National Biodiversity Assessment 2018

SOUTH AFRICAN INVENTORY OF INLAND AQUATIC ECOSYSTEMS (SAIIAE)

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A list of meetings held for the work leading to the production of this technical report of NBA 2018 can be found as Appendix A.

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Minutes of meetings held by the WECC and RECC are held by SANBI. Please contact Mrs Carol Poole should you wish to gain access to these records. Key decisions taken, relevant to the South African Inventory of Inland Aquatic Ecosystems (SAIIAE), are listed in Appendix A.

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LIST OF ACRONYMS

AEA	Albers Equal Area
ARC	Agricultural Research Council
ARC-ISCW	Agricultural Research Council: Institute of Soil, Climate and Water
C.A.P.E.	Cape Action for the Protection of the Environment
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEAT	(Former National) Department of Environmental Affairs and Tourism
DEM	Digital Elevation Model
DRDLR:NGI	Department of Rural Development and Land Reform: Directorate National Geo-spatial Information
DWAF	(Former National)Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECC	Ecosystem Classification Committee
EFZ	Estuarine Functional Zone
EIA	Environmental Impact Assessment
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
EPL	Ecosystem Protection Level
ESRI	Environmental Systems Research Institute
ETS	Ecosystem Threat Status
FCG	Freshwater Consultancy Group
FS DESTEA	Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs
GDE	Groundwater Dependent Ecosystems
GEF	Global Environment Facility
GIEMS	Global Inundation Extent from Multi-Satellites
GIS(s)	Geographical Information System(s)
GISc	Geo-Information Science
GPS(s)	Global Positioning System(s)
GTI	GeoTerra Image Pty Ltd
HGM	Hydrogeomorphic (wetland type(s))
ICLEI	International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability
LDEDET	Limpopo Department of Economic Development, Environment & Tourism
LiDAR	Light Detection and Radar
MTPA	Mpumalanga Tourism and Parks Agency
NEMBA	National Environmental Management: Biodiversity Act
NFEPA	National Freshwater Ecosystems Priority Areas
NLC	National Land Cover
NBA	National Biodiversity Assessment
NC DENC	Northern Cape Department of Environment and Nature Conservation
NECC	National Ecosystem Classification Committee
NEMP	National Eutrophication Monitoring Programme
NLC	National Land Cover
NRF	National Research Foundation
NWA	National Water Act
NWCS	National Wetland Classification System
NWI	National Wetland Indaba
NWM	National Wetland Map
NWVD	National Wetland Vegetation Database
PES	Present Ecological State
RECC	River Ecosystem Classification Committee
SAIIAE	South African Inventory of Inland Aquatic Ecosystems
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks

SANBI	South African National Biodiversity Institute
SAEON	South African Earth Observation Network
SASDI	South African Spatial Data Infrastructure
SKA	Square Kilometre Array
SPOT	*Satellite Pour l'Observation de la Terre*
SQ4	Sub-quaternary catchment
SWSA	Strategic Water Source Areas
UFS	University of the Free State
UKZN	University of KwaZulu-Natal
UNIVEN	University of Venda
USAID	United States Agency for International Development
UWC	University of the Western Cape
WCS	Wetland Consultancy Services Pty Ltd
WECC	Wetland Ecosystem Classification Committee
WGS84	World Geodetic System of 1984 (spheroid and datum)
WRC	Water Research Commission
WTW	Water Treatment Works
WWTW	Wastewater Treatment Works

LIST OF ACRONYMS USED FOR PROVINCES

EC	Eastern Cape
FS	Free State
GT	Gauteng
KZN	KwaZulu-Natal
LP	Limpopo
MP	Mpumalanga
NC	Northern Cape
NW	North West
WC	Western Cape

GLOSSARY OF TERMS

Artificial waterbodies / artificial wetlands: include terrestrial and aquatic ecosystems which have been modified by humans to varying degrees either within or in the vicinity of aquatic ecosystems. Such data sets may include point or polygon data on the extent and distribution of for example artificial wetlands, aquaculture facilities, bridges, canals, excavations, railways, reservoirs, roads, salt works, sand mining, treatment works and weirs.

Aquatic ecosystems: 'an ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis et al., 2013:94)

Biodiversity: 'The diversity of genes, species and ecosystems on Earth, and the ecological and evolutionary processes that maintains this diversity' (SANBI, 2016:5)

Classification: refers to the categorisation of watercourses according to their resource quality objectives as per Chapter 3 of the National Water Act (RSA, 1998:13).

Commission error: for the purpose of this report, terrestrial areas mapped as wetlands.

Coordinate system used for data: is the South African Albers Equal Area conical projection with the central meridian at 25°E, parallels at 24°S and 33°S and the spheroid and datum the World Geodetic System of 1984 (WGS84).

Floodout: 'Lobate/fan-shaped sediment body that radiates downstream from an intersection point of a discontinuous channel. Typically comprise sandy materials immediately downstream of the intersection point, but may terminate in swamps or marshes as fine-grained sediment accumulates downstream.' Brierley and Fryirs (2005: 113).

Groundwater: 'subsurface water in the saturated zone below the water table' (DWAF, 2008:9).

Inland Aquatic Ecosystems: 'an ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis et al., 2013) and which occurs inland and is not estuarine or marine in nature.

Lacustrine: (non-vegetated wetlands) 'Relating to a system of inland deep-water and wetland habitats associated with lakes and reservoirs and characterized by the absence of trees, shrubs, or emergent vegetation.' (Collins English Dictionary – Complete and Unabridged, 12th Edition 2014 © HarperCollins Publishers 1991, 1994, 1998, 2000, 2003, 2006, 2007, 2009, 2011, 2014; https://www.thefreedictionary.com/lacustrine).

Lakes: 'are depressions in the valley bottoms which may be temporarily, seasonally or permanently inundated. Unlike pans, they are not deflationary erosional features, but instead they have, or would have had, an outlet at the downstream end of the valley (a low point); which has been variously blocked or otherwise restricted by dune deposits; terminal moraines (e.g. Lake District; U.K.), landslides or other depositional features across the valley bottom. Their shape is therefore determined by the surrounding slopes/higher ground (in contrast to the deflational processes creating the typical circular or oval depressional pan shapes)'' (DWAF, 2008:20).

Limnetic: '(*cf*. littoral) inundated to a maximum depth of 2 m or more at the average annual low-water level of an open waterbody '(Ollis et al., 2013)

Littoral: '(*cf*. limnetic) inundated to a maximum depth of less than 2 m at the average annual low-water level of an open waterbody '(Ollis et al., 2013)

Omission error: for the purpose of this report, wetland areas not mapped in a NWM.

Palustrine: (vegetated wetlands) 'Relating to a system of inland freshwater wetlands, such as marshes, swamps, and lake shores, characterized by the presence of trees, shrubs, and emergent vegetation.' (Collins English Dictionary – Complete and Unabridged, 12th Edition 2014 © HarperCollins Publishers 1991, 1994, 1998, 2000, 2003, 2006, 2007, 2009, 2011, 2014; https://www.thefreedictionary.com/palustrine).

Riparian habitat: 'includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas' (RSA, 1998:9).

Rivers: a linear inland aquatic ecosystem with clearly discernible bed and banks, which permanently or periodically carries a concentrated flow of water. A river is taken to include both the active channel and the riparian zone as a unit (Adapted from Ollis et al., 2013:100).

Strategic Water Source Areas: "Strategic Water Source Areas (SWSAs) are defined … as areas of land that either: (a) supply a disproportionate (i.e. relatively large) volume of mean annual surface water runoff in relation to their size and so are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b)." (Le Maitre et al., 2017:17).

Sub-quaternary catchments (SQ4s): A fifth level of catchment division which has been derived in South Africa from a 50 m spatial resolution Digital Elevation Model (DEM) for the National Freshwater Ecosystems Priority Areas (NFEPA) project (Nel et al., 2011). The Department of Water and Sanitation (DWS) uses this data set for their Present Ecological State (PES) assessments issued in 2011. See also Quinary.

Typing of Inland Aquatic Ecosystems: refers to the categorisation of ecosystems according to the Classification System for wetlands and other Aquatic Ecosystems in South Africa.

Quinary: A fifth level of catchment division which has been derived in South Africa from the 90 m spatial resolution DEM which was hydrologically corrected from the original Shuttle Radar Topography Mapper (SRTM) DEM. A similar procedure to the SQ4s were used, however the boundaries of the updated quaternary catchments from WRC Report No. 1908/1/11 (Weepener et al., 2012) were used to constrain the calculation. (Maherry et al., 2013. WRC Report No. 2020/1/12). See also Sub-quaternary catchments (SQ4s).

Washes: a term used in the arid and semi-arid regions which refers to the broad, gravelly, normally dry bed of an intermittent stream (derived from Bates and Jackson, 1987:730, Glossary of Geology). A wash is a type of floodout.

Watercourses: 'Watercourses' includes both the channel and banks of all rivers, springs, and natural channels 'in which water flows regularly or intermittently' (RSA, 1998:9).

Wetlands: 'means land which is transitional between terrestrial and aquatic systems 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 to life in saturated soil' (RSA, 1998:9).

Wetland delineation: 'the determination and marking of the boundary of a wetland… [and] … marking the outer edge of the temporary zone of wetness' (adapted from DWAF, 2008:11). In this document the term is used to refer to both in field and desktop delineation.

References for the Glossary:

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EXECUTIVE SUMMARY

A South African Inventory of Inland Aquatic Ecosystems (SAIIAE) was established during the National Biodiversity Assessment of 2018 (NBA 2018). The SAIIAE offers a collection of data layers pertaining to ecosystem types and pressures for both rivers and inland wetlands.

The SAIIAE builds on previous efforts while also introducing improvements and several new elements. An inventory of inland aquatic ecosystems responds to a multi-stakeholder need for the planning, conservation and management of these systems, as mandated by a number of legislative Acts, including the South African National Water Act (NWA) and the National Environmental Management: Biodiversity Act (NEMBA). This report provides a full overview of historical efforts in the inventorying of inland aquatic ecosystems, as well as efforts undertaken between 2015 and 2018 in the update of data layers associated with river and inland wetland ecosystem types for the NBA 2018.

Key highlights

- A South African Inventory of Inland Aquatic Ecosystems (SAIIAE) have been established as a collection of data layers that represent the extent of river and inland wetland ecosystem types as well as pressures on these systems.
- The extent of inland wetland ecosystems have been increased by 123% compared to the NFEPA wetlands.
- Eight unique limnetic depressions (lakes) have been identified.
- A confidence map of inland wetlands guides users to appropriate use of the map.

Key findings

- Inland Aquatic ecosystems are represented by a river lines data set as well as polygons of river and inland wetland types in NWM5. Both data sets should be used to represent inland aquatic ecosystems.
- NWM5 represents nearly 4 million hectares (ha) of aquatic ecosystems which cover 3.3% of the surface area of South Africa. These include:
    - Inland wetlands which constitutes > 2.6 million ha or 2.2% of the surface area of South Africa;
    - > 1 million ha of river channels; and
    - 201 381 ha of estuarine ecosystems (<0.2% of the surface area of South Africa).
- The rivers data set represent 200 955 km of river length of which 164 018 km (82%) is situated within South Africa. The majority of the rivers in South Africa (90%) has a river ecosystem types assigned; 10% are ephemeral and episodic systems within the arid Northern Cape Province and <0.1% coincide within an estuary. Mainstem rivers constitute 76 830 km (47%) of the total length of the South African rivers, and tributaries 87 188 km (53%).
- Eight limnetic depressions (lakes) have been identified where the depth of the water-level at low tide is > 2 m. These system constitute 13 376 ha of which Lake Sibayi is the largest.
- Artificial wetlands have been mapped as a separate layer, totalling almost 600 000 ha.

List of Limnetic depressions (lakes) of South Africa:

Name	Extent (ha)	Percentage of the total extent of limnetic depressions
Barberspan	1 720.6	12.9
Chrissiesmeer	1 282.6	9.6
De Hoop	949.3	7.1
Groenvlei	357.3	2.7
Lake Banagher	184.5	1.4
Lake Fundzudzi	192.3	1.4
Lake Sibayi	8 360.1	62.5
Tevredenpan	329.2	2.5
Total extent	13 376.0	

Knowledge gaps

- Address uncertainties pertaining to the conceptual ecosystem types implemented and species biodiversity observed.
- Inland aquatic ecosystems in the arid region are poorly understood. In the rivers data layer these are typed as ephemeral and episodic rivers. In the NWM a high uncertainty of the hydrogeomorphic typing is associated with these systems. Further work should be done to better define and distinguish water courses, floodouts and washes in these regions.

Key Messages

- Baseline data related to inland aquatic ecosystems are crucial for planning, conservation and management of inland aquatic ecosystems. Currently the baseline data sets provide a poor representation of inland aquatic ecosystem types, as well as their pressures and impacts. The inland wetlands, for example, showed a 69% low confidence for representing the extent of ecosystems, with an estimated 50% omission error. Confidence and accuracies of other data layers, such as rivers and artificial wetlands, are deficient.

Priority actions

Institutional collaboration across all organisations and stakeholders for the improved understanding, mapping, conservation, monitoring and management of inland aquatic ecosystems should be established and sustained. Responsibilities related to ecosystem data sets should be listed by relevant data custodians under the South African Spatial Data Infrastructure (SASDI) Act.

- Research priorities:
    - Improve understanding of the relationship between the ecosystem types and species biodiversity.
    - Improve understanding and classification of watercourses, particularly in arid systems.
    - Broad regional representation of Level 2 of the Classification Systems should be informed by analysis of relevé data from the National Wetland Vegetation Database (Sieben, 2015).
    - Improvement of the extent of river and inland wetland ecosystem type.
    - Improved national modelling and monitoring of inland wetlands across long-term hydrological regime cycles. This will improve our understanding of ecosystem types and

    their functions. Currently Geographical Information Systems (GISs) are used for once-off prediction of extent, types and condition. Time-series should be considered in such modelling. The improvement of freely available remote sensing images at finer scale
    - Methods of accuracy assessment of the extent and types of inland aquatic ecosystems at various scales.
- Collation of species data, particularly macro-invertebrate data (Nel and Driver, 2012)
- Improved understanding between the association of ecosystem services and ecological infrastructure with ecosystem types (adapted from Nel and Driver, 2012).

The following chapters provide relevant detail to this summary:

- Chapter 1: Introduction and overview of the SAIIAE
- Chapter 2: The origin and improvement of the rivers data set for the NBA 2018
- Chapter 3: The origins of the National Wetland Map of South Africa
- Chapter 4: The results of the update of National Wetland Map 5
- Chapter 5: Probability modelling of wetlands for South Africa
- Chapter 6: Evaluation of the watercourse probability map for supplementing the National Wetland Map
- Chapter 7: Conclusions and Recommendations

1. CHAPTER 1: THE DEVELOPMENT OF A SOUTH AFRICAN INVENTORY OF INLAND AQUATIC ECOSYSTEMS

Chapter Citation: Van Deventer, H. 2018. Chapter 1: The Development of a South African Inventory of Inland Aquatic Ecosystems. South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

This chapter is compiled and expanded from a number of other publications including:

- *Van Deventer, H.; Smith-Adao, L.; Petersen, C.; Mbona, N.; Skowno, A.; Nel, Jeanne L.2018 Review of available data for a South African Inventory of Inland Aquatic Ecosystems (SAIIAE). WaterSA, 44(2):184 – 199. http://dx.doi.org/10.4314/wsa.v44i2.05*

This chapter provides an overview of the original mapping of hydrological features and aquatic ecosystems in South Africa since the 1940s, and subsequent development of directories of aquatic ecosystems since the late 1980s. The National Freshwater Ecosystem Priority Areas (NFEPA) project of 2011 marked the first milestone where both rivers and wetlands were typed into ecosystem types at a country-wide scale. This supported the conservation planning outputs of NFEPA, and the National Biodiversity Assessment (NBA), in 2011. The first South African Inventory of Inland Aquatic Ecosystems (SAIIAE) now builds on these previous efforts and expands the directory to a wider representation of watercourses, and additional information for the purpose of inventorying, assessment and planning. An update of the Classification System and terminology is given, as well as unique ecosystem types identified for wetlands.

