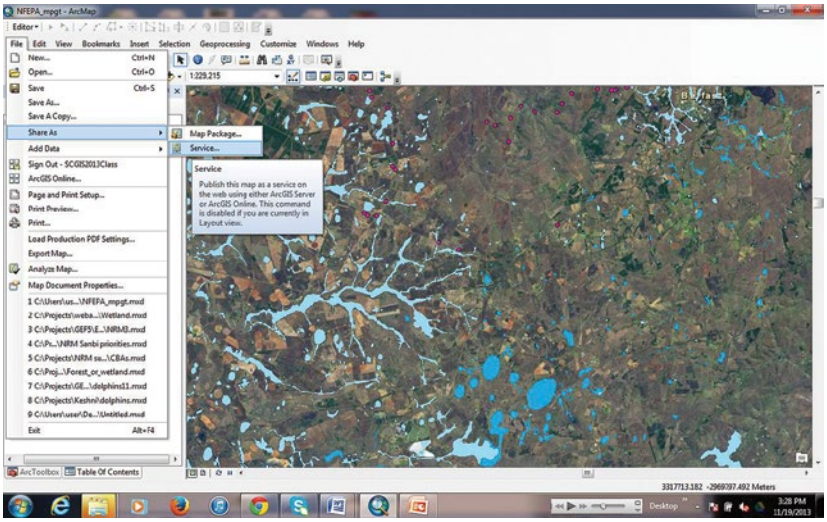
ATTRIBUTE FIELDS	
Field Name	Description
FID	Unique number in each feature
Shape	Type of feature
HGM_Fi	Hydrogeomorphic types from the wetland classification system
Veg_Fi	Scoring assigned to the vegetation condition ranging from 1 (good) to 10 (worst)
Hydrolo_Fi	Scoring assigned to the hydrology condition ranging from 1 (good) to 10 (worst)
DomP_Fi	Identification of common wetland plants that were seen during wetland assessment
ConfR_Fi	Three levels of details assigned to each feature associated with details assessment (high to moderate) or less detailed assessment (low)
Con_Fi	Confidence scores assigned to the features when reviewed from 1 (good) to 4 (bad)
Catchment	Water Management Area consisting of quinaries and other ecosystem features
Wet_ID	Identifier used to tell which polygons belong to the same wetland system and point from the field survey notes
WetunitID	Identifier that tells which polygons belong to the same wetland system
Wetunit_sq	A combination of WETUNITID and UNIT_ID that distinguishes sub-quaternary catchments
MajWetVe_1	Type of bioregion in which a polygon falls in
WETTYPE4	Type of bioregion identifying the hydrogeomorphic type
Pernat0	Percentage natural land cover within each wetland. The SANBI update of the national land cover for South Africa was used, which uses fairly recent provincial data (as available in 2009)
Pernat50	Percentage natural land cover within a 50 m buffer of the wetland. The SANBI update of the national land cover for South Africa was used, which uses fairly recent provincial data (as available in 2009)
Pernat100	Percentage natural land cover within a 100 m buffer of the wetland. The SANBI update of the national land cover for South Africa was used, which uses fairly recent provincial data (as available in 2009)
Pernat500	Percentage natural land cover within a 500 m buffer of the wetland. The SANBI update of the national land cover for South Africa was used, which uses fairly recent provincial data (as available in 2009)
MinPNat	The minimum value of Pernat0, Pernat50, Pernat100 and Pernat500
WetCon2	NFEPA condition
FEPA	FEPA feature identification between 1 FEPA and 0 NonFEPA feature
NATART	Distinguishes between 'natural', 'artificial' and 'estuaries'. '1' natural and '0' artificial

Appendix B:
How to maintain and use the ARCGIS application for data collection

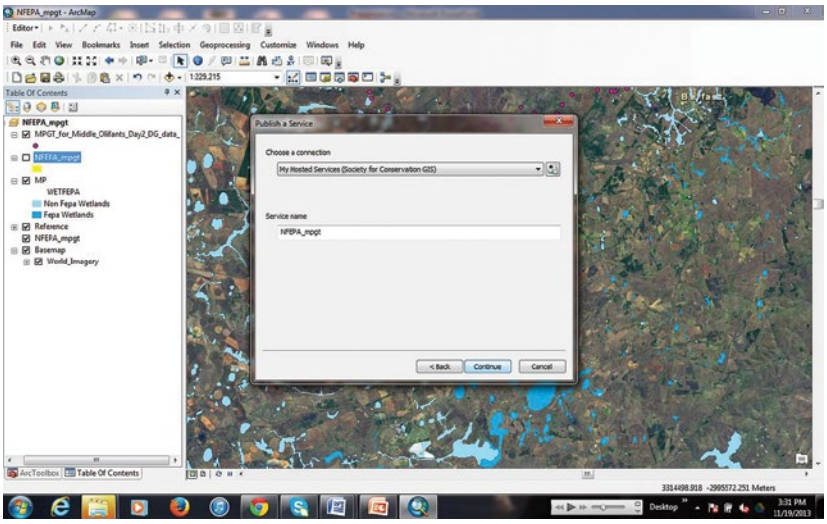
This is an easy guide on how to use the ArcGIS mobile to collect and publish field data.

For the account controller

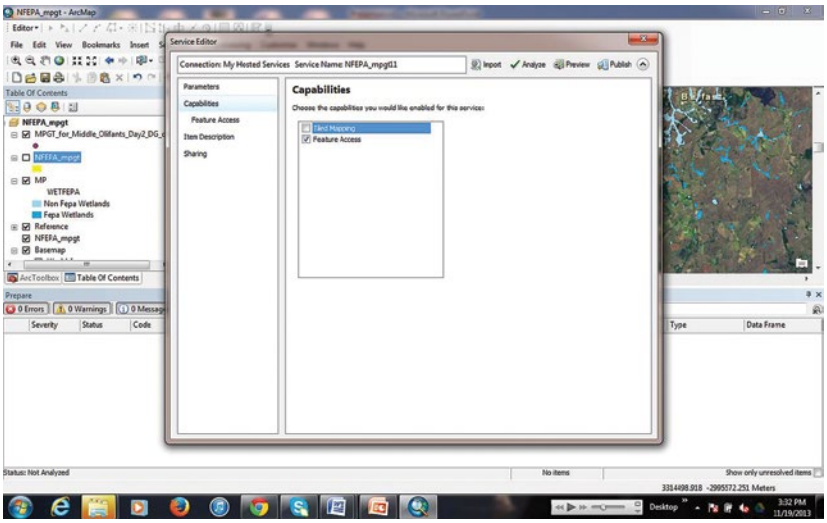
SCREENSHOT	INSTRUCTION
	Prepare all your layers in ArcGIS desktop. Save it as an .mxd file. Please fill in the map properties document.
	Login to ArcGIS online account. Click File> Sign In. Type your name and password for ArcGIS online and click 'Sign In'.



Share the map as a service. File > Share As > Service.



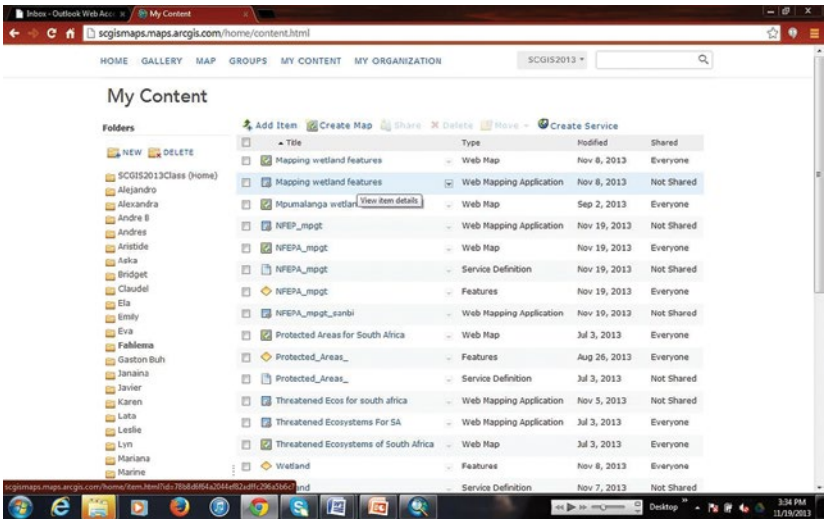
In the drop-down list of connection types, choose My Hosted Services. Then type a name for your service and click 'Continue'. This should be your account details.