1.1 The history of the development of a directory and map of freshwater ecosystems

The South African National Water Act (NWA), Act 36 of 1998 (RSA, 1998), provides governance to ensure equitable rights, use and protection of water resources in South Africa. The Department of Water and Sanitation (DWS) is the primarily implementing and governing agency of the NWA. The condition of the aquatic ecosystems in terms of quantity and quality is addressed through the classification of water resources in which resource quality objectives are defined. The NWA includes all watercourses, surface water, estuaries and aquifers as water resources governed by the Act. ‘Watercourses’ includes both the channel and bands of all rivers, springs, natural channels ‘in which water flows regularly or intermittently’ (RSA, 1998:9), wetlands, lakes or dams. Definitions are provided for aquifers, riparian habitats and wetlands (Box 1).

Box 1: Selective definitions of terms related to Inland Aquatic Ecosystems from the National Water Act (1998: 8-9)

(i) ``aquifer'' means a geological formation which has structures or textures that hold water or permit appreciable water movement through them;

(xxi)``riparian habitat'' includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas;

(xxix)``wetland'' means land which is transitional between terrestrial and aquatic systems 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 to life in saturated soil.

In addition to the NWA and the National Environmental Management: Biodiversity Act (NEMBA), Act 10 of 2004 (RSA, 2004), provides for the management, planning, monitoring and conservation of the biodiversity associated with water resources, whether ecosystems or species. The South African National Biodiversity Institute (SANBI) is the implementation agency responsible for monitoring and reporting on the status of biodiversity in South Africa.

In response to both the NWA and NEMBA, an inventory of all water resources, including information related to the quantity, quality, use, biodiversity and protection of water resources, is required. International definitions of the term ‘inventory’, especially as related to water resources have been primarily defined in the ecological domain, and include multiple components required for supporting monitoring, assessment and planning (Finlayson and Spiers, 1999; Finlayson et al., 1999). A ‘directory’, in contrast, is considered merely a list of, for example, wetland ecosystems and their coordinates. Components of an inventory may therefore be more than just a list or spatial map of the water resources and would include information on (compiled from Finlayson and Spiers, 1999):

- Supra-habitat / System (e.g. estuarine, lacustrine, marine, fresh)
- Habitat (e.g. saltmarsh, peat, mangrove)
- Floral/faunal groups (orders or taxa; migration and nesting behaviour or sites)
- Climate
- Impacts (land use, invasives, pollution)
- Function
- Hydrology (e.g. hydroperiod)
- Biodiversity value(s)
- Cultural value(s).

Owing to the multitude of components in an inventory, it may well be that the components are stored in multiple databases in a variety of formats. Aspects of water resources and related biodiversity are governed by more than one Act and government departments in South Africa. It follows that it will require a diversity of institutions to compile and coordinate a thorough inventory of water resources.

The mapping of hydrological features of South Africa, including rivers, waterbodies and springs, have been done since the 1940s by the South African Surveys and Mapping Directorate of the Department of Land Affairs. These data sets are updated every three years and still form a significant spatial representation of water resources in the country (Van Deventer et al., 2018). The Department of Water Affairs and Forestry (DWAF) has historically ensured that the 1:500 000 and 1:50 000 rivers data from Surveys and Mapping are hydrologically correct and reach codes were calculated for the 1:500 000 rivers data set. Hydrological features as mapped by the current Department of Rural Development and Land Reform: Directorate National Geo-spatial Information (DRDLR:NGI), is considered a core data set for South Africa under the Spatial Data Infrastructure Act, Act 54 of 2003. Attribute information includes the seasonal variability of the water resources (perennial, non-perennial or dry) and names of the features.

Features listed in the NWA are, however, not completely represented by the topographical hydrological data. Not only are wetlands partially represented, estimated at less than 54% of what can be mapped by a wetland specialist at local scale (Mbona et al., 2015; Schael et al., 2015; Van Deventer et al., 2016; Melly et al., 2016), but the spatial extent of river channels are inadequate for fine-scale planning, while features such as aquifers and riparian habitats are poorly represented. Further work was required to improve these base layers from how they are served to the public by the above institutions, in order to use rivers in hydrological modelling and to develop river and wetlands data into ecosystem types for response to the NEMBA.

Directories of the diversity of aquatic ecosystems in South Africa date back to the early 1970s and 1980s (Noble and Hemens, 1978; O'Keeffe, 1986). Subsequently, the Department of Environmental Affairs and Tourism (DEAT) compiled directories in the late 1990s (Cowan and Van Riet, 1998). Since 2004, SANBI has been involved in the update of the National Wetland Map (NWM) and the rehabilitation of wetlands through the Working for Wetlands Programme of DEAT. The use of spatial data and Geographical Information Systems (GISs) has become prevalent since the mid 1990s, supporting improved spatial representation and analysis of water resources and their associated biodiversity. This allowed river ecosystem types to be included in South Africa's first National Spatial Biodiversity Assessment of 2004. River types were modelled using a combination of attributes from DRDLR:NGI and DWAF (Nel et al., 2004). The former DWAF and current Department of Water and Sanitation (DWS) has been supplementing the major river systems (1:500 000 scale rivers data set) with information on the condition of the water resource. This partially fulfils the needs of an inventory for the NWA and enables the assessment of river ecosystems in a NBA for the NEMBA.

More recently, a Water Research Commission (WRC) project funded a project to investigate the development of a draft National Wetland Classification System (NWCS) following previous work done internationally and locally (Ewart-Smith et al., 2006). The NWCS was subsequently adopted by SANBI as a policy document (SANBI, 2009). The typing of wetland ecosystems for the purpose of conservation planning of freshwater ecosystems in South Africa was applied in the National Freshwater Ecosystems Priority Areas (NFEPA) project (Nel et al., 2011). The NFEPA wetland types, as well as the river ecosystem types, were used for the first time in the assessment of the threat status and protection levels of freshwater ecosystems at a national scale in the NBA 2011. During the same period of time, the NFEPA wetlands were also used for classification in Reserve Determination, a requirement of the NWA which, until that time, had not been possible to achieve spatially. Although neither of the data sets constituted a complete inventory of water resources or aquatic ecosystems, the effort has drawn much attention to the challenges associated with completeness and accuracy of representation of these data sets in response to the NWA and NEMBA. The momentum gained after 70 years of mapping hydrological features, and more than 30 years of attempting to classify ecosystems, with ecosystem typing finally being enabled through GIS, has resulted in a growing number of users and professionals interested in the improvement of water resources in South Africa. The NFEPA project, therefore, serves as an enabling bench-mark. From this grew a robust inventory that can be used in planning and assessment.

1.2 The South African Classification System of Inland Aquatic Ecosystems

In a recent update of the NWCS, under the new name *Classification System of wetlands and other aquatic ecosystems* (hereafter referred to as the Classification System), an 'aquatic ecosystem' is defined as 'an ecosystem that is permanently or periodically inundated by flowing or standing water; or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis et al., 2013:1). Aquatic ecosystems include 'rivers; lakes, ponds, dams and other waterbodies; estuaries; and (shallow) marine systems' (Ollis et al., 2013:1). The system divides aquatic ecosystems into three broad systems, being Inland, Estuarine and Marine Systems. The Classification System adopts a tiered/hierarchical structure, with Inland Systems being divided in several ways from the upper to the lower levels:

- the ecosystem context at Level 2 (regional setting) and Level 3 (landscape units);
- the functional unit at Level 4 (hydrogeomorphic unit) and Level 5 (hydrological regime); and
- descriptive characteristics at Level 6.

At functional unit Level 4, the Classification System lists 6 hydrogeomorphic (HGM) units, namely, channelled valley-bottoms, depressions, floodplains, seeps, unchannelled valley-bottoms and wetland flats. Valley-head seeps and seeps from the NWCS were lumped together.

Inland Systems were further subdivided into three broad types, including rivers, open waterbodies and inland wetlands. This is in keeping with the South African NWA, which distinguishes rivers from inland wetlands and other watercourses. In the Classification System, these three broad categories are collectively referred to as 'Inland Aquatic Ecosystems' which corresponds to the broader sense of the term 'wetland' as it is applied by Ramsar. However, the South African NWA differentiates between rivers, wetlands and other watercourses.

1.3 Developments during the course of the NBA 2018

The Classification System was adopted for the update of the NWM in preparation for the freshwater component of the NBA 2018. During the course of the NBA 2018, a number of Ecosystem Classification Committees (ECCs) were established, including those for Rivers (RECC) and Wetlands (WECC). A National Ecosystem Classification Committee (NECC) was established to coordinate alignment between the Terrestrial, Marine, Estuarine and the Freshwater ecosystems as components of the NBA 2018. Discussions during these meetings, as well as those at the reference committee workshop held between 2 and 4 October 2017 for the freshwater ecosystems

(Appendix A), have resulted in a number of key decisions and changes for the freshwater ecosystems. These decisions include:

(i) **The alignment between ecosystem types for the NBA 2018** necessitates clear boundaries between the four major ecosystems (Figure 1.1). This resulted in a reconsideration of the representation of freshwater ecosystems within the vegetation map. It was concluded that the vegetation map be used to represent terrestrial ecosystems, with the exception of only a select set of estuarine and inland aquatic ecosystems. Changes to the representation of freshwater ecosystems in the vegetation map and amalgamation of the ecosystem map will be documented in a report by the vegetation map team at SANBI and the National Ecosystem Classification System Report (Dayaram et al. 2018; SANBI, in prep). In the first semester of 2018, the mapping of coastal ecosystems has further refined the boundaries between inland wetlands, coastal ecosystems and estuarine systems.

(ii) **Using the term 'Inland Aquatic' to align with the Classification System.** It is recognised that Inland Aquatic Ecosystems include other systems which are not technically 'freshwater', namely brackish and saline systems. To avoid confusion and ensure alignment with the Classification System, it was agreed to formally adopt the term 'Inland Aquatic' as opposed to 'Freshwater' for the inventory and assessment reports of the NBA 2018.

(iii) **The consideration and inclusion of coastal ecosystem for the NBA 2018** was requested by the leads of the estuarine and marine ecosystems. Noble and Hemens (1978) provides criteria and examples of coastal aquatic ecosystems (Table 1.1). The coastal ecosystems mapped by Dr Linda Harris from the Nelson Mandela University (NMU) included primarily the shore from the base of the dunes to shallow marine systems. It is however recognised that seawater and marine species do infiltrate further inland into inland aquatic ecosystems beyond the coastal shore, however uncertainties prevail on the extent of influence. The Inland Aquatic team and reference committee members therefore gives recognition to a broader coastal region of influence, which potentially may be prevalent in the Albany Thicket, Indian Ocean Coastal Belt, Namaqualand Sandveld, South and West Strandveld Bioregions.

(iv) **Identification of 8 unique limnetic depressions (lakes) totalling 13 376 ha.** Limnetic depressions are inland wetlands which are inundated to a maximum depth of ≥ 2 m at the average annual low-water level of the open waterbody (Ollis et al., 2013). Wetlands within the Estuarine Functional Zone (EFZ) were removed from the list of coastal ecosystems identified by Noble and Hemens in 1978 (Table 1.1). Attributes of these systems were updated in the field related to the hydrological regime or Level 5 of the Classification System in NWM5. No specification is given in the Classification System of the minimum extent of this depth or duration of flooding in a cycle of the hydroperiod of the system. Further studies would be required to refine the definition and evaluate the suitability of the listed candidate wetlands. Although Lake Futululu and Teza (KwaZulu-Natal) were considered for the list, Lake Futululu has reduced in size and depth to such a degree that it is considered more shallow (Grenfell et al., 2010; Grenfell, pers. com.) and insufficient evidence exist for Lake Teza (Scott and Steenkamp, 1996) for it to be classified as limnetic. Both Lake Futululu and Teza may also be coastal ecosystems.

(v) **Rivers and inland wetlands were the only two sub-components of Inland Aquatic ecosystems.** Inland Aquatic Ecosystems with open water features were considered to be either Estuarine Systems (estuaries or lagoons) or Inland Systems (artificial or depressions, whether littoral or limnetic). Therefore the subcategory 'open waterbodies' of the Classification System were omitted from the inventory and assessment of Inland Aquatic Ecosystems.

(vi) **Updates to the Estuarine Functional Zones (EFZ) as a result of new Light Detection and Radar (LiDAR) data** resulted in adjustments to the NWM. In addition, micro-estuaries were also added to the polygon data set of the estuaries. Alignment between the inland wetlands and estuaries was ensured through erasing all the estuaries from the inland wetlands and then merging it back into the NWM5. Updates to the names of the estuaries were also transferred to the river systems (Figure 1.1).

(vii) **Level 2 and 4A should be used to describe and assess wetland ecosystem (bio)diversity.** Levels 2 and 4A of the classification system effectively describe the biodiversity of wetland ecosystem types. Level 2 describe the broad biodiversity setting of the types, whereas level 4A includes the hydrogeomorphic or functional diversity of wetlands. Although the landscape unit (Level 3) does not describe (bio)diversity, it contributes to the identification of hydrogeomorphic wetland ecosystem type (HGM Units at Level 4A).

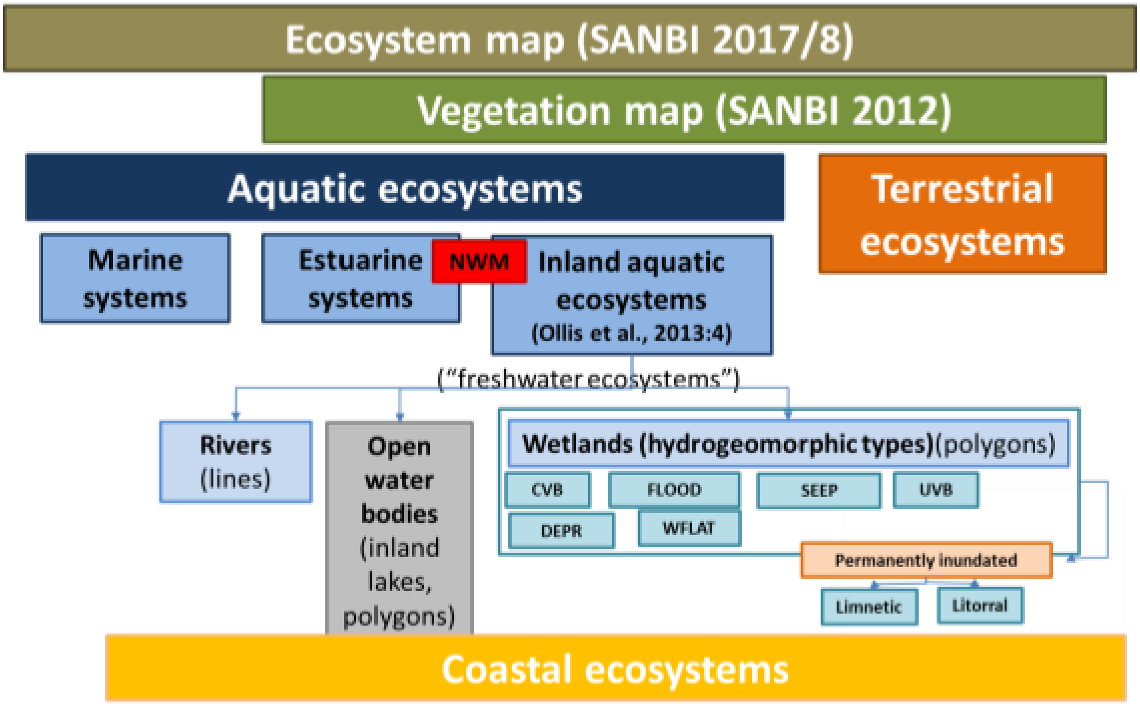

Figure 1.1: Diagram illustrating the conceptual alignment between different ecosystems, their representation and the hierarchical nested classification of aquatic ecosystems.

Table 1.1: The original list of coastal ecosystems by Nobel and Hemens (1978) and the list of unique limnetic depressions of South Africa

Systems identified by Noble and Hemens (1978) as coastal ecosystems:	**Inland Aquatic Ecosystems identified in 2017 as unique limnetic depressions in South Africa**	**Extent (ha)**
Cubhu*	Barberspan (North West), *depth 7.5m*	1 721
De Hoopvlei**	De Hoop (Western Cape)***	949
Groenvlei**	Groenvlei (Western Cape)***	357
Kuzilonde*	Lake Banagher (Mpumalanga), *average depth 4 m*	185
Nsezi*	Lake Chrissie (Mpumalanga), *average depth 6-8 m*	1 283
Nhlabane*	Tevredenpan (Mpumalanga)	329
Mgobezeleni*	Lake Fundudzi (Limpopo), *maximum depth 27 m*	192
Mzingazi*	Lake Sibayi (KwaZulu-Natal), *average depth of 13 m and maximum depth of 41 m (Miller, 1998)****	8 361
Shazibe*		
Sibayi / Sibaya**		
Soetendalsvlei*	(Total extent)	(13 376)
Verlorevlei*		
Wadrifsoutpan* and other west coastal vleis**		
Zeekoevlei*		

** identified as Estuarine Systems mapped within the Estuarine Functional Zone (EFZ). **Inland Aquatic Systems. Information sourced from Noble and Hemens (1978);* https://www.lakepedia.com/; Hill (1969); Miller (1998). ***Although these are currently inland aquatic ecosystems, the recent geological uprift of the coastal plain has resulted in a cut-off between the ocean and the inland system. Relics of marine species are still found in these systems and therefore these systems are considered not only unique, but also coastal as a result of the combination of inland aquatic and marine features.

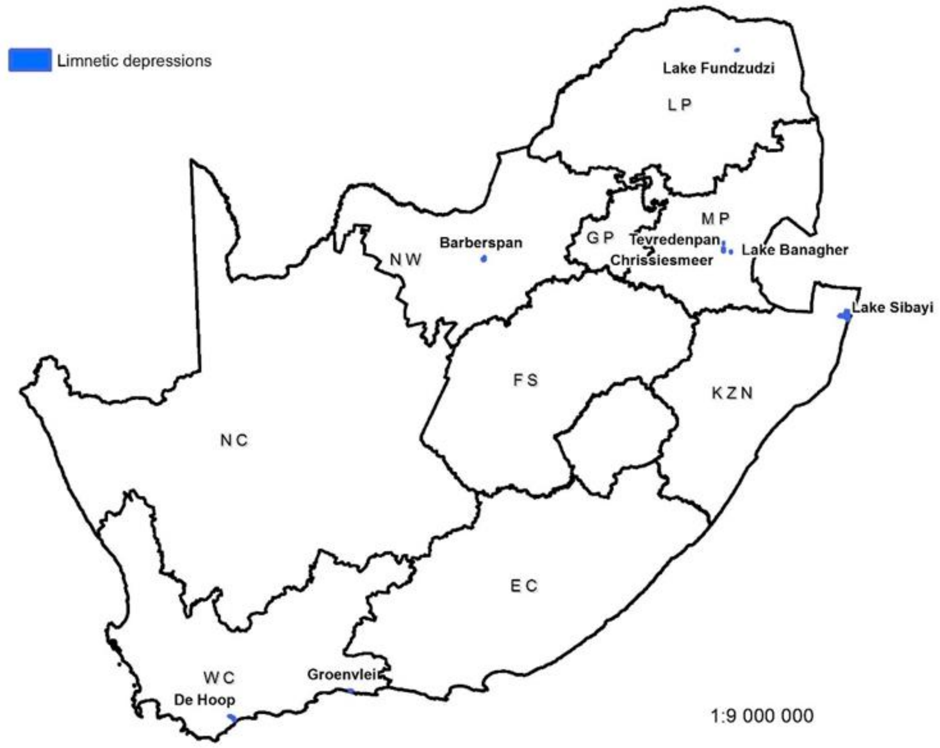

Figure 1.2: Location of known limnetic depressions (lakes) in South Africa.

1.4 The South African Inventory of Inland Aquatic Ecosystems (SAIIAE)

Compilation of the first South African Inventory of Inland Aquatic Ecosystems (SAIIAE) was undertaken as part of the NBA 2018, with the primary intention of including those data sets related to ecosystems type and condition. It, therefore, partially addresses the aspects of these Systems required to respond to the NWA, with a stronger focus on NEMBA and the listing of ecosystems. Four broad categories of spatial data features were collected, including those related to rivers, wetlands, condition and others (Table 1.2). The latter consisted of data which could be used for assessing the protection levels of the sub-ecosystems, as well as features related to tourism, cultural value and ecological infrastructure.

Table 1.2: List of feature classes collected for the first South African Inventory of Inland Aquatic Ecosystems (SAIIAE)

River sub-systems	Wetlands sub-systems
1:50 000 rivers (DWS)	NWM1 – 4 (SANBI)
1:500 000 rivers (DWS)	NWM5 (results of this report)
	Plots that relate to wetlands from the National Vegetation Database (NVD_Wetland_Plots) (Dayaram, 2017)
	Peatland points (Grundling et al., 2017)
	Possible locations of oxbow rivers for the identification of floodplain systems (Oxbows) (results of this report)
Condition (pressures)	**Other information**
Land cover 1990 and 2013/4 (GTI Pty Ltd)	Waterfalls (results of this report)
Land cover update (SANBI, 2017)	Springs (DRDLR:NGI, 2006 and 2016)
Wastewater Treatment Works (WWTW) (CSIR, 2015)	Thermal springs (Olivier and Jonker, 2013)
Water Treatment Works (WTW) (CSIR, 2015)	Protected Areas (SANBI, 2017)
Invasive species *Prosopis* (Van den Berg, 2010)	SWSA (Le Maitre et al., 2017)

Data collection was undertaken firstly through a data audit and survey of the available data sources for the SAIIAE, with more than 500 Interested and Affected Parties (I&APs) contacted (Van Deventer et al., 2018). The results of the audit showed that the records were mostly related to wetland ecosystems, and few records related to species, the regional context within which inland aquatic ecosystems occur, condition or monitoring history. An initial comparison between the hydrological classes from the most recent land cover data set (GTI, 2013/4) and the hydrological categories mapped through heads-up desktop digitising of hydrological features, showed that the fine-scale mapping of inland wetlands resulted in a much higher percentage wetlands with improved interpretation of the HGM wetland types. The use of sensors with a higher spectral and spatial resolution remains to be assessed for their potential to contribute to improved mapping of wetland ecosystems. The audit paper (Van Deventer et al., 2018) revealed that 5 million ha of fine-scale wetland mapping data sets were received from a number of organisations. The DRDLR:NGI contributed the largest percentage (73%) of hydrological feature mapped at a fine scale, although not done by wetland specialists. Less than 8% of the country's sub-quaternary catchments (SQ4s) have been mapped by wetland specialists or typed to the HGM wetland types of the NWCS or Classification System. Recommendations were made with regards to collaboration between DRDLR:NGI, DWS and SANBI for an improved, coordinated effort of fine-scale mapping of wetlands, as well as attending to the collation and curation of other data sets related to inland aquatic ecosystems.

Secondly, and in parallel to the data audit, improvement of the river and wetland sub-ecosystems has been undertaken. More attention was given in this inventory update to inland wetlands than rivers in recognition of the extensive underrepresentation (omission errors) and commission errors of inland wetland ecosystems.

The CSIR has also reconsidered the feasibility of mapping the landscape units, or level 3 of the Classification System, at a country-wide scale. Since NWM5 was undertaken at a fine-scale (see Chapter 4) and not modelled, a data set reflecting landscape units was not considered an immediate priority. It remains a research topic of interest for the inland aquatic ecosystems, though, and effort has therefore been spent on assessing whether morphometrics of a Digital Elevation Model (DEM) could be used to model landscape units. At the time of this publication, the CSIR has drafted their report on the intermediate findings (Van Deventer, 2018).

The chapters of this report details more information on the following themes of the SAIIAE:

- Chapter 2: The origin and improvement of the rivers data set for the NBA 2018
- Chapter 3: The origins of the National Wetland Map of South Africa
- Chapter 4: The results of the update of National Wetland Map 5
- Chapter 5: Probability modelling of wetlands for South Africa
- Chapter 6: Evaluation of the watercourse probability map for supplementing the National Wetland Map
- Chapter 7: Conclusions and Recommendations

The first South African Inventory of Inland Aquatic Ecosystems (SAIIAE) built on previous efforts for the establishment of a directory to represent watercourses and additional information for the purpose of inventorying, assessment and planning.

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2. CHAPTER 2: ORIGIN, DEVELOPMENT AND IMPROVEMENT OF THE RIVERS DATA SET

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This chapter provides an overview of the origin, development and improvement of the 1:500 000 spatial data set of the rivers of South Africa. For the purposes of the National Biodiversity Assessment (NBA) 2018, a rivers network Geographic Information Systems (GIS) layer is required in order to map and classify the river ecosystem types across the country. River ecosystem types represent the diversity of river ecosystems. These subtypes are components of rivers with similar physical features and serve as essential coarse-filter biodiversity surrogate (Nel et al., 2011). A river ecosystem is viewed as a system operating within its surrounding surface and sub-surface catchment environment, and includes biotic interactions amongst animals, plants and micro-organisms, as well as abiotic chemical and physical interactions (modified from Angelier, 2003). This chapter begins with a summarized history of the 1:500 000 river coverage. It then outlines the updates of this data set relevant specifically to the NBA 2018. The chapter ends by describing possible future updates to the rivers data set.

2.1 History of the 1:500 000 rivers data set

In this section key information is drawn from DWAF (2006). In the early 1990s the Department of Land Affairs: Chief Directorate of Surveys and Mapping (DLA:CDSM) created the original 1:500 000 river network coverage by scanning and vectorising the blue plates of their published 1:500 000 map sheets. In 1995 the Institute for Water Quality Studies (IWQS, now Resource Quality Information Services, RQIS) of the DWAF, saw the need for an accurate regional rivers data set to serve as a background vector coverage for cleaning up point records of national DWAF monitoring sites. IWQS also had plans for developing a water quality monitoring network, for which a hydrologically-correct river network was required. They appointed the consulting group GisLAB to produce a contiguous and consistent arc data set from the DLA:CDSM (now the Department of Rural Development and Land Reform: National Geo-spatial Information or DRDLR:NGI) raw data. GisLAB filled gaps in the network, aligned arcs downstream, ensured that all existing surface monitoring points were on a river arc and ran the first Strahler stream ordering process on the coverage. IWQS allocated reach codes to the river arcs using the quaternary drainage region polygons from the 1990 Surface Water Resources of South Africa Study (WR90) database (Midgley et al., 1994). A reach code is a unique identifier for each reach in the river network, based on the approach applied in the USGS National Hydrography Dataset (https://nhd.usgs.gov/). Starting in the late 1990s, the river arcs were adjusted to match the 1:50 000 data, where available, to within approximately 50 metres.

The river coverage extends to the limits of international basins (e.g. Namibia and Zimbabwe), at the lower accuracy of the available base data, i.e. at a scale of 1:1 000 000. The fundamental assumption behind this simplified GIS river network is that water flows downhill along single channels. Multiple-thread channels, impounded flow and exchange with the atmosphere or soil are ignored. An important component of the river coverage is the set of attributes attached to each arc which provide useful information for basin network analysis. These include a name, where available, and various network descriptors such as flow variability and Strahler order. In time, this data set has found widespread practical application in, for example, river management and conservation, hydrological modelling and river profile generation. The latest version of the 1:500 000 river coverage for South Africa is available from the DWS and can be downloaded from the following website: http://www.dwaf.gov.za/iwqs/gis_data/river/rivs500k.aspx. It is now almost stable (i.e. representation and attributes) following years of editing procedures, consistency checks, network and name verifications and a consolidation process. The digital elevation model (DEM) determination process of Weepener et al. (2011) also provided several corrections.

Users, nonetheless, do occasionally report errors and inconsistencies that are related to some shortcomings in the data set. For example, the reach codes within a quaternary drainage region changed unpredictably when new rivers were added to the region, depending on their position in the Strahler hierarchy. This no longer occurs because the Department of Water and Sanitation (DWS) shut down the system on which the editing took place, so development of the rivers data set on the RQIS website is frozen. Ideally, the reach codes should remain attached to the same reach except in the case of splits and additions. Recursive errors could be related to the DWAF monitoring point locations. Monitoring points incorrectly positioned would have influenced the retention or deletion of river arcs. It is also essential to check arcs for errors related to river names, although most of the unnamed river arcs do not have names on the original 1:50 000 maps. In addition, at certain places the river arcs still do not spatially match the 1:50 000 rivers. However, the greatest discrepancy is in the flow variability, i.e. the classification of rivers as perennial, non-perennial or dry from the 1:50 000 river coverages, which DLA:CDSM derived from aerial photographs. These data are less accurate because they depended to a large extent on the season during which each aerial photograph was taken and whether the river channel had water in it at the time of mapping (Nel et al., 2011).

2.2 Update of the 1:500 000 rivers data set for the NBA 2018

In the NBA 2018 the National Freshwater Ecosystem Priority Area (NFEPA) rivers GIS layer was used to represent the diversity of rivers nationally (Table 2.1 and Figure 2.1). This layer was also used in the freshwater component of the NBA 2011 assessment. Only minor river arc edits (e.g. deleting duplicate vertices) were performed. This updated rivers data set represent 200 955 km of river length of which 164 018 km (82%) is situated within South Africa. Mainstems make up 76 830 km (47%) of the total length of the South African rivers, and tributaries 87 188 km (53%). When comparing the NBA 2011 and NBA 2018 assessments, total river length within South Africa differs only slightly (i.e. a decrease in 242 km or 0.1%) (Table 2.1). The NFEPA rivers GIS layer was compiled from the DWA 1:500 000 river network coverage (Figure 2.2a) and 97 coastal rivers (Figure 2.2b and Table 2.1) from the 1:50 000 rivers GIS layer (DLA:CDSM, 2006). These smaller streams were added to the DWA rivers data set so that all rivers associated with estuaries could be included in the NFEPA analyses (Nel et al., 2011; Nel and Driver, 2012). They were connected to estuaries mapped for the NBA 2011 (Van Niekerk and Turpie, 2012). The NFEPA rivers GIS layer was coded to distinguish quaternary catchment (Midgley et al., 1994) mainstems and tributaries (Table 2.1), river segments and river reaches. Mainstems typically pass through a quaternary catchment into a neighbouring quaternary catchment while tributaries nest within a single quaternary catchment (Nel et al., 2011). The quaternary catchment is used as the basic unit for national water resource management (mean size 650 km^2), and each contains hydrological data (gauged or simulated) that is updated occasionally.