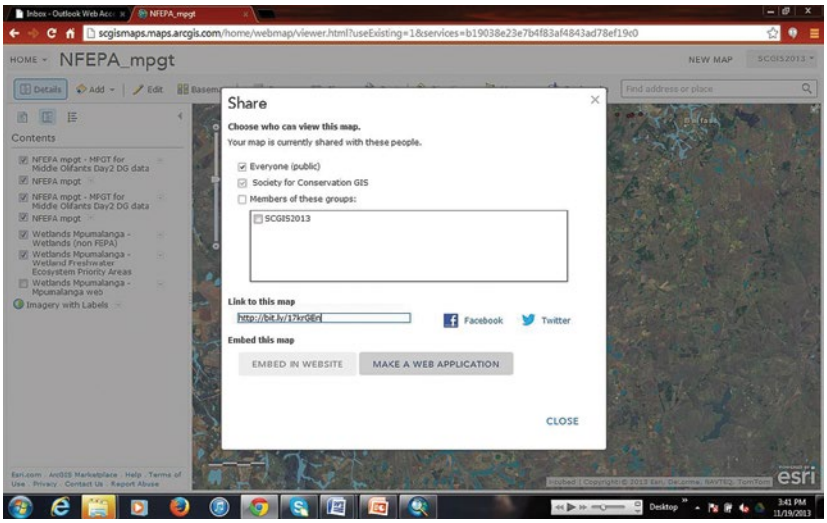
In the left pane of the Service Editor, click 'Capabilities', and then check 'Feature Access' to expose your service as a feature service. You can optionally also check 'Tiled Mapping', although in most scenarios you would use a different set of layers and a different map document for publishing your tiled map. You can click the sub-item 'Feature Access' in the left pane of the Service Editor to set advanced properties relating to what clients can do with the service.

In the left pane of the Service Editor, click 'Item Description' and enter a summary and tags for your service. You will need to enter this information before you can publish the service.

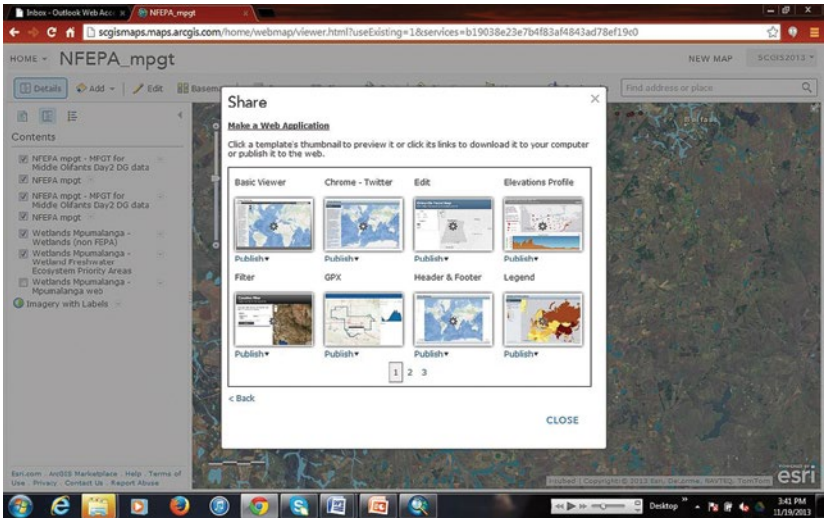
Login to your online account on internet.



Locate the map in My Content and open it.

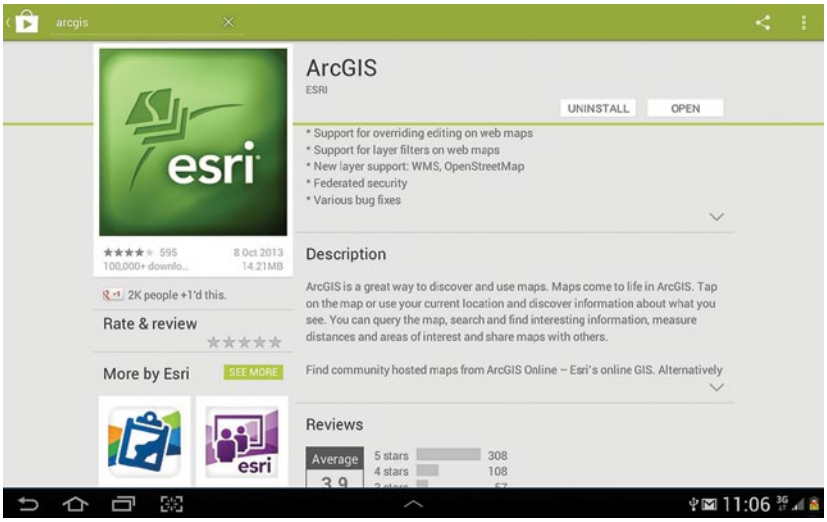
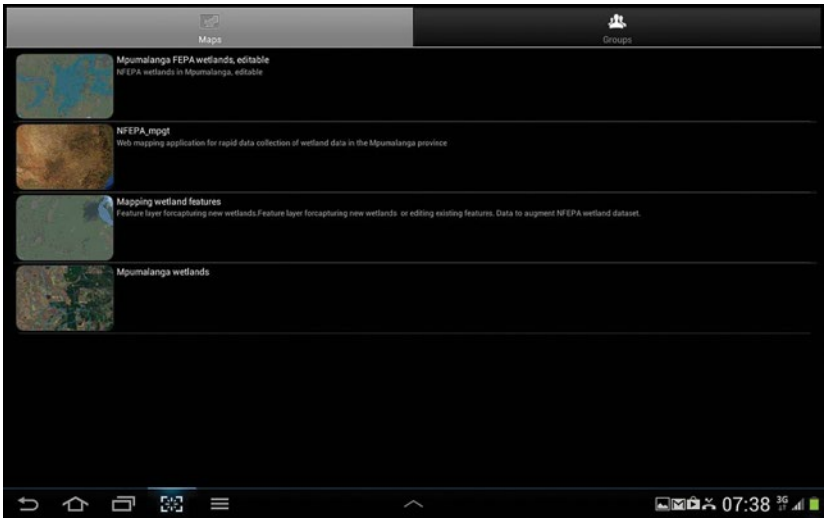


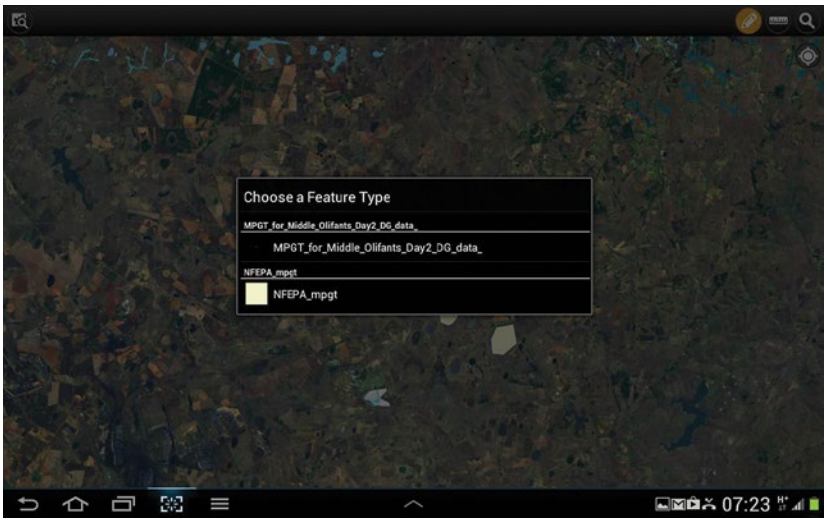
Share the map. By default, your service is private, meaning it is only accessible to you. Your service will always be visible in My Content, but you can also choose to share it with everyone or just members of certain ArcGIS online groups.



Make it editable in order for people to be able to add new data.

Using ArcGIS mobile on a mobile device

SCREENSHOT	INSTRUCTION
	Search for and download the ArcGIS mobile app from your app store.
	Open the app.
	Search for the appropriate map through ArcGIS online.



Open the editable layer.

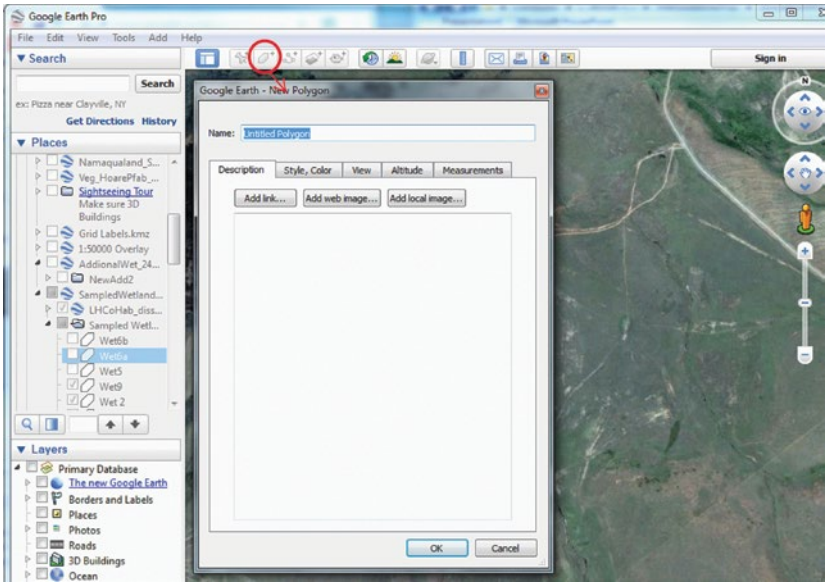
Using the GPS on your device, find your current location. Start editing the attribute table.

Add the polygon and save the edits.

Appendix C:
Delineating HGM units using Google Earth and QGIS

Using Google Earth to map wetlands

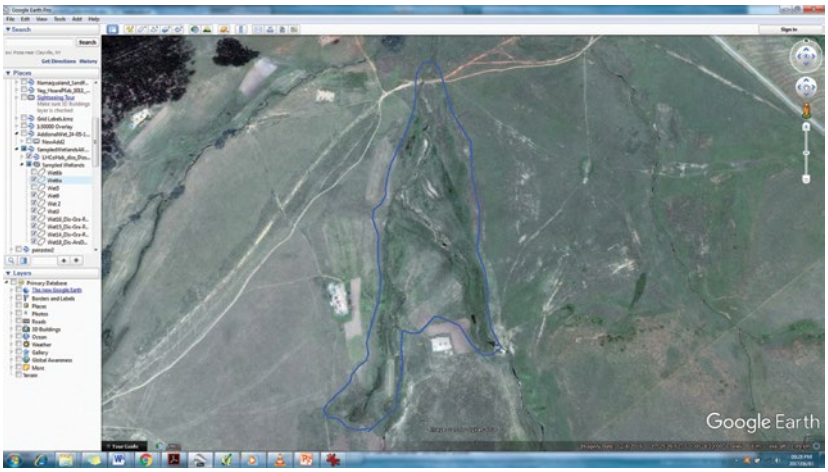
SCREENSHOT	INSTRUCTION
	Zoom to your study area in Google Earth either manually or by entering GPS co-ordinates in the search bar.
	Begin by scanning the imagery to train your eye, taking note of where the wetland begins and ends. The wetland usually terminates at a point at which a geological control occurs. Geological controls are landscape features that act as plugs that slow the flow of water downstream, causing the water to back up and form wet areas, forming the wetland. Geological controls usually appear as the area downstream of the wetland at the junction at which the wetland narrows into a stream. If a geological control is not immediately evident, then proceed with the delineation beginning at a point which is clearly visible to you as forming part of the wetland boundary.



Select the 'Add Polygon' icon at the top of your window. Rename the polygon in the window which pops up. Do not close this window until you have finished drawing the polygon which delineates the wetland.

Click the cursor at the point at which the wetland you are working on flows out into a stream or at a point that is clearly evident to you as forming part of the edge of the wetland and work your way upstream along the boundaries of the wetland.

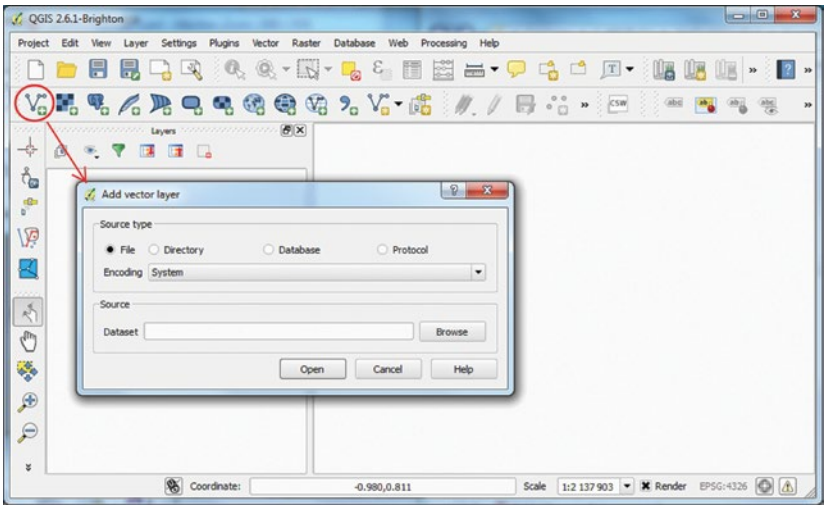
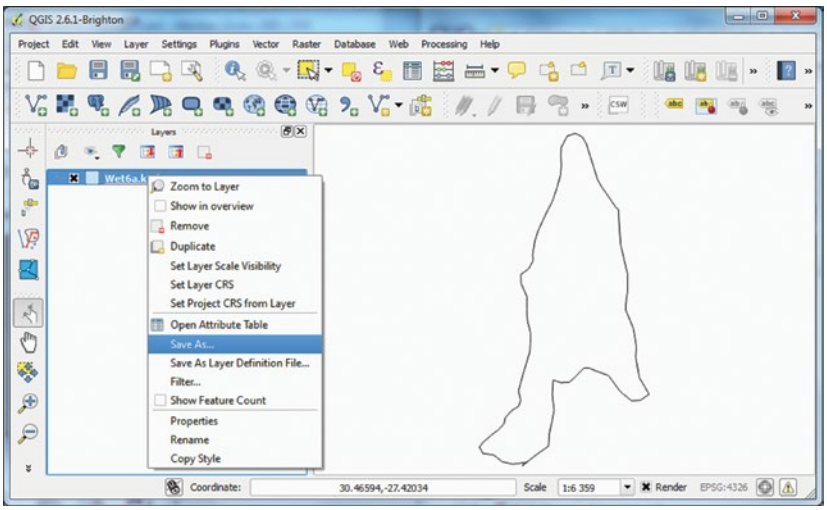
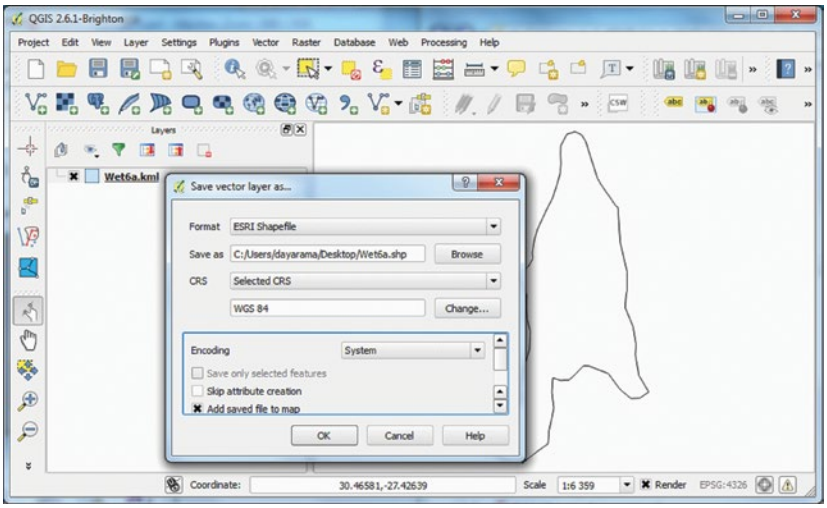
TIP: Click the 'Style, Color' tab in the pop-up window and under 'Area' change the 'Filled+Outlined' option to 'Outlined'. Begin drawing the outline of the wetland by clicking the pointer around the outside edges.