Table 2.1: The different river layers with total lengths (km) for the mainstem rivers and tributaries in South Africa

DWA rivers (2008)		Additional rivers		NFEPA rivers (2011)		NBA rivers (2018)	
Mainstem	Tributary	Mainstem	Tributary	Mainstem	Tributary	Mainstem	Tributary
14 818	86 134	832	0	76 190	87 238	76 830	87 188
100 952		164 260				164 018	

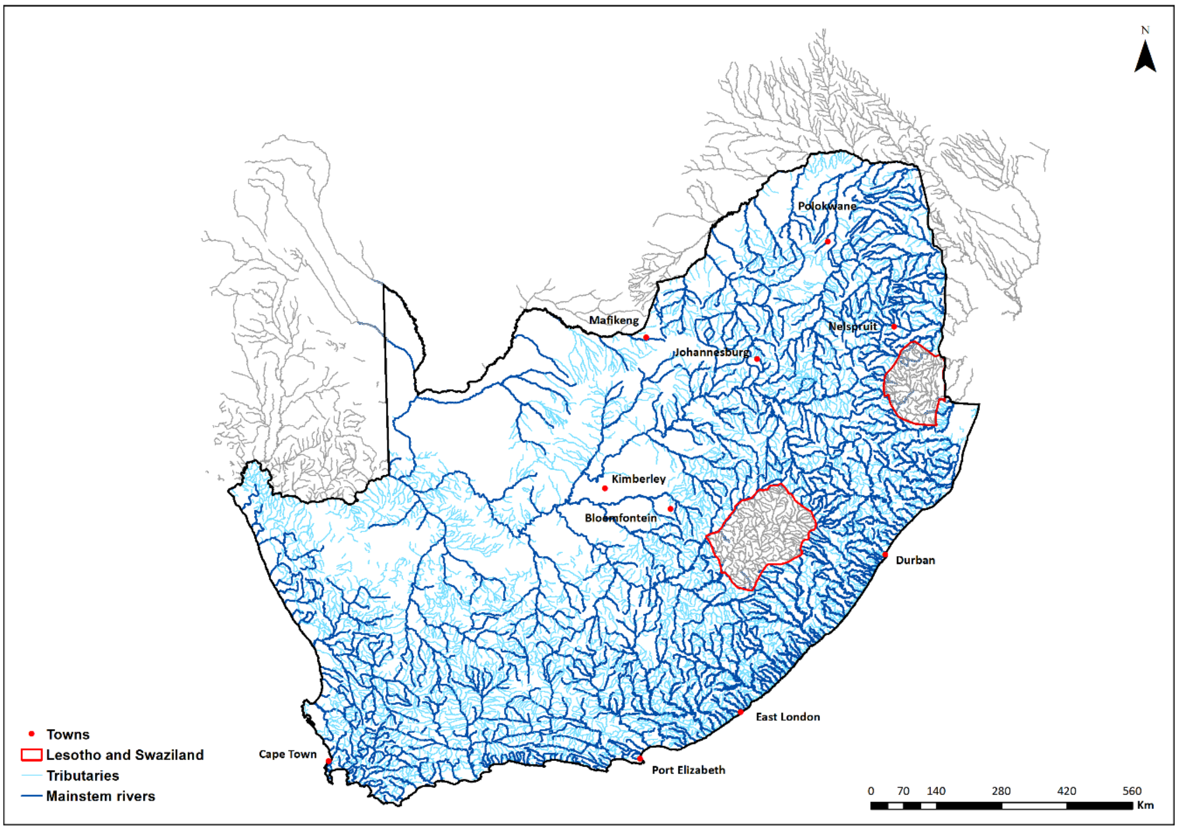

Figure 2.1: NBA 2018 rivers layer with quaternary mainstem rivers and their tributaries. Rivers in grey are shared rivers in neighbouring countries.

A river segment represents the portion of river joining two 1:500 000 river confluences. Sub-quaternary catchments or quinary catchments (mean size of 135 km^2) were delineated around river segments. They are nested within quaternary catchments and were used by NFEPA as the units of selection or planning units for identifying priority areas (Nel et al., 2011). Quinary catchments were refined by Maherry et al. (2013). River reaches may be several metres or kilometres in length. They can be made up of a number of river segments and signify the whole river sub-system. In the RQIS river data set, a reach is the piece of river between two river confluences or nodes. Other attributes attached to the NFEPA rivers GIS layer, for example, included the Level 1 ecoregion (Kleynhans et al., 2005), geomorphic zone (Rowntree and Wadeson, 1999; Rowntree et al., 2000; Moolman, 2008), river ecosystem type and river condition (Nel et al., 2011; Nel and Driver, 2012). The NFEPA rivers were also shifted from the original Cape datum to the World Geodetic System 1984 (WGS84) datum.

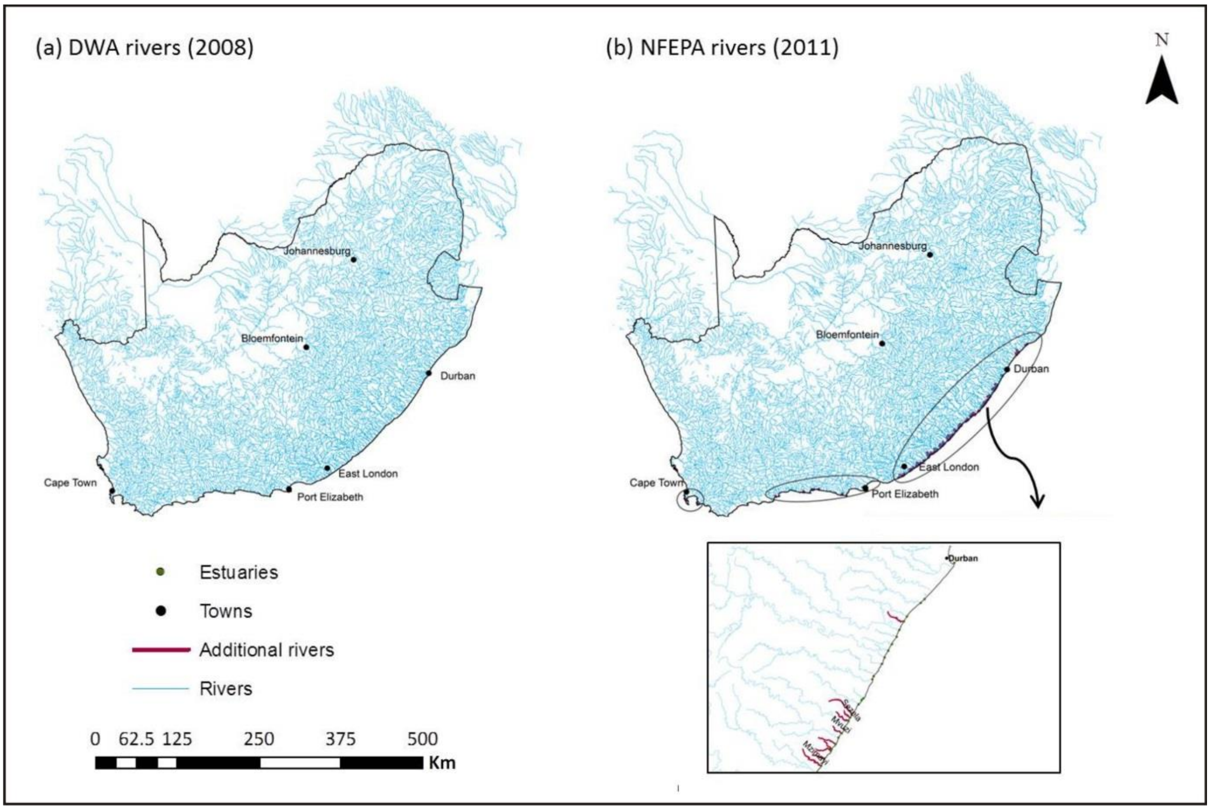

Figure 2.2: Improvement of the 1:500 000 river coverage of South Africa. DWA rivers layer before NFEPA (a) and NFEPA rivers layer with 97 additional 1:50 000 rivers (b).

2.3 Recommendations for updating the 1:500 000 rivers data set

Recommendations to improve the 1:500 000 river coverage include working towards stable reach codes and a comprehensive hydrological data set (e.g. variables such as channel elevation, stream velocity and connectivity). This would require migrating the rivers data set from an ArcInfo coverage to an ArcGIS geodatabase with topology recorded within the rivers network, as well as between the rivers network and other data sets. High resolution digital elevation models should be considered for improving drainage network generation and the accuracy of the rivers network. Future developments ought to also include applying the updated 1:500 000 verification and reach allocation procedures to the 1:50 000 rivers (DWAF, 2006; Van Deventer et al., 2018). This would necessitate substantially more computing time since the 1:50 000 river coverages are more accurate and comprehensive, being about 100 times larger than the 1:500 000 river coverage. A finer river network GIS layer for example biodiversity planning or land-use planning may be preferable, as this would indicate smaller streams and habitats that need to be managed and conserved. The 1:50 000 rivers have undergone extensive editing (e.g. flow direction) in the early 2000s in a different process managed by the DWAF and are now hydrologically-corrected (i.e. upstream and downstream linkages can now be defined for each river reach). They were vectorised from the 1:50 000 topographical map series in the late 1990s by the DLA:CDSM (DWAF, 2006), now DRDLR:NGI.

Other specific recommendations from members of the River Ecosystem Classification Committee (RECC) and Reference Committee for inland aquatic ecosystems, pertaining specifically to future NBA assessments of river ecosystems, include:

- Improvement of the spatial accuracy of the rivers layer used for assessments. There is a need for using a higher resolution rivers network, a new national hydrologically-corrected rivers data set derived from the 1 arc-second (30m) SRTM data, or better resolution if available. This include addressing the mismatch of various 1:500 000 rivers with that of the 1:50 000 rivers.
- Transferring attributes such as river ecosystem type and condition from the 1:500 000 rivers network to the 1:50 000 river coverages. However, it was noted that the 1:50 000 rivers also have errors and that employing them in national scale assessments could be problematic.
- Obtaining higher confidence in the flow variability attributes attached to the 1:500 000 rivers network. In addition, the river flow categories should be revised and more categories must be added, for example those recommended by Uys and O'Keeffe (1997).
- Exploring new approaches to the classification of geomorphic zones developed for non-perennial river systems, which cover a large area of southern Africa. Jaeger et al. (2017), for example, recognise a 'floodout' zone in non-perennial river systems, wherein channel breakdown through transmission losses results in environments of net deposition with diverse and sometimes distinctive geomorphic features, sedimentary deposits and ecosystem characteristics.

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3. CHAPTER 3: ORIGINS OF THE NATIONAL WETLAND MAP

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This chapter provides an overview of the origins of the National Wetland Map (NWM) from versions 1 to 3, as well as the wetlands that were compiled for the National Freshwater Ecosystems Priority Areas (NFEPA) project.

3.1 Initiatives towards directories of wetlands

During the 1970s the South African government initiated a number of research projects to investigate the diversity of inland aquatic ecosystems of the country. This resulted in two key reports on the diversity of inland aquatic ecosystems (Noble and Hemens, 1978; O'Keeffe, 1986). The report offers a directory (list and map) of the location of some of these systems. The interest in inland aquatic ecosystems has sparked a number of conferences, reports and research projects around the country, for example, the CSIR conference held 15-16 October 1987 on 'Ecology and conservation of wetlands in South Africa' (Walmsley and Botten, 1987). Subsequently, the DEAT has developed a second national directory of wetlands in 1998, using Geographical Information Systems (GIS) at that time (Cowan and Van Riet, 1998). Although the authors of these early reports have taken care in mapping wetland extent, type and condition with great care, the lack of readily available spatial information from this time has resulted in a slow percolation of the information into current inventories.

A period followed during which the capabilities of remote sensing and GIS were evaluated to spatially represent hydrological features including waterbodies and wetlands. This period was also characterised by the increasing use of Global Positioning System (GPS) receivers by civilians. The use of GPSs has enabled more accurate mapping of features. This has resulted in the widespread use of the World Geodetic System 1984 (WGS84) spheroid and the Hartebeesthoek94 datum in South Africa since 1 January 1999 (DRDLR:NGI, 2013). The formalisation of a framework for the responsibility of spatial data amongst organisations followed with the gazetting of the South Africa Spatial Data Infrastructure (SASDI) Act (No. 54 of 2003).

The first land cover products of 1996 and 2000 (Fairbanks et al., 2000; Van den Berg et al., 2008) were generated during this time and served as main input layer for the establishment of a formal National Wetland Map. Although the national Department of Land Affairs, Chief Directorate of Surveys and Mapping, has been involved in mapping hydrological feature related to wetlands for the previous 70 years, these data sets only became freely available as shapefiles in the late 1990s. Initially only aerial and orthophotography was available to the wider community with interest in capturing wetlands in spatial formats, but since 2001, Google Earth imagery has released historical images dating as far back as 1984 (Europa Technologies United States Department of State Geographer, 2010). The past twenty years has therefore offered a significant different scope for the mapping and modelling of the extent and HGM types of wetlands compared to the first thirty years. The past ten years have therefore seen an increasing number of efforts investigating possible improvements in modelling wetlands from remote sensing and GIS (see Van Deventer et al., 2018).

3.2 Origin of the National Wetland Maps 1 - 3

The first three maps of South African wetlands were produced under the National Wetland Inventory project, which moved to the South African National Biodiversity Institute (SANBI) in 2004 as part of the Working for Wetlands Programme. In the Programme, remote sensing, field and a desktop approach using GIS, had been used to map and classify wetlands into different wetland types based on available data at the time.

The first National Wetland Map (NWM1) Beta Version or Map 1, layer was derived from the National Land Cover 2000 (NLC2000) GIS layer (Thompson et al., 2002; Van den Berg et al., 2008), in which wetland polygons are described as 'Wetland' or 'Waterbody' (Figure 3.1). NLC2000 was derived from multi-season Landsat imagery of primarily the year 2000 (GTI, 2008). NWM1 was released in 2006 for public use. Polygons did not distinguish between natural or artificial waterbodies but merely between waterbodies and wetland categories, as derived from NLC2000. Historical wetlands lost through impacts were therefore not represented in NWM1.