Click 'Okay' when you have returned to the starting point. You will now have a polygon in the shape of the wetland.

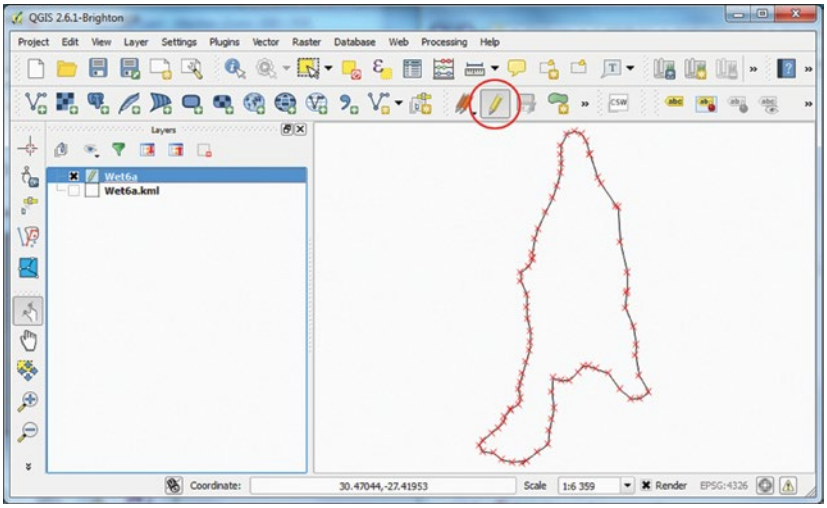
Don't forget to save your polygon. Make sure to save polygons as .kml NOT as .kmz.

Bringing wetland mapped in Google Earth into QGIS (version 1.10)

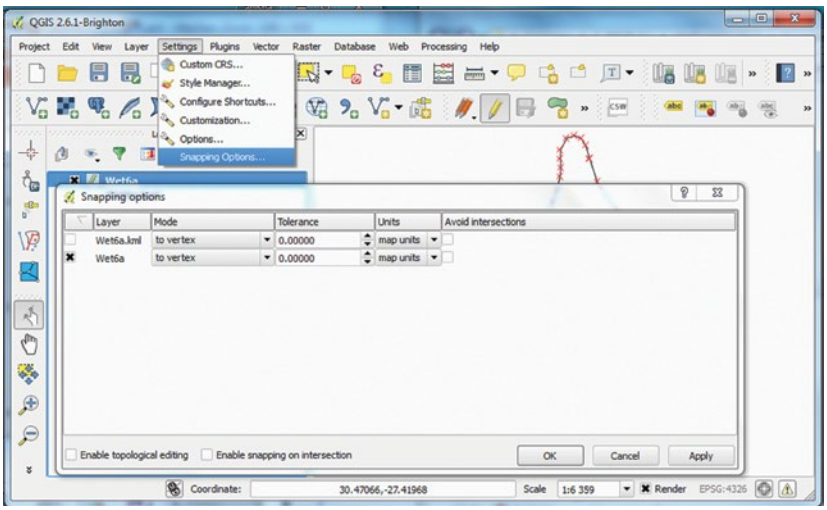
SCREENSHOT	INSTRUCTION
	It is easiest to delineate HGM units in a GIS program such as ArcMap or QGIS. The following steps outline how you would go about converting the files you created in Google Earth into shapefiles, which can then be cut into the respective HGM units using QGIS: Open a new project in QGIS. Click the 'add vector layer' icon.
	Browse to the. kml of the wetland and click the 'Open' tab. Right-click on the layer in the layers window and click the 'Save as' option.
	In the pop-up window, under format, change it from '.kml' to 'ESRI Shapefile'; save to desired destination, change CRS to 'Selected CRS' WGS 84. Click 'Add saved file to map'. Click 'Okay'.

Using QGIS to map wetlands

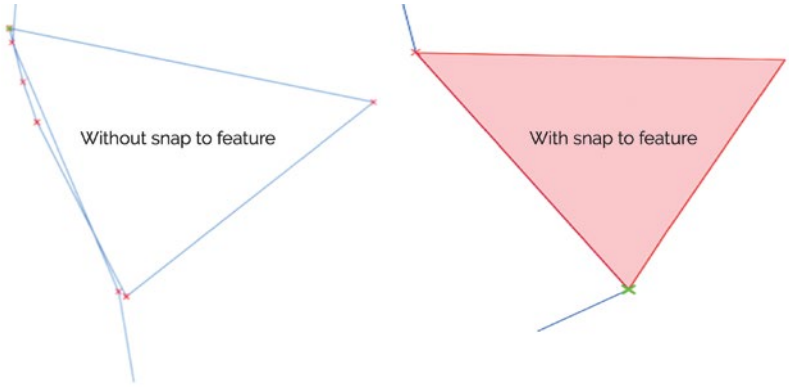
1. Zoom to the wetland.
2. Pan across the imagery of your wetland to identify the different HGM units. Hint: Use the 5m_contours to find where seeps and valley-bottoms occur.

SCREENSHOT	INSTRUCTION
	Click the 'Toggle Editing' icon and a pencil should appear under the layers window next to Wetland_1. You can then begin cutting the existing polygon into the respective HGM units. Remember to start the 'scissor' from outside the edge of the polygon you wish to cut.

Each polygon should now correspond to a new line in the attribute table. You can populate this table with the appropriate HGM unit. Once you have completed cutting and editing the table, click 'Save edits'. (If you do not have raster imagery to load into QGIS, then you may delineate the HGM units manually in Google Earth using the 'Add polygon' icon and then importing into QGIS. However, note that delineating in Google Earth has many limitations as the free version does not have several useful tools such as the 'cut' tool. This means that HGM units will have to be created as separate polygons. The 'snap to feature' tool is also not available; therefore, gaps may appear between polygons.) **TIP**: Populate the attribute table with data common to all the features that you will be delineating e.g. vegetation type. Also create the column for HGM units before you cut the polygon so that this information is carried through to each polygon without you having to re-type it.



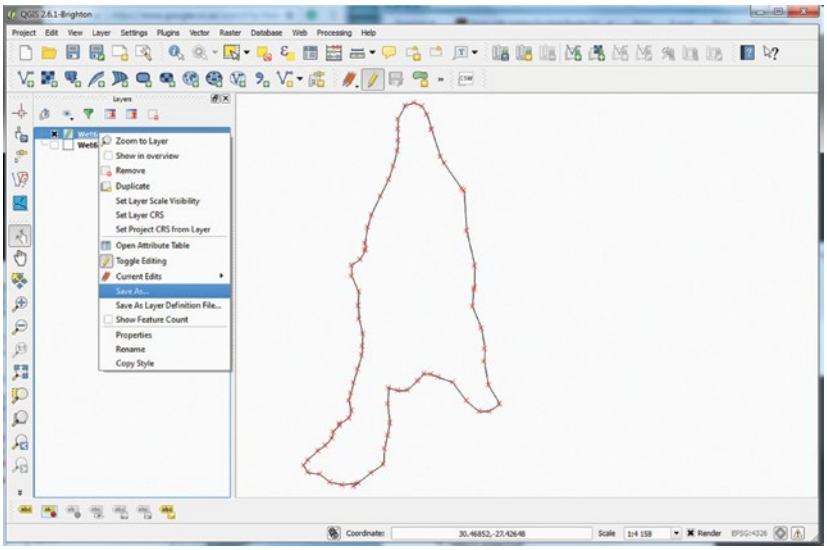
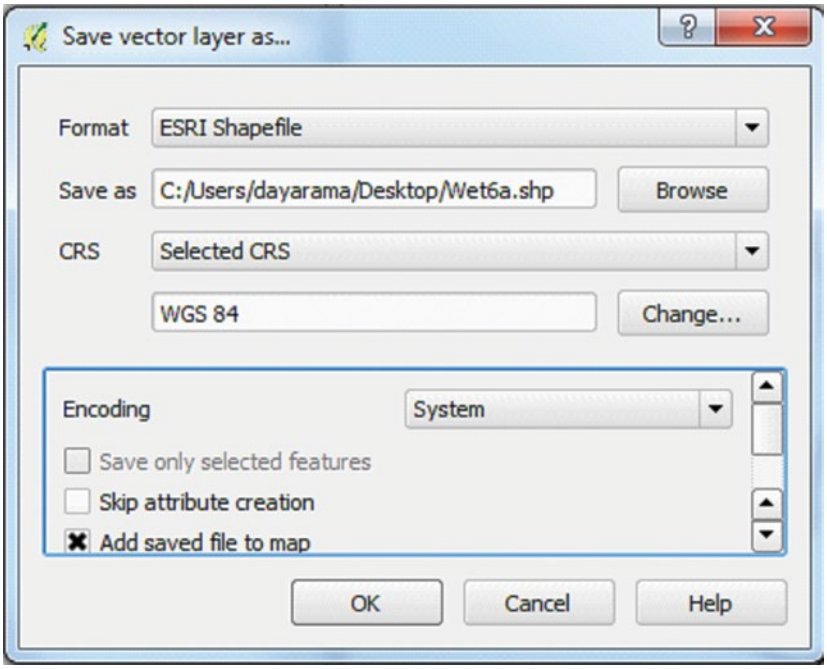
If you realise that you would like to add a part to the existing polygon, e.g. if you decide that a particular landscape feature is part of the wetland, you may do this using the 'Add feature' tool while in the toggle editing mode. To ensure that the lines of the new polygon you are adding lay adjacent to the original polygon, activate the 'Snapping options' before adding the feature. Click the 'Settings' tab in the menu. Then click 'Snapping options' and select the layer for which you wish to function to be active. In this case, we select the wetland layer. Change the Tolerance value to 0.0001.



Right-click on the wetland layer in the layers window. Select the 'Toggle editing' tab. Thereafter, click the 'Add feature' tab. You may now add your new feature. You will notice that the vertices that you add as you click will try to stick to existing vertices. The diagram to the left shows the difference between adding a feature with and without the snapping tool. You can then fill in the attribute data relating to your new polygon.

Identifying and delineating impacts on vegetation, hydrology and geomorphology

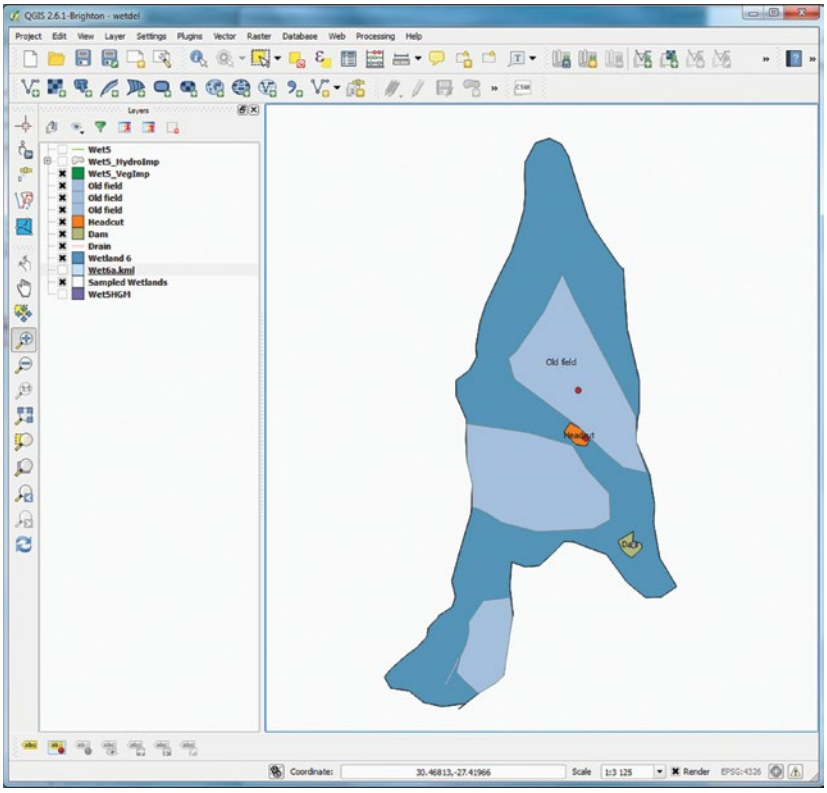
The easiest way to ensure that you divide the wetland into impact units while still keeping the same boundary is to make a copy of the wetland polygon and save it under another name, e.g. vegetation impacts. You can then click the 'Toggle editing' option and the cut tool to cut the polygon into each impact unit.

SCREENSHOT	INSTRUCTION
	To save a copy of the wetland polygon, right-click on the name of the wetland layer in the layers window and select the 'Save as' option.
	In the new window that opens, select 'ESRI Shapefile' under 'format' and choose an appropriate file destination and CRS. **TIP**: If you are working between Google Earth and QGIS, it is best to set the CRS of all layers to WGS1984 so that all layers share the same CRS. Tick the box which says 'Add saved file to map'. Click 'okay'.

You may want to edit the properties of the polygon so that the insides are not filled in order to see the imagery below.

Click the 'Toggle editing' mode on and you can now cut the wetland polygon into the relevant impact units.

In this example, several old fields can be recognised on the wetland (insert in red).



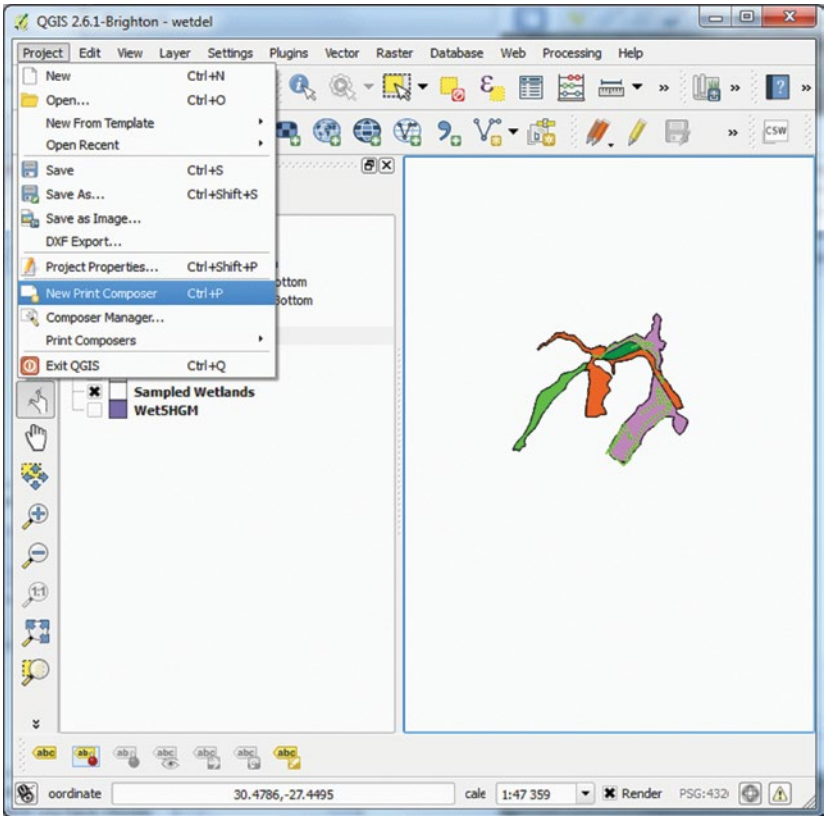
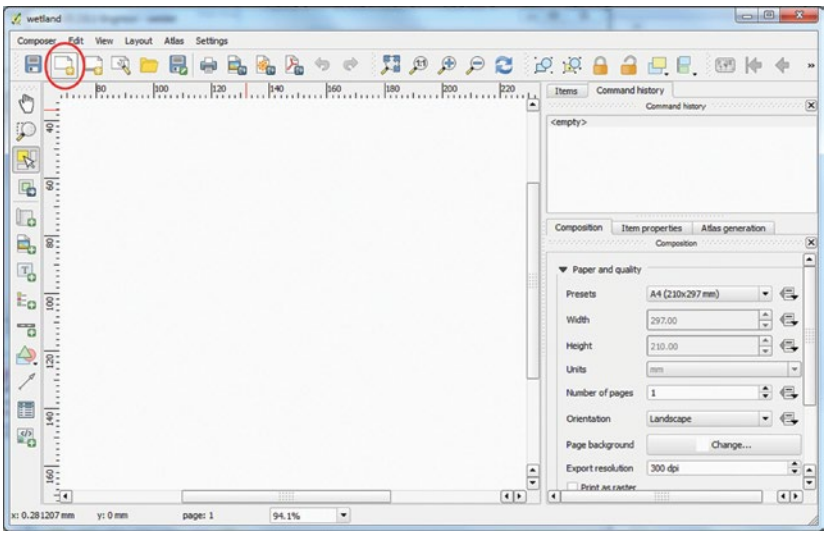
Cut these features out of the original shape and then name them according to their impact unit in the attribute table while still in the toggle editing mode. The features highlighted will be called 'Old fields'. Click 'Toggle editing' off.