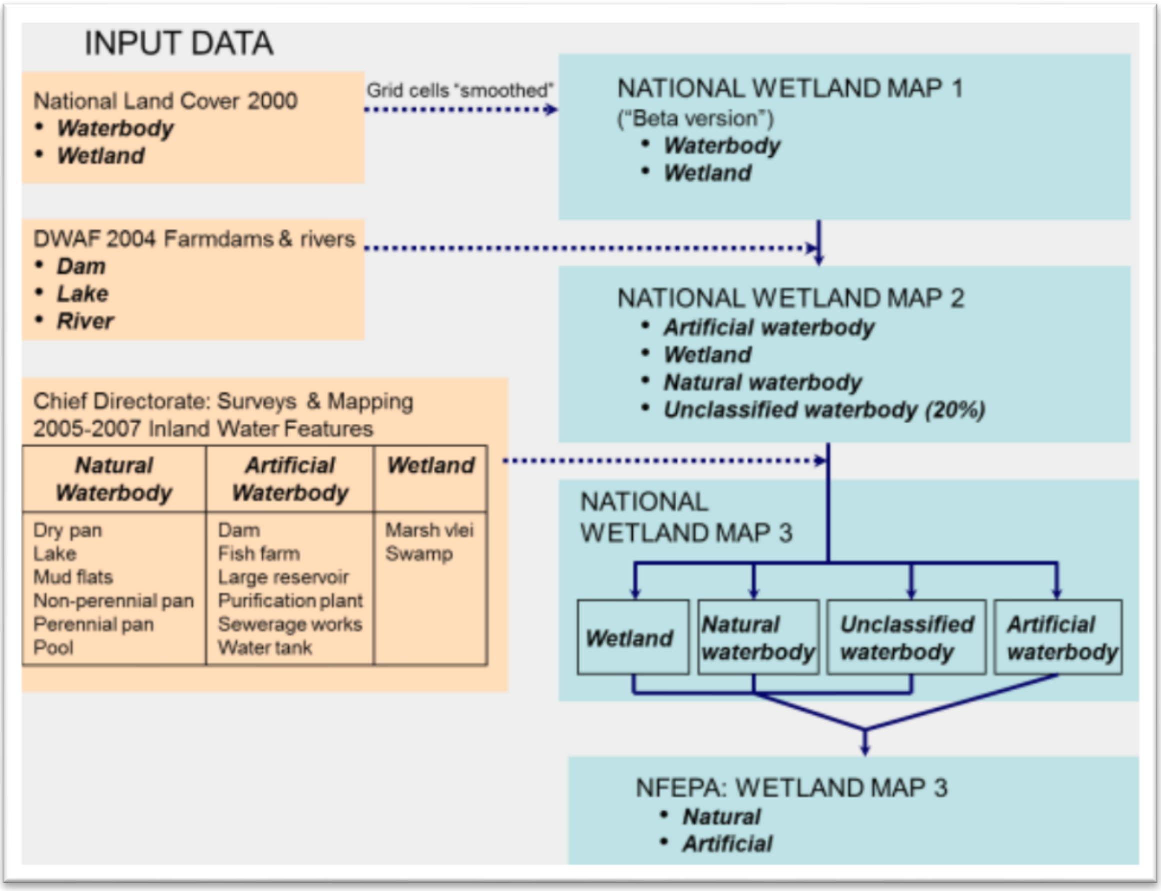


Figure 3.1: Flow chart illustrating the combination of hydrological data sets into National Wetland Map 3.

Wetlands and waterbodies categories from an improved version of the NLC2000 data set were used to derive NWM2 in March 2008. Upon request of SANBI and the Water Research Commission (WRC), both NWM2 and the National Wetland Probability Map (NWPM) (Thompson et al., 2002) were provided to

GeoTerraImage (GTI) for the assessment of accuracy (GTI, 2008). The assessment considered congruency between the data set and reference data which primarily consisted of features mapped by the former Department of Land Reform: Chief Directorate Surveys and Mapping (DLA:CDSM) for the topographical maps, as well as data from the Mpumalanga and KwaZulu-Natal provinces. The majority of the reference data sets represented non-wetland categories and few included fine-scale mapped wetlands and were not mapped by wetland specialists. The congruency assessment found that both NWM2 and the NWPM had an overall agreement of between 30 and 90% for both the wetland and water classes (GeoTerraImage, 2008). A high commission error was also observed for both data sets, in relation to the reference data sets. A number of recommendations were made to improve the NWM2, including the use of a new range of multi-seasonal images and higher spatial resolution imagery. A confidence index was also produced, ranking the suitability of the Landsat imagery for each topographical map sheet, as well as the result of confidence in the mapping of wetland extent.

Subsequent to the report, NWM2 was updated using polygons of dams and lakes and the rivers network (line) data supplied by the former Department of Water Affairs and Forestry (DWAF, date unknown). The resultant layer constituted of four GIS layers: wetlands; natural waterbody; artificial waterbody and 20% of polygons unclassified (Table 3.1).

Table 3.1: Inland water features grouping from the National Wetland Maps 2 and 3

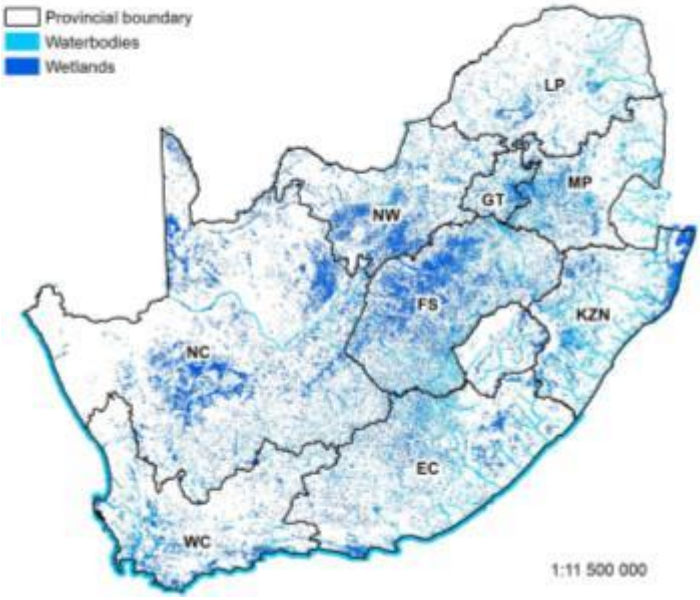
Natural waterbodies from DLA:CDSM (2006)	Artificial waterbodies (DWAF, date unknown)
Dry pan	Dam
Lake	Fish farm
Marsh/Vlei	Large reservoir
Mud flats	Purification plant
Non-perennial pan	Water tank
Perennial pan	Sewerage works
Pool	
Swamp	

In NWM3, data from DLA:CDSM was included and four layers created to include the data from NWM2; more artificial waterbodies from DLA:CDSM and those in NWM2 from DWAF; as well as natural waterbodies from DLA:CDSM and remaining unclassified waterbodies.

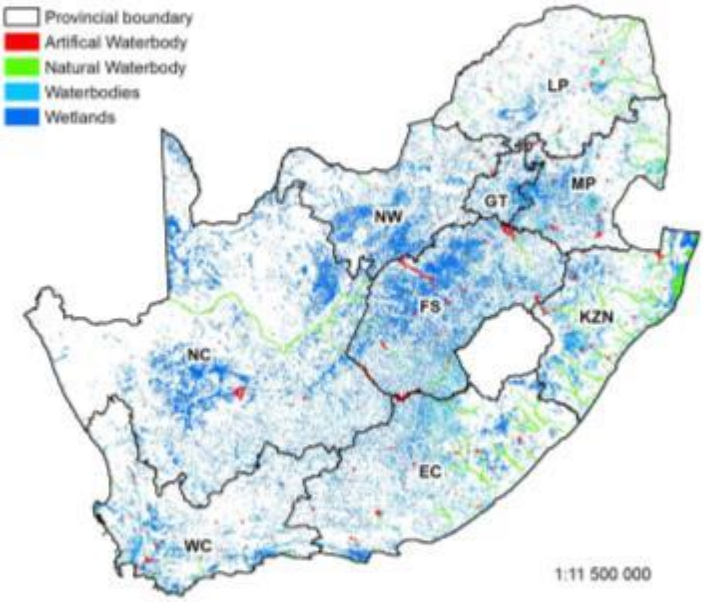
In an analysis done by the CSIR showed that all three versions had mapped nearly 2 million hectares of wetlands and other waterbody features (Table 3.2) with an increase in extent and more attribute information in the data set(s) (Figure 3.2).

Table 3.2: Extent of inland aquatic ecosystems mapped in NWM1 - 3

National Wetland Map version	Total wetland and waterbodies mapped (ha)	Natural wetlands (ha)	Artificial wetlands (ha)
NWM1	1 961 948.5	-	-
NWM2	1 896 797.5	1 575 683.3	321 114.2
NWM3	2 055 674.5	1 527 607.4	528 067.3


Provincial boundary
Waterbodies
Wetlands
LP
MP
GT
NW
FS
KZN
NC
EC
WC
1:11 500 000

(A)


Provincial boundary
Artifical Waterbody
Natural Waterbody
Waterbodies
Wetlands
LP
MP
GT
NW
FS
KZN
NC
EC
WC
1:11 500 000

(B)

(C)

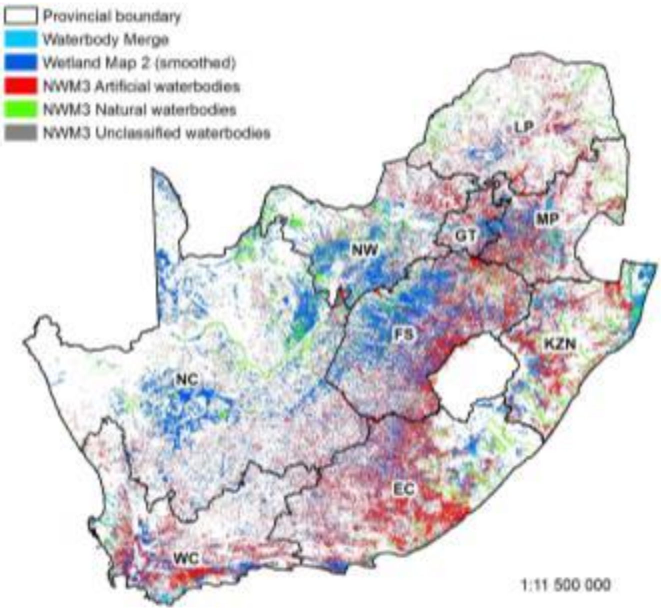


Figure 3.2: Extent and types of wetlands mapped in (A) NWM1; (B) NWM2; and (C) NWM3.

3.3 Wetlands from the NFEPA Atlas, NWM4

A number of improvements to the NWM3 were made during the NBA2011 and NFEPA projects (Nel et al., 2011) in which existing sub-national (data sets at provincial, district or smaller catchment scale) wetland delineations from other biodiversity planning initiatives were added to the NWM3. These included the following sub-national data of wetland delineations:

- Wetlands for the entire KwaZulu-Natal Province (received from Ezemvelo KZN Wildlife);
- C.A.P.E. fine-scale biodiversity planning wetlands of Saldanha/Sandveld, Riversdale plain and Upper Breede River Valley (available from www.bgis.sanbi.org);
- Overberg, Niewoudtville and Kamieskroon wetlands (available from www.bgis.sanbi.org); and
- selected wetlands of conservation importance in Mpumalanga Province (available from Mpumalanga Parks and Tourism Agency).

The C.A.P.E. fine-scale biodiversity planning project was still in development at the time when the wetlands data set for the NFEPA and NBA 2011 projects were compiled. More wetlands data sets from the C.A.P.E. project became available after the NFEPA and NBA 2011 projects were completed.

Not all of the above data sets had typed wetlands to HGM units and therefore some of the seven HGM wetland types of the NWCS (SANBI, 2009). These included channelled valley-bottoms, depressions, floodplains, seeps, valley-head seeps, unchannelled valley-bottoms and wetland flats (Figure 3.3). While the artificial wetlands and depressions types were inferred from the former DLA-CDSM of 2006, the remaining wetland types were modelled using landforms and ancillary data sets (Nel et al., 2011; Van Deventer et al., 2014; Van Deventer et al., 2016). In this version the artificial wetlands were not separated from the natural inland wetlands but were issued as a topologically integrated shapefile at a country-wide extent. The NFEPA wetlands layer had also aligned the inland wetlands with the estuaries which had been mapped for the NBA 2011 (Van Niekerk et al., 2011). The resultant layer showed that 165 953 ha was mapped as estuaries (0.1% of the country's surface area), 528 188 ha was mapped at artificial wetlands (0.4%) and 2 252 118 as natural inland wetlands (1.8%) (Van Deventer et al., 2016).

The output of the improved wetlands data set was released with the NFEPA atlas and has subsequently been termed the 'NFEPA wetlands' by many individuals and institutions. The output was however adopted as NWM4 by SANBI and has been used in a number of applications to date.

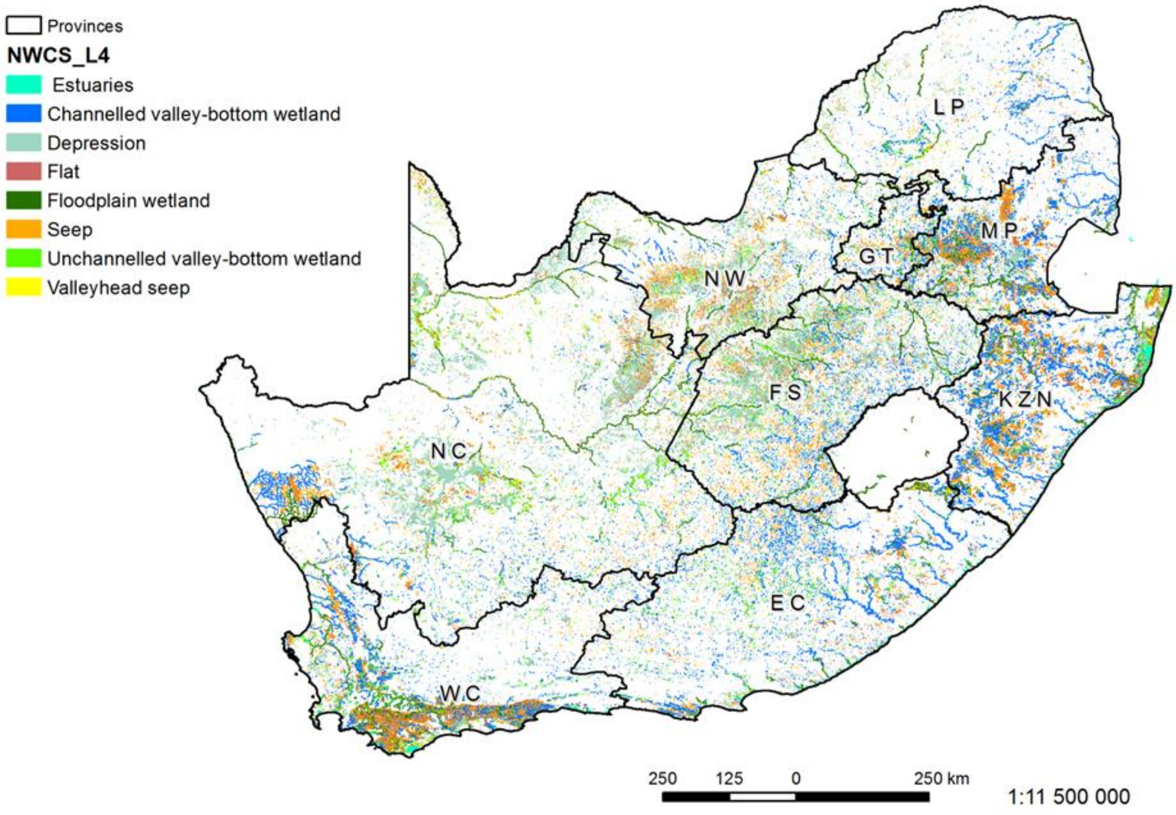


Figure 3.3: Natural wetland types mapped in the NFEPA project.