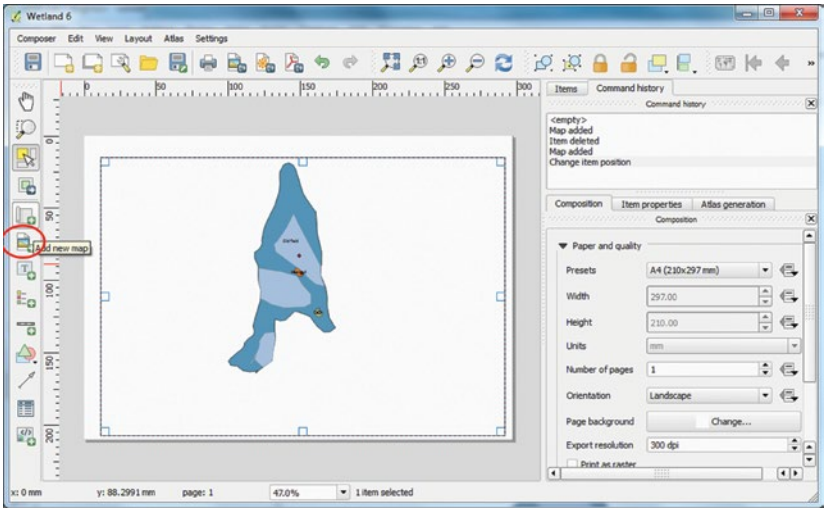
We then wish to view the impacts. Therefore, open the layer properties and change the 'Attribute settings' to 'Categories' as well as all the values, setting the field to the one under which you noted the name of the impact units.

You may then export a copy of the wetland polygon and repeat the process for impacts on hydrology and impacts on geomorphology.

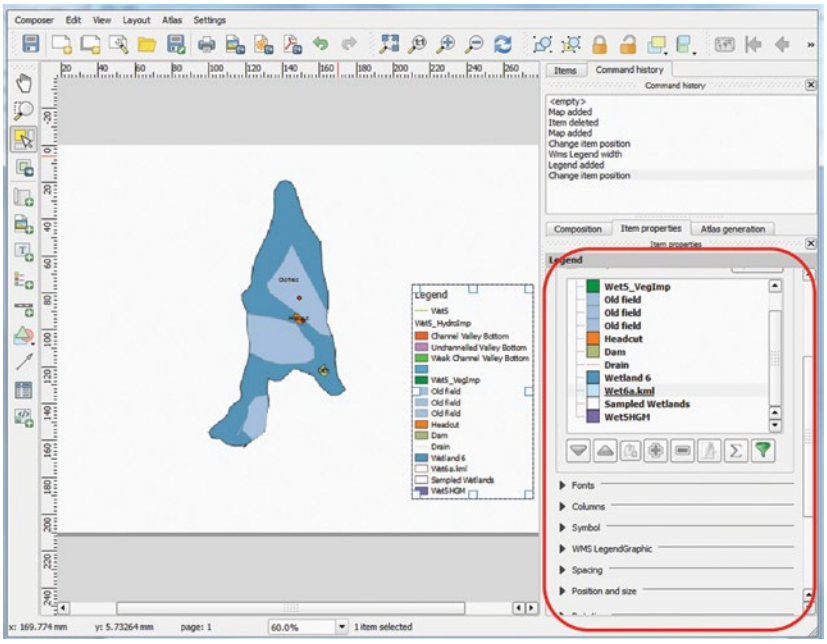
Displaying and exporting shapefiles into maps

You may wish to present the polygons that you created as maps or images for insertion into reports. There are several ways and formats in which to export maps as there are many options available with the various GIS software. In this exercise, one form of display will be shown in order to expose you to what is possible; however, you are encouraged to explore other options provided by the software.

SCREENSHOT	INSTRUCTION
	Once you are satisfied with your desktop delineation and the colours you have chosen to display the impact units you have identified, you may switch to the map creation view. In QGIS, navigate to 'File' > 'New print composer'.
	Once you have clicked enter, a new window will pop up named 'Composer 1'. In this new window, click the icon 'Add new map'.



You can then draw the extent of your map in the area provided and your polygons will be imported onto the screen in the composer. You may move your map to a suitable position on the screen and then click the 'Add legend', 'Add scale bar' and 'Add title' icons to add these features to your screen.



Click on each item and edit them in the 'Item properties' menu on the right-hand side of the composer window.

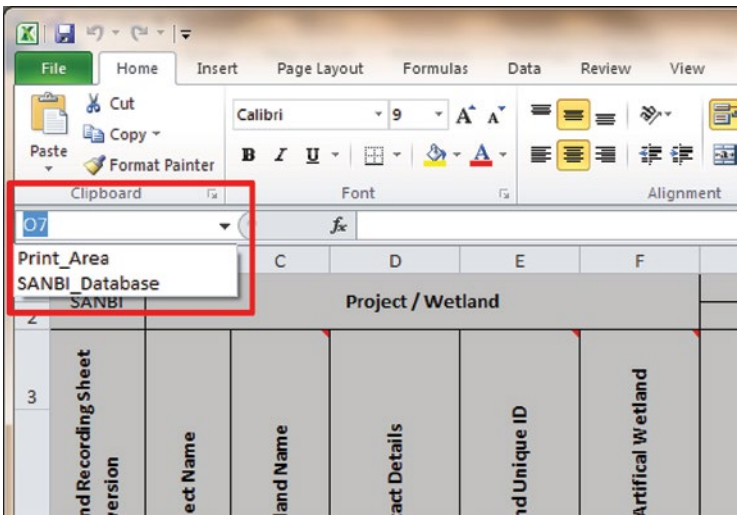
Once you have finished editing, click 'File' > 'Export as image' and save in an appropriate destination. You will now have a finished image showing the delineation of your wetland and associated impacts.

Appendix D:

Converting the MS Excel Spreadsheet to a database that can be used within a GIS environment

The following step-by-step guide details the process to convert a spreadsheet into a database format, which can be used within a GIS environment for reporting, analysis and mapping purposes (using ESRI's ArcGIS as an example).

Should you require more details on the tools within a GIS to load the recording sheet and link/join it to the map data, please refer to the appropriate software manual for details of the features and available functions.



Exporting the spreadsheet as a database

As the content needs to be made available within a GIS environment, the spreadsheet has been structured as a database to make it easier to use. The spreadsheet extent (cell ranges) can be defined as a named range defining all the rows and columns in the reporting sheet. Make sure that you select all the rows (all the records you have created) and all the headings when defining this range. A range is defined by selecting the records and then entering a name to uniquely name the specific range of cells in the spreadsheet. Please refer to the figure on the left for an illustration of the command used to name a range of cells.

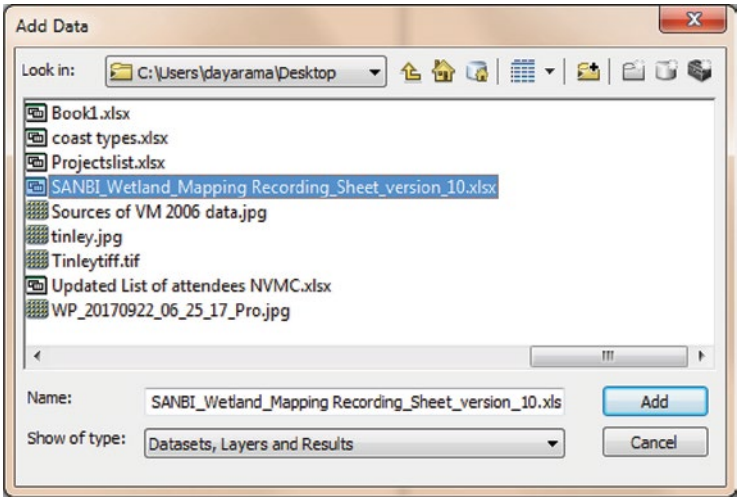
There are already two ranges defined, namely 'SANBI_Database' and 'Print_Area'.