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4. CHAPTER 4: NATIONAL WETLAND MAP 5 (NWM5)

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This chapter provides an oversight of the rationale and approach for the update of the National Wetland Map 5 (NWM5) which will be used in the National Biodiversity Assessment of 2018 (NBA 2018). This chapter documents the principles adopted and methods used for the mapping of HGM wetland types and the integration of existing data sets for various parts of the country. The results of reviews done by experts are provided as well as the results of the final NWM5. A confidence map guides users as to the completeness of the extent of inland wetlands mapped in an area, as well as the accuracy confidence of the attribution of hydrogeomorphic wetland types. Recommendations for improvements to the NWM are provided in conclusion.

> Wetland 'means land which is transitional between terrestrial and aquatic systems 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 to life in saturated soil.' NWA 1998:9

4.1 Recognition of errors and shortcomings of the NFEPA wetlands (NWM4)

Since the publishing of the NFEPA wetlands, or NWM4, in 2011, many users have noted the amount of errors present in this data set. Possibly the majority of the errors originated from the National Land Cover (NLC) of the year 2000 (Van den Berg et al., 2008), derived from the spectral modelling of Landsat 4-5 Thematic Mapper (TM) imagery with a 30 m spatial resolution. Reflectance values of inland wetlands are as diverse as their nature across the country, and the broad bands of these older generation sensors are incapable of distinguishing these systems adequately. In addition, using GIS to model of some HGM wetland types has contributed further problems by dividing single wetland units into more than one polygon (see Van Deventer et al., 2014; Van Deventer et al., 2016). The following issues have been observed (Figure 4.1):

- There are up to 46% estimated omission errors of wetlands in several landscapes when compared to wetlands mapped at a fine scale (Mbona et al., 2015; Schael et al., 2015; Van Deventer et al., 2016; Melly et al., 2016);
- Polygons mapping artificial wetlands, fire scars and shadows of mountains as wetlands (commission errors, estimated at 30% of the data set) or selective parts of the extent of wetlands;
- Horizontal shifts of polygons in comparison to more recent space-borne *Satellite Pour l'Observation de la Terre*-5 (SPOT-5), the 50 cm spatial resolution colour orthophotography of the Department of Rural Development and Land Reform: Directorate National Geo-Information (DRDLR:NGI) of 2012/3, Google Earth and other aerial photography;

- Polygons subdivided into HGM wetland types, showing zig-zag boundaries which resulted from using a raster-derived landforms data set for typing wetlands (Van Deventer et al., 2014; Van Deventer et al., 2016);
- Errors in HGM wetland types as a result of automated modelling of some of these units. The landform tool that was used showed to have over-predicted valley floors and benches while underestimating slopes and plains (Van Deventer et al., 2014; Van Deventer et al., 2016);
- Areas mapped around dams were initially thought to be natural palustrine and seep wetlands however upon closer inspection after NWM4, agreed to have rather be classified as artificial as well for the purpose of a national map;
- Slivers of inland wetland polygons which have resulted from a number of overlays and editing processes.

Errors of omission and commission can both affect the assessment of the Ecosystem Threat Status and Ecosystem Protection Levels, the headline indicators of an NBA. Errors of commission, which result in the overestimation of the extent of an inland wetland ecosystem type, are particularly problematic in that they can lead to significant underestimation of threat status and over estimation of protection levels. For the purposes of the NBA 2018, it was therefore crucial to reduce commission errors. In an attempt to address the vast number of issues reported for NWM4, as well as the underrepresentation of the extent of wetland ecosystem types, an approach was followed to first use the fine-scale wetlands (i.e. high confidence) data collected for NWM5 (Van Deventer et al., 2018), and then evaluate whether the NFEPA data could still add value. The following sections (4.2 to 4.9) describe the way in which the fine-scale data was amalgamated and typed whereas section 4.10 describes the comparison of this amalgamated data set (NWM5) with the NFEPA wetlands /NWM4.

Figure 4.1: Examples of errors in the NFEPA wetlands: (a) An artificial wetland outlined in yellow modelled as a wetland flat. The extent should be corrected to match the image and the type corrected to artificial; (b) Commission errors which were inherited from NWM3, the shadows of mountains are likely to have resulted from the spectral modelling of Landsat satellite imagery; (c) Wetland HGM types outlined in yellow have been split in a zig-zag way by the landforms data set used to model HGM wetland types in the NFEPA wetlands. In addition the polygon shows a shift towards the east compared to the image. These should be corrected by merging the split polygon, reshaping or deleting it and retyping it to the correct HGM wetland type; (d) Part of an NFEPA polygon remaining in an area and typed as a wetland flat. The extent includes terrestrial (commission error) and wetland areas have been missed (omission error) which should be corrected, as well as the HGM wetland type; (e) Small sliver polygons also remained where larger river polygons were removed; (f) artificial wetlands mapped; (g-h) mining excavations and tailing impoundments; (i) a swimming pool; (j) power station and (k) the shadow of silos. These should be deleted.

4.2 Approach, process flow and protocols used for NWM5

A key decision made at the onset of the improvement of NWM5 was to first split fine-scale, desktop mapped wetlands data from wetlands modelled either from a Digital Elevation Model (DEM) or satellite imagery (Appendix B). This implied that all the fine-scale wetlands data sets would be identified, amalgamated and typed to HGM unit separate from any modelled data. Only after the compilation of a fine-scale version of NWM5, would the modelled data be considered for integration.

An update of the hydrological features mapped by the DRDLR:NGI was issued as provincial geodatabases at the end of March 2016. This data set showed a larger amount of hydrological features captured by the DRDLR:NGI, compared to the 2006 data set which was readily available at the Council for Scientific and Industrial Research (CSIR). Although the DRDLR:NGI issues updates every 3 years, the time constraints on the inventory resulted in consideration of only the 2006 and 2016 data sets. As a first step in the compilation of the fine-scale NWM5 (Figure 4.2), the 2016 provincial geodatabases were merged to a national geodatabase using the Geographical Information Systems (GIS) software ArcGIS 10.3 (ESRI, 1999-2014) and topological errors cleaned and referred to as NWM5.1 (Figure 4.1; Appendix C). All data were projected to the South African coordinate system used by the NBA 2018, the Albers Equal Area (AEA) Conical projection with the spheroid and datum being the World Geodetic System of 1984 (WGS84). This coordinate system least distorts the surface area extent calculated for ecosystems. This coordinate system uses the 25°E as central meridian with two standard parallels including 24°S and 33°S.

A geodatabase was chosen as the preferred format of the spatial data related to the South African Inventory of Inland Aquatic Ecosystems (SAIIAE), since it could economically and effectively contain multiple feature classes under a single feature data set and allow for the assessment and correction of topological errors. Most particularly, the use of defined subtypes for multiple categories in all the fields, and relationships between these, had the advantage that during distributed editing of the subsequent versions, consistency in classifications will persist which limits timeously editing after amalgamation.

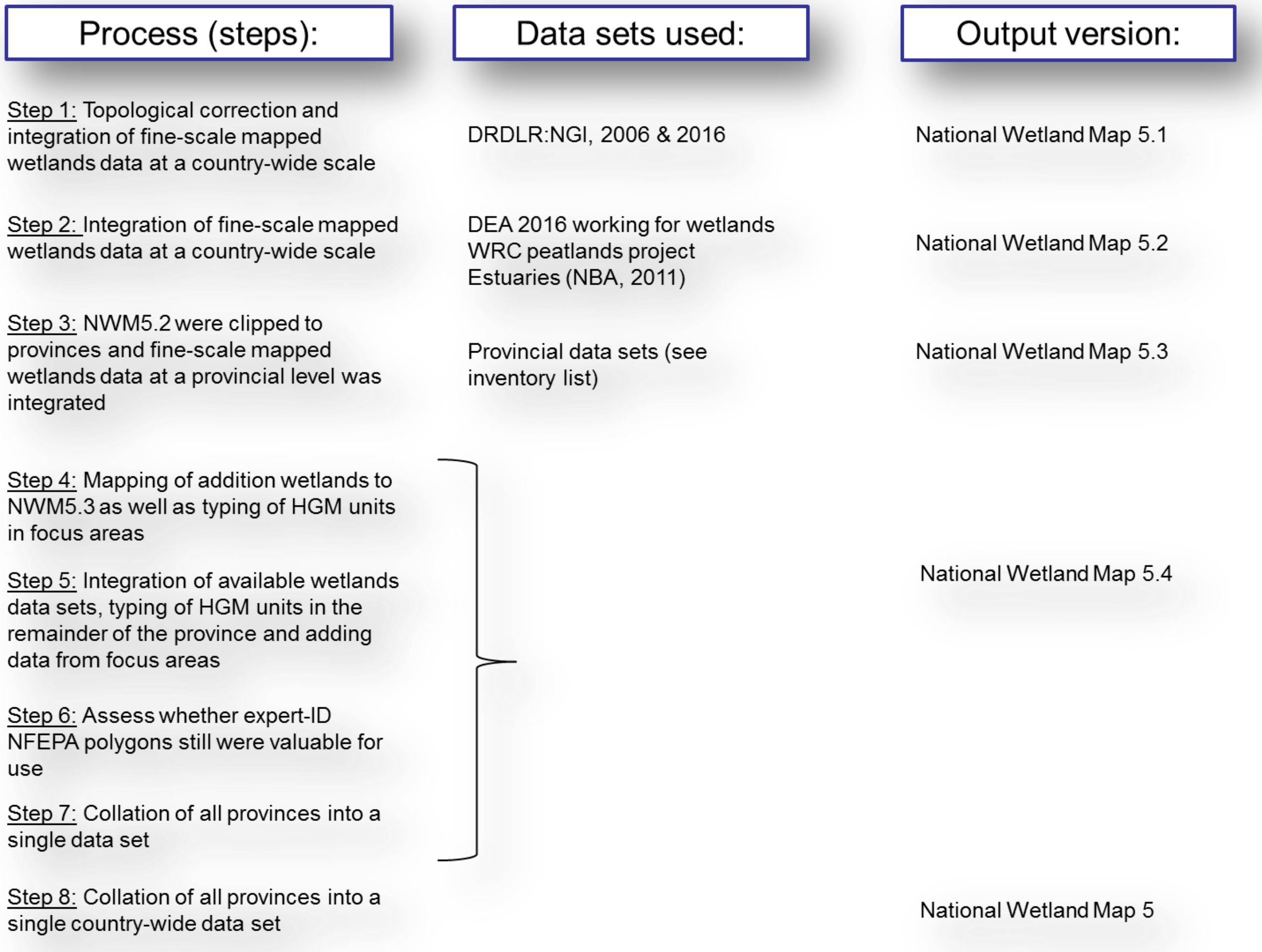


Figure 4.2: Flow diagram showing the process of compilation of NWM5.

Concurrent to the period during which the NWM5.1 was compiled, the CSIR and the South African National Biodiversity Institute (SANBI) undertook a data audit of available data which could be used for the SAIIAE. In particular, fine-scale wetlands data were sought for improving the NWM. A wide range of wetland data sets had been received during the course of more than a year (2016-2017) for use in NWM5 and has been compiled as an inventory list (Van Deventer et al., 2018). The list was updated for this publication and is available in Appendix E.

In the second step of integration of fine-scale mapped wetlands data, nationally available data from the Working for Wetlands team (under the DEA), the Water Research Commission (WRC) project (Grundling et al., 2017) and the estuaries from the NBA 2011 have been integrated into NWM5.2 (Figure 4.2; Appendix E). Hereafter the data was clipped to the provincial boundaries of the Municipal Demarcation Board's 2011 data set and distributed to a number of assistants for further processing. The available fine-scale data sets for the provinces were then evaluated for fit-for-purpose and a selected number of these chosen to integrate (Appendix E).

Fine-scale wetlands data received for the purpose of updating NWM5 (Van Deventer et al., 2018; Appendix E) were incorporated with NWM5.2 for each province into a NWM5.3 version, with the naming convention of the output feature class given as [province_name_NWM5.3_coordinate system]. For example, for Gauteng it would be GT_NWM53_AEA. Firstly, the existing HGM wetland types allocated to fine-scale wetlands map data from the fine-scale data received, were transferred to the subtype fields of NWM5.3. In addition, a field Condition was added, and where information on the condition was available, this was transferred too.

Secondly, topology was calculated for the feature data class to show where duplicate polygons occurred, as a result of the merging. This allowed the assistant to review these multiple polygons and make a choice of extent and HGM wetland type. The error inspector tool in ArcGIS then allows for the topological overlap error to be dealt with through either merging, subtracting or deleting selective polygons. A choice can then be made to select the polygon with the preferred HGM type and name of the wetland (from NWM5.2 or higher confidence fine-scale wetlands data).

Principles and guidelines were compiled and provided to assistants for the data capturing and integration process (Appendix B & D). Three key principles guided the compilation of NWM5 to be used in a biodiversity assessment:

- **The original extent of the wetland should always be captured for the purpose of an NBA.** The original extent of wetlands is required for the assessment of ecosystem types in the NBA 2018 (SANBI, 2017). Even though this project had no funding to capture wetlands from historical imagery, the principle implied that all artificial wetlands and modifications to wetlands were removed, and gaps within large valley bottom systems were filled up. This will be elaborated on in the sub-sections to follow.
    - For planning purposes, however, the current extent of wetlands is relevant and should again be combined with the artificial wetlands and other modifications.
- **The maximum extent of a wetland should always be captured.** Ideally, multi-temporal imagery across large annual cycles and seasons should be used to determine the maximum inundated extent of a wetland across hydrological cycles.
- **The HGM wetland types and condition assigned in fine-scale wetlands data sets received from wetland experts should always be retained.** Where HGM wetland types and condition of wetlands has been assigned by wetland specialists, even if desktop assessed, retain these and do not remodel these wetlands. The time-period within which the condition was determined should be documented.

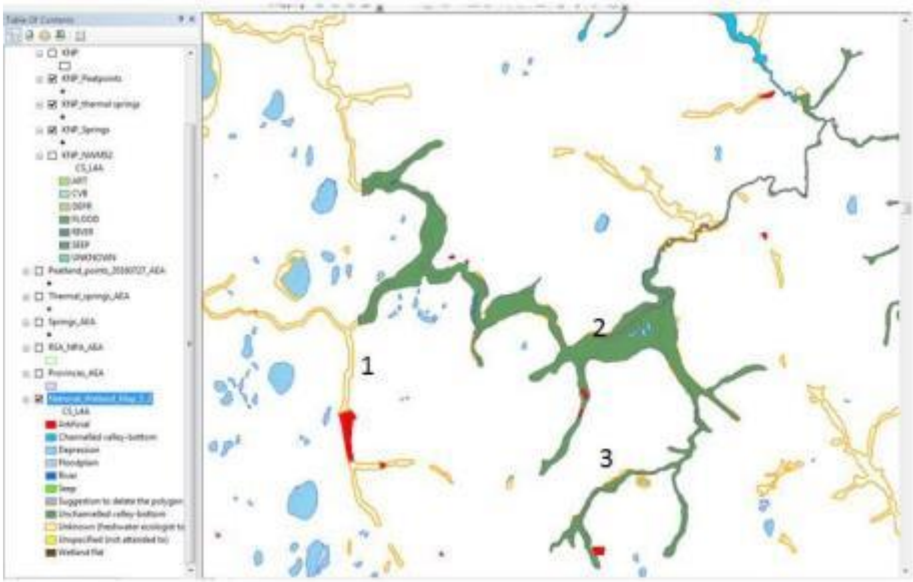
In addition to the guidelines listed in Appendix F, assistants also had to export all artificial wetlands to a separate layer, and then remove artificial wetlands from the NWM layers, within the focus areas as well as later in the remainder of the provinces (following subsections). Although it is internationally recognised that artificial wetlands may contribute to biodiversity, for the purpose of assessing the headline indicators of the NBA 2018, these systems are not considered and have therefore been kept in a separate layer. Artificial wetlands were dealt with in three ways (Figure 4.3.A):

i. Where small artificial wetlands, such as farm dams, were largely surrounded by a valley-bottom or floodplain system, the polygon had to be merged with the surrounding HGM wetland type in NWM5 (Figure 4.3.A.1-3). The extent of the features were kept in the Artificial wetland layer;
ii. Large dams were deleted from the NWM5 but retained in the Artificial wetland layer (Figure 4.3.A.4). Large dams cover both terrestrial and wetland ecosystem types, although the extent of each could not be estimated from the current 'flooded' imagery. The original extent of the original inland wetlands, prior to the construction of the dam, would have to be captured from historical aerial photography to determine the original extent of the wetland. Ninety-two (92) large dams, monitored by the Department of Water and Sanitation (DWS) in the National Eutrophication Monitoring Programme (NEMP), should be considered as a first priority. The NEMP monitors 105

systems, of which we have received a list of 92 large dams, 5 inland wetlands and 5 Estuarine Functional Zones (EFZs); and

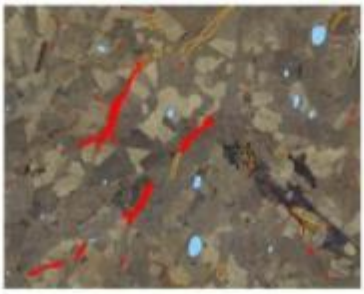
iii. Isolated dams were deleted from the NWM5 (Figure 4.3.A.1-3). In focus areas the extent of the smaller HGM wetland type, which would be present where a series of small dams occur, had to be captured, while in the remainder of the provinces, these smaller systems were not captured.

A) MOTIVATION FOR REMOVING ARTIFICIAL WATER BODIES TO SEPARATE FEATURE CLASS

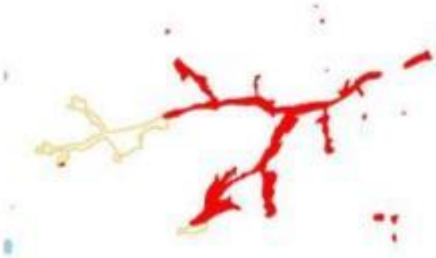


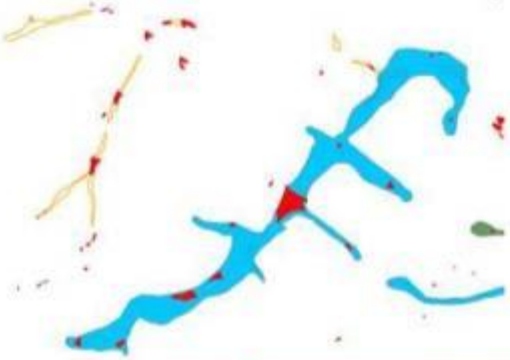
1 – these artificial wetlands extended the original extent of the wetlands. Removal of these artificial waterbodies would leave a gap where the natural extent was. Recommendation: Update in NWM6 to connect wetlands.
2 – these artificial water bodies are completely surrounded by a valley-bottom wetland. Merge it into the adjacent Wetlands. The NWM5.2 version will be used to extract the artificial water bodies to a separate feature class.
3 – removal of this artificial water body will have no impact on the extent of natural wetlands.

4. Removal of the large dams will leave a big gap which should be filled in NWM6 with the historic extent of the original natural wetland.

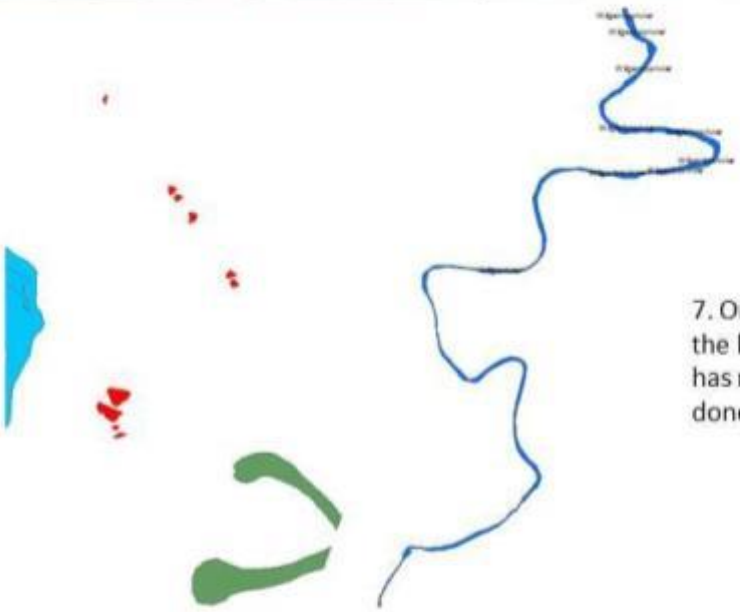


5. These large artificial waterbodies should be double checked. They are perhaps valley-bottom wetlands and should not be deleted, but kept and in corrected in NWM6.



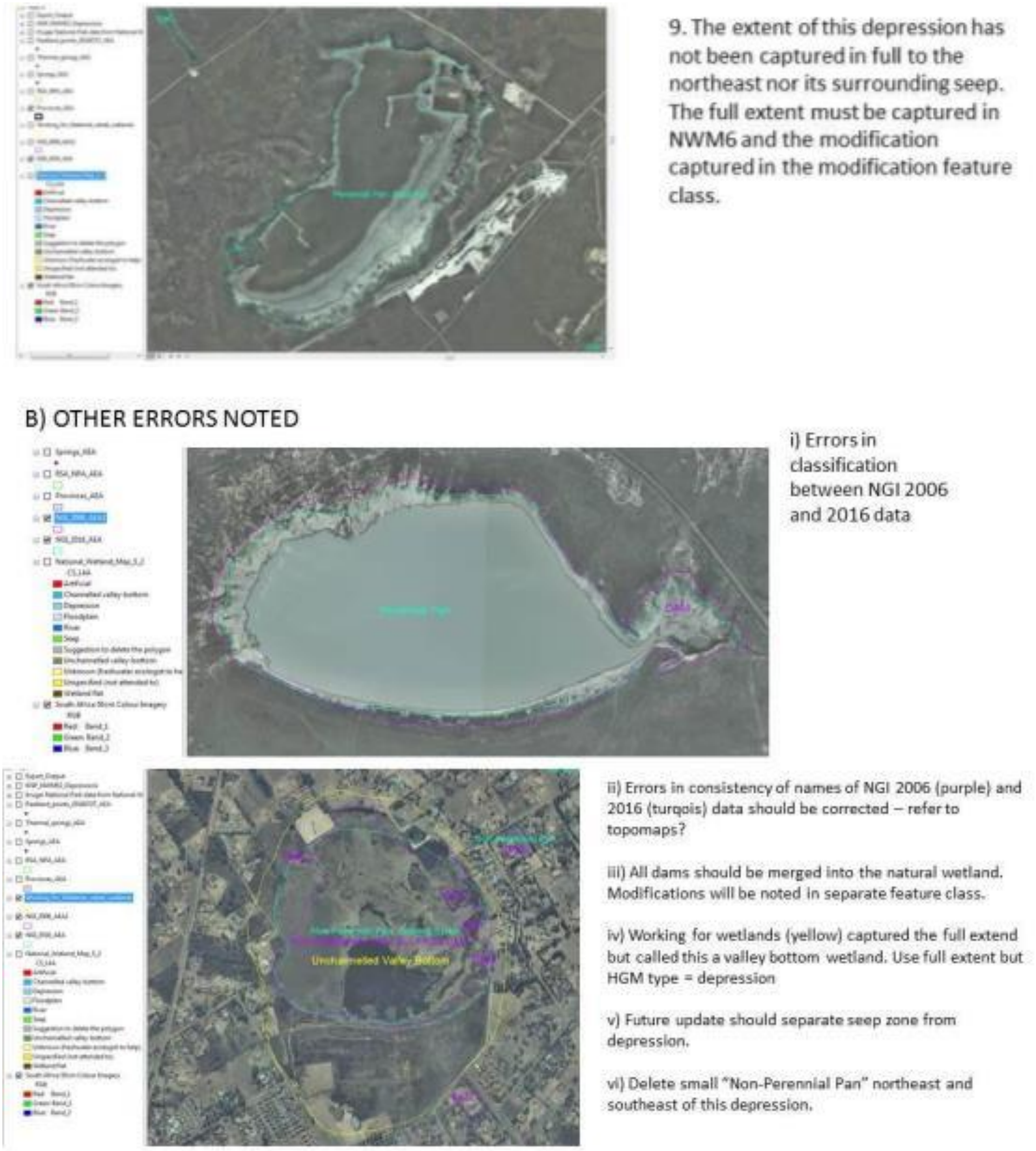


6. These artificial waterbodies would be extracted to a modification layer but then also merged in the NWM5 with the adjacent valley-bottom wetlands.



7. Omissions: valley-bottoms along the line of dams and sinuous river has not been captured. Should be done in NWM6.

8. The depression should extend to include the dam and other perennial pan. The Dam should go to the modifications feature class.



9. The extent of this depression has not been captured in full to the northeast nor its surrounding seep. The full extent must be captured in NWM6 and the modification captured in the modification feature class.

B) OTHER ERRORS NOTED

i) Errors in classification between NGI 2006 and 2016 data

ii) Errors in consistency of names of NGI 2006 (purple) and 2016 (turqois) data should be corrected – refer to topomaps?

iii) All dams should be merged into the natural wetland. Modifications will be noted in separate feature class.

iv) Working for wetlands (yellow) captured the full extend but called this a valley bottom wetland. Use full extent but HGM type = depression

v) Future update should separate seep zone from depression.

vi) Delete small "Non-Perennial Pan" northeast and southeast of this depression.

Figure 4.3: Figure posted for discussion on the NBA 2018 Inland Aquatic Google Forum illustrating (A) scenarios in which artificial wetlands should be removed or integrated into NWM5 and (B) errors related to artificial wetlands detected in the NWM5.3 versions.

The following subsections will detail more of steps 4 -7 (Figure 4.2) taken at a provincial level for the mapping and integration of the fine-scale version of NWM5. Concurrently to the process of mapping and integrating the fine-scale wetlands data, a *wetland probability map* was developed by Dr Nacelle Collins from the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA). The errors in NWM4, particularly the omission errors, inspired Dr Collins to improve the modelling of wetlands for the Free State Province. The output has been very impressive and therefore we have asked him whether he would be willing to run the same script for the rest of the country, which he did. The methods and outputs of this data set are provided in Chapter 5 of this report. A comparison between the fine-scale and modelled wetlands data sets will enable more choices in the compilation of a final NWM5 for the NBA 2018, and could contribute to future fine-scale mapping of NWM updates. The comparison between fine-scale wetland maps and the *wetland probability map* has been done for selected areas and the results hereof are presented in Chapter 6 of this report.

4.3 Mapping of inland wetlands for districts of South Africa

Inland wetlands have been mapped at a fine scale (below 1:10 000) for nine district municipalities of South Africa during the update of the NWM5 and the NBA 2018 (Figure 4.4, see section 4.4). These updates supplemented the inland wetlands data received for four metropolitan districts, including City of Cape Town (CoCT), City of Johannesburg (CoJ), eThekwini and Nelson Mandela Bay District Municipalities (See Chapter 1 and the inventory list for more details). The former district boundary of the City of Tshwane Metropolitan Municipality (CTMM) has also been incorporated, which constitutes the western half of the current City of Tshwane District Municipality. These districts have been mapped to various degrees of scales and accuracies, and few have aligned the inland wetlands with the estuarine ecosystems.

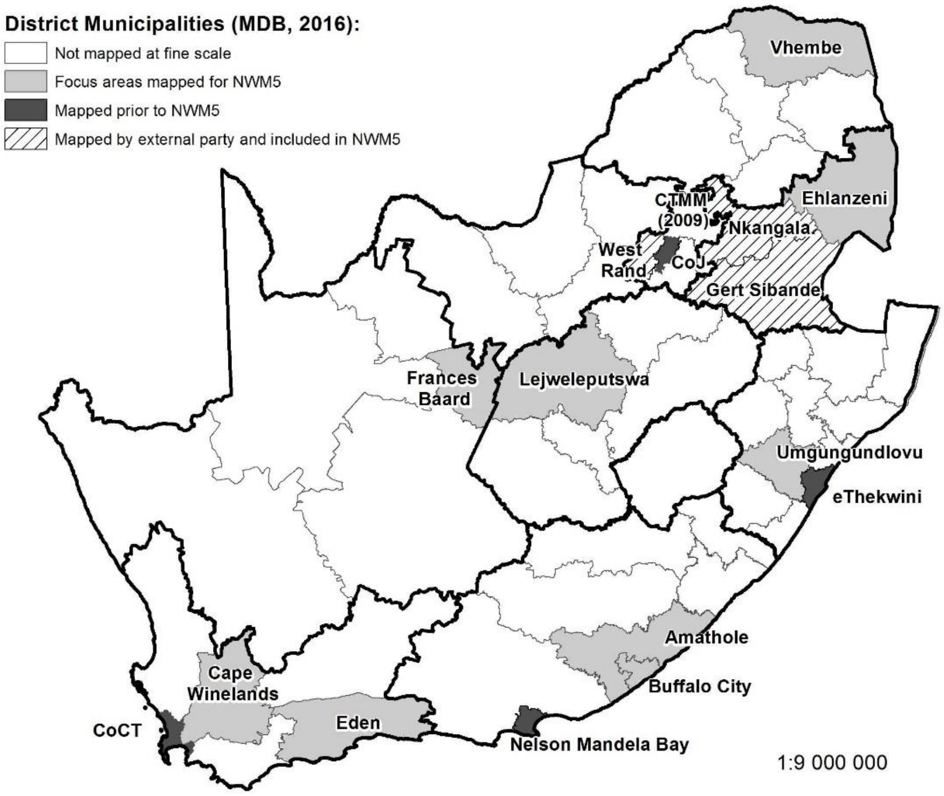


Figure 4.4: Location of priority areas where wetlands were mapped for NWM5.

In addition to the available data sets as well as the focus areas, efforts to update the inland wetlands for three other districts were also under way. Improvements to the inland wetlands in the Gert Sibande and Nkangala District were done by Dr Mervyn Lötter and Mr Hannes Marais of the Mpumalanga Tourism and Parks Agency (MTPA). The baseline of the NWM5.3 for the Mpumalanga Province, which included the all data received for the province, was used to improve the extent and hydrogeomorphic typing of the inland wetlands.