Making the database available for use within a GIS system

When using older versions of MS Excel (i.e. 2003), one could export the spreadsheet to a database (DBF) file, which allows one to load it into most GIS packages as a descriptive or attribute table. This can then be linked to the physical mapping boundary data (i.e. wetlands polygons stored in an ESRI Shapefile) and used for mapping, reporting or analysis.

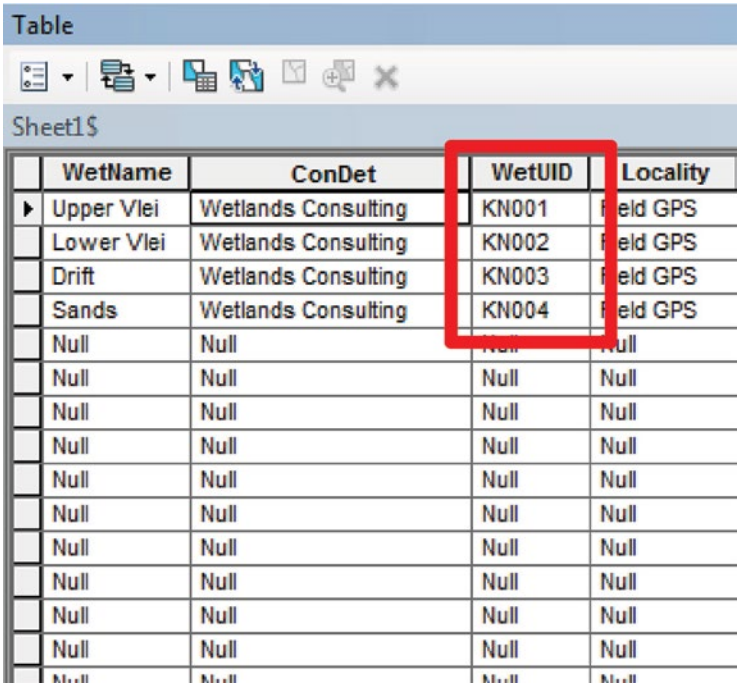
In the case of newer versions of MS Excel (i.e. 2010), one needs to access the data by loading the spreadsheet into the GIS package as it cannot be exported as a DBF file. The GIS software (i.e. ArcGIS) can either load the spreadsheet directly or can access it through a database connection.

This is also possible when using MS Excel 2003 files and is in some respects a more elegant solution as the user does not need to ensure that the correct version of the spreadsheet has been converted, as one works with the spreadsheet directly.



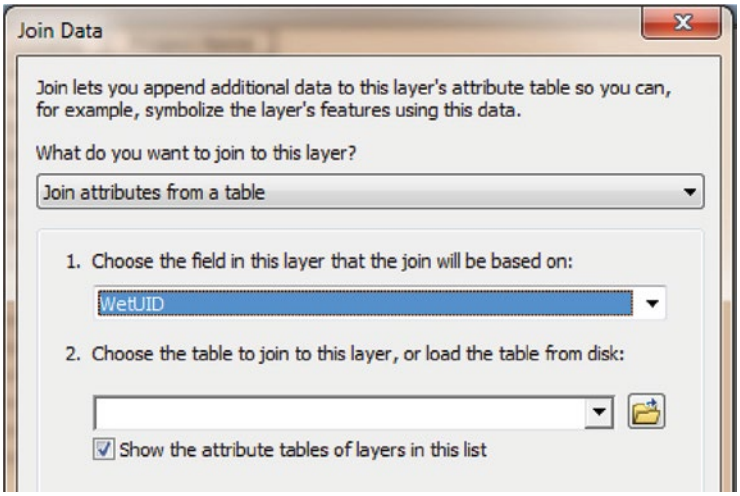
Loading the database into a GIS system

Where accessing the spreadsheet directly, the recording sheet with its named (defined) ranges and the reporting sheet (database) needs to be loaded directly into the GIS software as a feature table as illustrated the figure on the left. This is a simpler approach in some ways as this removes the requirement to first export the data to a DBF file.



Linking the recording sheet to the mapping data within a GIS system

The recording sheet, as implemented within MS Excel, reflects feature-level metadata for each of the mapped wetland units. Each record reflects information pertaining to a specific wetland area (unit) and is uniquely identified through a code (WetUID). This is a common key between the physical boundary definition as mapped in the GIS and the metadata recording sheet. This allows one to join the map and the recording sheet together to provide a coherent definition of the wetland and all its associated descriptive information.



By using the standard table 'join' functions within a GIS program such as ArcGIS, it is possible to link the map and the recording sheet together, thereby providing a coherent view of the wetlands as mapped in conjunction with their associated metadata.

The figure on the left illustrates the tool used to join two tables together within the ArcGIS environment. When the reporting sheet is joined to the map data it can be used to symbolise, query, analyse and report (thematic map) on the wetland data. This is where the data is the most useful and provides a decision-support platform.

Appendix E:
Checklist of tasks for mapping projects

Desktop preparation

Choose project extent and gather existing data:

- Clip existing and supporting GIS datasets to project boundary.
- Decide on a catchment to begin mapping.

Decide on project attributes (what information to record), prepare spreadsheets and field datasheets.

Decide on project mapping approach: modelling or heads-up digitising.

Spatial boundary (and hydrogeomorphic units):

- Review existing datasets and incorporate high confidence polygons.
- Generate new wetland data through remote sensing/modelling AND/OR use heads-up digitising for new wetlands, checking across multiple imagery sources (SPOT, Google Earth, aerial photo, various dates). Include a topology review of the data.
- Divide wetlands into draft hydrogeomorphic types.

Attributes:

- Review existing datasets and bring across any relevant attributes from any existing specialist mapping or other datasets.
- Allocate attributes, including HGM type, to newly mapped wetlands.

Final preparations:

- Review desktop mapping results (wetland boundaries and attributes) with team and identify questionable areas to visit in the field. Plan the most efficient route for visiting these sites during ground-truthing.
- Print out hard copy maps, datasheets and/or upload to digital devices for field.

Field work

- **Detailed site assessment:**
  - Walk through part or full wetland, take detailed plant and soil observations (with auger).
  - Choose accessible sites, representatives of each of the wetland types in the catchment, sites to help calibrate scoring of wetland impacts/condition across the catchment.
- **Rapid site assessment / Drive through catchment:**
  - Walk through part of wetland or view from vantage point, no soil observations, rapid plant observations.
  - Depending on time and accessibility, visit as many wetlands as possible, aim to understand the range of wetland types and condition across the catchment as well as to improve spatial boundary accuracy.

Spatial boundary (and hydrogeomorphic units):

- Verify or change existing boundary and HGM unit information on hard-copy map print-out or mobile device.
- Generate new data: GPS wetland boundary (detailed) OR take a GPS point (rapid) and estimate new boundary on hard copy map or adjust on mobile device.

Attributes:

- Detailed site assessment – fill out long datasheet, take photos.
- Rapid site assessment / drive through catchment – fill out short datasheet, take photos.

Desktop follow-up

Spatial boundary (and hydrogeomorphic units):

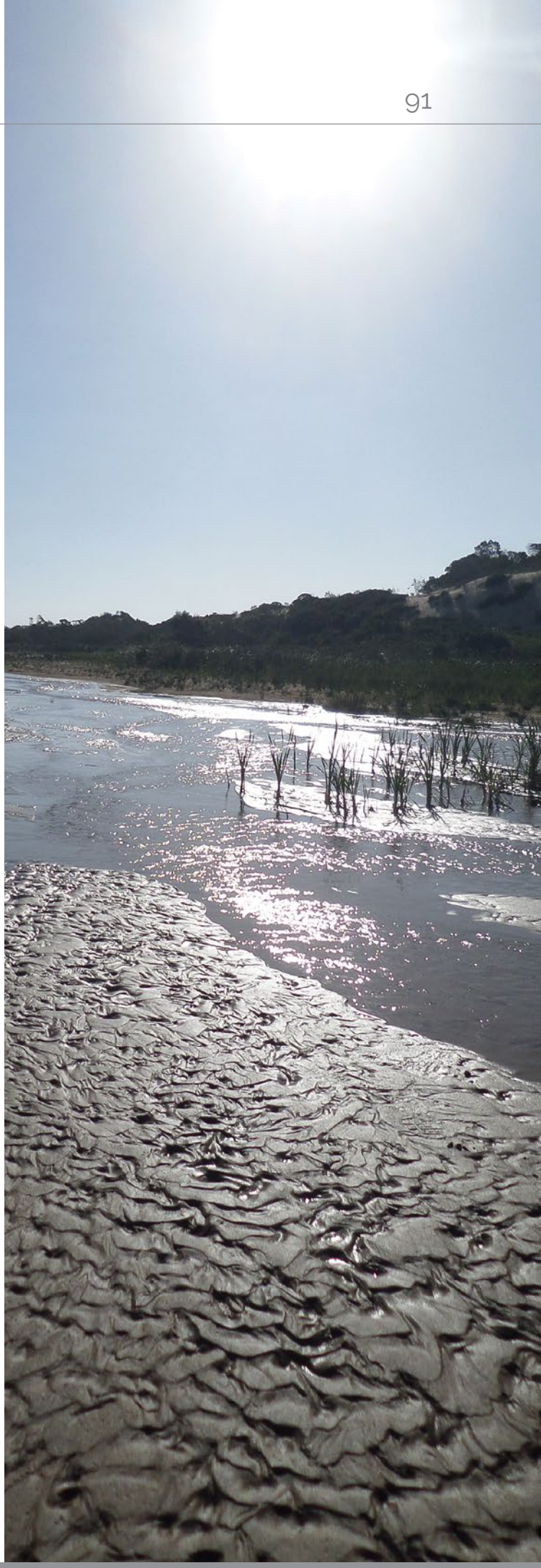
- Approach the GIS spatial update one quinary catchment at a time.
- Use new boundaries drawn in the field or from GPS to update in GIS the boundaries of all field-assessed wetlands (assign moderate to high confidence).
- Update in GIS all remaining wetland boundaries in the catchment based on general knowledge gained from field visits and catchment drive through (assign moderate to low confidence).
- Review and finalise the spatial division of wetlands into hydrogeomorphic units for all wetlands in the catchment.

Wetland attributes (HGM, condition, regional type):

- Enter GPS points and attribute data from long and/or short datasheets.
- Carry attribute information over to updated wetland polygons.
- Assign moderate to low confidence attribute information to all remaining polygons in the catchment based on knowledge gained from field visits and catchment drive through.

Quality control and expert review

- Review GIS topology.
- Review wetland boundary and attributes with team and local experts.



Appendix F:
Example field datasheet

Mpumalanga Wetland Ground-Truthing Field Form

Sub-WMA		**GPS co-ordinates***	
Quinary catchment #		**Date**	
Wetland name / id #		**Team**	NM NJ HM SM Other:
Photo numbers			
Confidence ☐ Assessment from a distance ☐ Walked part of wetland ☐ Walked through entire wetland			

**take gps where wet id unknown / at wetland boundary / adding new wetland / specific notes*

1. Confirm existing wetland boundary Y / N Adjusted Y / N

2. HYDRO-GEOMORPHIC (HGM) TYPE(S)

☐ Dam ☐ Seep ☐ Depression/Pan: SALT OPEN SEDGE GRASS REED FRINGE UNSURE					
☐ Valley Bottom: CHANNELLED UNCHANNELLED BOTH UNSURE ☐ Floodplain wetland ☐ Flat					
Position in landscape	☐ Slope ☐ Plain (flat) ☐ Valley bottom				

3. WETLAND HEALTH

Dominant water source(s). *(for health score, consider if impacted or natural)*	☐ River ☐ Overland flow ☐ Hillslope interflow / shallow groundwater ☐ Groundwater *(permanently wet?)* ☐ Rain ☐ Unsure				
Observed land use and disturbances that may affect catchment and wetland vegetation and hydrological functioning:					
Dam	Grazing	Cultivation	Brick making	Abstraction	Plantation
Old land	Drain/s	Dumping/infilling	Mining	Bridge	Road
Invasive plants	Cattle trampling	Erosion	Vegetation clearing	Other:	
Notes: to help with final wetland health score, consider the percent area affected by the above land use/disturbances on a scale of 1-5 where 1= **Less than 10%;** *2=***10% - 25%;** *3=***25%- 50%;** *4=* **50%-75%;** *5=***75%-100%**					

FINAL WETLAND HEALTH SCORE

Hydrology										PES	*Notes: one score for entire wetland; 0 is natural, 10 is heavily impacted*
1	2	3	4	5	6	7	8	9	10		*Hydrology score reflects impacts within wetland and its catchment –is quantity, timing or flow impacted into, through or out of wetland?*
Vegetation											*Vegetation score reflects impacts within wetland only*
1	2	3	4	5	6	7	8	9	10		*PES = average of hydrology/vegetation where A=1 unmodified B=2; C=3-4 moderate; D=5-6 largely modified; E=7-8; F=9-10 critically modified*

4. REGIONAL WETLAND TYPE

Soil texture	☐ Peat ☐ Black/high organic ☐ Loam ☐ Clay ☐ Sand ☐ Silt/mud ☐ Bedrock						
Observations: dense clay / bedrock / gley colours / mottles / oxidised roots Depth within soil pit_____cm							
Hydroperiod	☐ Unsure *Note: soil/plants help indicate hydroperiod; Intermittent =<3 months; Seasonal >3 months*						
Inundation	Intermittent	Seasonal	Permanent	**Saturation**	Intermittent	Seasonal	Permanent

Dominant and Indicator wetland plants

ARNE Arundinella nepalensis OBL / G	MIJU Miscanthus junceus FACW / G	
CYER Cyperus eragrostis OBL / S	NYTH Nymphoides thunbergii OBL / A	
CYMA Cyperus marginatus OBL / S	PHAU Phragmites australis OBL / R	
IMCY Imperata cylindrica OBL / G	SCBR Schoenoplectus brachyceras OBL / S	
JUEF Juncus effusus OBL / S	SCMU Schoenoplectus muriculatus OBL / S	
JUEX Juncus exsertus OBL / S	SCFI Scirpus ficiniodes OBL / S	
JULO Juncus lomatophyllus OBL / S	TYCA Typha capensis OBL / R	
JUOX Juncus oxycarpus OBL / S	XYNA Xyris natalensis OBL / Herb	
LEHE Leersia hexandra OBL / G		

Where plant species names are unknown: ☐Sedges[S] ☐Grasses[G] ☐Reeds[R] ☐Aquatic[A] ☐Other

OBL [obligate] = always (100%) in wetland; FACW [facultative wetland]= 60-99%; + FAC [facultative] = 50% in wetland

Notes

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Wetlands provide important ecosystem services in both rural and developed parts of South Africa, but are one of the country's most threatened habitats. Therefore, there is a need to understand, conserve and restore them. Repeatable standards and accurate methods for collecting data can help achieve these goals. The purpose of this manual is to act as a resource to all wetland practitioners so that data collected can contribute to national and local projects through a standard and strategic process.

This manual is a tool for wetland practitioners, at all levels, to improve procedures for mapping wetlands using a set of standards for data collection and storage, so that data feeds into national level databases such as the National Wetland Inventory, and informs national policy tools such as National Freshwater Ecosystem Priority Areas.

The manual begins with an explanation of what a wetland is, and the different types of wetlands that one may encounter in the South African landscape. It then outlines an approach for designing a wetland mapping project and capturing data that has been tested and refined by several experts in the discipline. This section is followed by tips on recognising, digitising and classifying wetlands and human impacts on wetlands from desktop imagery and in the field. Examples of wetlands that have been mapped and classified are provided with searchable co-ordinates to enable the user to locate the wetland using a geobrowser such as Google Earth and further explore it from various angles.

Several additional tools such as datasheets and checklists are provided. A step by step guide to basic delineation using free and licensed mapping software is shared in the appendices.

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