For the West Rand District Municipality in the Gauteng Province, the United States Agency for International Development (USAID, 2018) provided funding to the International Council for Local Environmental Initiatives (ICLEI) for the improvement of the inland wetlands. The funds were seconded to Aurecon Pty Ltd who obtained the NWM5.3 of the Gauteng Province to use as baseline. Mr Joseph Mulders supplemented the baseline data with the *wetland probability map* (Chapter 5) and amended the outlines and hydrogeomorphic types of the polygons from the probability map. Further amendments have been done by Dr Heidi van Deventer (CSIR) before inclusion into the final NWM5.

In total, 16 of 52 districts of South Africa have therefore been included in NWM5, which constitutes about 31% of the total number of districts.

4.4 Mapping wetlands in nine focus districts in the country

Nine District municipalities within the country were selected as focus areas based on availability of resources and the situation assessment results (Table 4.1). Funding for a number of interns was enabled through the following sources:

- South African National Biodiversity Institute (SANBI) Research Assistant funding;
- CSIR Parliamentary Grant (PG) funding;
- Water Research Commission (WRC) Project K 2546, 'Enabling more responsive policy and decision-making in relation to wetlands through improving the quality of spatial wetland data in South Africa';
- Global Environment Facility 5 (GEF5);
- International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability as part of their LAB wetlands project mapped the Eden district municipality following the protocols developed as per Appendix F; and
- South African Earth Observation Network (SAEON).

Table 4.1: Focus areas where mapping of HGM wetland types were improved in NWM5 and their respective funding sources

Area	Source
Amathole District Municipality(EC) Cape Winelands District Municipality (WC) Ehlanzeni District Municipality (MP) Umgungundlovu District Municipality (KNZ)	Global Environment Facility 5 (GEF5), Water Research Commission (WRC) Project K5/2546*, the CSIR's Parliamentary Grant (PG) and funding from the National Research Foundation (NRF)
Buffalo City Metropolitan Municipality (EC) Eden District Municipality (WC)	International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability as well as CSIR Parliamentary Grant (PG) funding and National Research Foundation (NRF)
Francis Baard District Municipality (NC)	South African National Biodiversity Institute (SANBI) & South African Earth Observation Network (SAEON)**
Vhembe District Municipality (LP)	WRC Project K5/2546
Letsjeweputswa District Municipality (FS)	CSIR PG and WRC Project K5/2546 funding

** Water Research Commission (WRC) Project K5/2546 titled "Enabling more responsive policy and decision-making in relation to wetlands through improving the quality of spatial wetland data in South Africa." This project provided funding for research assistance contracts and appointment of wetland specialist for quality control.*

***SAEON provided oversight of the data capturing process, though SANBI funded the human resources.*

Between 17 and 18 August 2016 a training workshop focussing on wetland delineation and mapping was hosted and administered by SANBI at the Kirstenbosch Botanical Gardens. The training workshop had a seminar-centric approach complimented by a practical field work excursion.

- The purpose of the training workshop was to expose attending delegates to the different kinds of HGM wetland types as well their associative vegetative and geophysical features;
- Train delegates in the practice of desktop mapping protocols and procedures as well as the principles and rules in capturing wetland data;
- The use of ESRI's ArcGIS mobile, ArcGIS Online and Quantum GIS's Qfield; and
- Expose delegates to working on the wetland inventory workspace i.e. the classification system and the geodatabase.

The training workshop was attended by 3 trainees from SANBI, the FCG, as well as 12 data capturers from ICLEI, the CSIR and SANBI (Table 4.2). Thereafter, assistants were expected to map the examples seen in the field at a desktop level using GIS and improvements were suggested.

Table 4.2: List of data capturers and assistants who participated in mapping wetlands in focus areas

Focus area (District Municipality)	Data Capturer or Assistant
Amathole (EC) Buffalo City (EC)	Leolin Qegu, intern from National Research Foundation (NRF) based at the CSIR Pretoria from 1 May 2016 to 31 March 2017.
Cape Winelands (WC)	John April, Sinekhaya Maliwa and Bongiwe Simka, interns from National Research Foundation (NRF) based at the CSIR Stellenbosch as well as staff from the Freshwater Consultancy Group (FCG): Tumisho Ngobela, Kate Snaddon and Dean Ollis
Eden (WC)	Mthobisi Wanda, ICLEI
Ehlanzeni (MP)	Millicent Dinala, intern funded through the WRC K5/2546 project
Francis Baard (NC)	Gcobani Nzonda, Research Assistant to SANBI from 26 September 2016 to 26 March 2017, funded through the WRC K5/2546 project, for a total of 936 hours (on average 35 hours per week)
Lejweleputswa (FS)	Ridhwannah Gangat, intern funded through the CSIR PG funding
Vhembe (LP)	Tebogo Kgongwana, intern funded through the WRC K5/2546 project
Umgungundlovu (KZN)	Phumlani Zwane, intern funded through the CSIR PG funding

Following the training workshop, assistants were expected to capture wetlands in the focus areas allocated to them using the guidelines documented in Appendix F. Further supervision was provided by Dr Heidi van Deventer at the CSIR as well as Ms Namhla Mbona at SANBI or alternatively through Skype meetings and sharing of screens. A number of data sets were provided to them for guiding data capturing as well as the guidelines for mapping wetlands in South Africa, which was in draft format at the time of the update of NWM5 (Job et al., 2018). For the update of the NWM5, the original intent was to use the most recent images which had national coverage. The 50 cm spatial resolution colour orthophotography through the ArcGIS online viewer from DRDLR:NGI was freely available for the update and dated back to between 2012 and 2013. SPOT imagery was also used in some instances, dating to similar years. Unfortunately both the colour orthophotos and SPOT images were largely taken during the dry season (possibly to avoid cloud cover) and were therefore less suitable for the purpose of inland wetland mapping. When a wetland deemed particularly difficult to discern the extent and/or HGM wetland type, multiple years of Google Earth imagery was used to facilitate the mapping.

The duration of data capturing took between approximately 3 months per focus area, followed by a review period. Most districts were captured and reviewed between 1 September 2016 and 31 March 2017, although a few commenced and were completed earlier.

4.5 Integration of wetland data sets for the remainder of provinces

No data capturing was done in the remainder of the provinces, except for a selected number of floodplains, the eight limnetic depressions, and wetlands within the majority of the Ramsar sites. A number of assistants who were mapping wetlands in the focus areas, continued with the integration of wetlands in the remainder of the provinces, with help from a number of additional assistants (Table 4.3). The period of integration took place between 1 April and 16 March 2018, with a reduction in the availability of staff's available hours dedicated towards this effort in the last three months of this period. Hence a number of unforeseen delays were experienced.

Table 4.3: List of data capturers who participated in the integration of wetlands outside focus areas

Focus area (Province)	Data Capturer
EC	Leolin Qegu, intern from National Research Foundation (NRF) based at the CSIR Pretoria from 1 May 2016 to 31 March 2017; thereafter Research Assistant to SANBI from 1 June 2017 to 30 November 2017, funded through the WRC K5/2546 project, for a total of 830 hours (on average 31 hours per week).
FS	Ridhwannah Gangat, intern funded through the CSIR Parliamentary Grant (PG) funding from 1 August 2016 – 31 March 2017; thereafter Research Assistant to SANBI from 1 May 2018 to 29 September 2017, for a total of 760 hours (on average 34 hours per week).
GT	Heidi van Deventer (CSIR), Carla-Louise Ramjukadh (CSIR and Ridhwannah Gangat, intern funded through the CSIR Parliamentary Grant (PG) funding extended with SANBI research assistant funding
KZN	Phumlani Zwane, intern funded through the CSIR PG funding from 1 August 2016 till 31 January 2017; thereafter Research Assistant to SANBI from 1 February 2017 to 31 March 2017, funded through the WRC K5/2546 project, for a total of 320 hours (on average 41 hours per week); Frikan Erwee, research assistant funded by SANBI during August 2017 for a total of 40 hrs.
LP	Namhla Mbona (SANBI)
MP	Millicent Dinala, intern funded through the WRC K5/2546 project on a full-time basis from 16 August 2016 to 14 February 2018, and thereafter a Research Assistant on the same project from 15 February 2018 to 14 August 2018 full time.
NC	Nhlanganiso Biyela (SANBI); full-time staff member contributing partially to the project.
NW	DWS team Directorate: Spatial & Land Information Management (SLIM)
WC	Kedibone Lamula (SANBI); full-time staff member contributing partially to the project.

During the mapping and integration of the NWM5.3 versions, the following errors had to be addressed:

- Depression and artificial wetlands attributes were accidentally mixed through an automated GIS process when data was integration into NWM5.2. This may be a result of limited computer processing power in combining data at a national scale. This resulted in a requirement of extensive checking of these polygons across the provinces, to ensure errors were eliminated. In the future, processing should be considered only at provincial level, unless processing power has improved.

- Polygons from the NWM3, including those modelled through remote sensing and split with the landforms data set, appeared to have crept back in to NWM5.3. This resulted from of the fine-scale wetland data sets which have used these. These were not necessarily eliminated across all provinces, though some assistants did pick up this error visually and have attempted to eliminate these as far as possible.
- Merging of duplication of polygons as a result of combining multiple data sets. Noticeably depressions were mapped by different projects using imagery from different dates. Where the differences were minor, the polygons were merged. Where the differences were larger, the outer part of the depression was made the seep and the inner polygon the depression HGM wetland type.
- Small slivers were merged with the larger polygon, after exploding all features, to ensure there are no multi-part polygons.
- River channels still posed a contentious matter. Originally, the sand banks and flood bands of the DRDLR:NGI data were merged into river channels, or identified as potentially riparian. Later on, the section of the channel running through a floodplain or valley-bottom wetland, were split and included in the HGM wetland type adjacent to the channel. Consensus was not reached amongst members of the team and reference committee on how to deal with the river channels, flood banks and sandbanks. A future update should table these for discussion to resolve a sensible way forward.
- Gaps within wetland and river channels were filled in some instances, but not all. Sometimes the gaps are true islands, however in other instances these were data capturing errors resulting from mapping errors or different purposes of mapping inland wetlands and hydrological features by DRDLR:NGI. Future updates should attend to these in more detail.

4.6 Review protocol for the focus districts and remaining parts of the provinces

In the focus areas, the reviewers commented on the extent and HGM wetland types of the draft NWM5 through generating points where errors were noted, and added suggestions in the attribute field of the shapefile (Appendix F). A total amount of 849 points were received and addressed across all focus areas (Figure 4.5) by the assistants (Table 4.4).

Table 4.4: List of data capturers and assistants who participated in corrections of mapped wetlands in focus areas

Focus area (District Municipality)	Review comments Capturer	Reviewers
Amathole (EC) Buffalo City (EC)	Leolin Qegu, intern from National Research Foundation (NRF) based at the CSIR Pretoria from 1 May 2016 to 31 March 2017.	Wetland Consulting services (WCS)
Cape Winelands (WC)	Freshwater Consultancy Group	Freshwater Consulting Group (FCG)
Eden (WC)	Mthobisi Wanda, ICLEI	Nancy Job, appointed by ICLEI
Enhlanzeni (MP)	Millicent Dinala, intern funded through the WRC K5/2546 project	WCS
Francis Baard (NC)	Basanda Nondlazi (CSIR) and Namhla Mbona	WCS
Lejweleputswa (FS)	Ridhwannah Gangat, intern funded through the CSIR Parliamentary Grant (PG) funding	WCS
Vhembe (LP)	Tebogo Kgongwana, intern funded through the WRC K5/2546 project	WCS
Umgungundlovu (KZN)	Phumlani Zwane, intern funded through the CSIR Parliamentary Grant (PG) funding	WCS

A document template was provided to all reviewers who were involved in the reviewing of the draft NWM5 for the remainder of the provinces (Appendix F). A random selection of 30 points per HGM wetland type was done in ArcGIS, and the resulted point shapefile, as well as corresponding polygons, was sent to the respected reviewers (Table 4.5). The Cape Winelands District was amended at desktop level by the Freshwater Consultancy Group (FCG) and therefore no points are reflected in Figure 4.5 for this District.

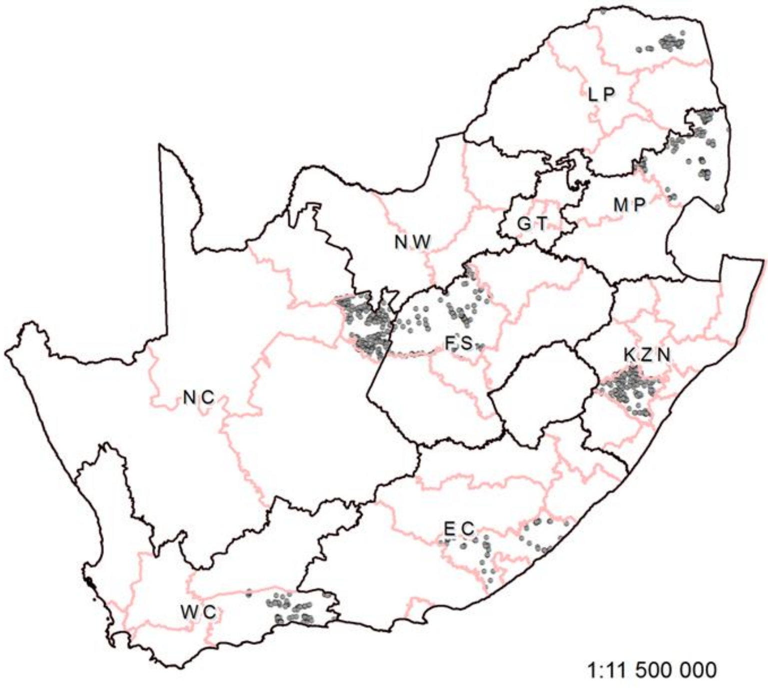


Figure 4.5: Shapefile points received from FCG and WCS for the review of wetlands mapped in the focus areas.

Table 4.5: List of assistants who participated in corrections of wetlands outside focus areas

Province	Person integrating provincial fine-scale data and editing layer	Person reviewing the layer
EC - Eastern Cape	Leolin Qegu (NRF intern based at CSIR Pretoria)	Mr Brian Colloty (Scherman, Colloty & Associates)
FS - Free State	Ridhwannah Ganget (GISc intern at CSIR Pretoria)	Dr Nacelle Collins (FS DESTEA)
GT - Gauteng	Ridhwannah Ganget (GISc intern at CSIR Pretoria)	Mr Retief Grobler (Imperata Pty Ltd) and Dr Althea Grundling (ARC-ISCW)
KZN – KwaZulu-Natal	Phumlani Zwane (CSIR GISc intern), Frikan Erwee (SANBI research assistant) and Millicent Ketelo Dinala (SANBI)	Mr Vince Egan or Mr Meshak Misindi, (LDEDET)
LP – Limpopo	Namhla Mbona (SANBI)	Mr Skhumbuzo Khubeka (EKZNW)
MP - Mpumalanga	Namhla Mbona (SANBI)	Mr Hannes Marais and Mr Mervyn Lötter, (MTPA)
NC - Northern Cape	Nhlananiso Biyela (SANBI)	Mr Enrico Oosthuysen (NC DENC) / Ms Nancy Job
NW - North-West	Ridhwannah Ganget (CSIR GISc intern)	Ms Hermien Roux (UNIVEN)
WC - Western Cape	Kedibone Lamula (SANBI)	Genevieve Pence (Cape Nature), Kate Snaddon (FCG), Nancy Job (UFS), Jeanne Gouws (Cape Nature), Dean Impson (Cape Nature)

The random selection of 30 HGM wetland type points per province, has resulted in 1 690 points across South Africa (Figure 4.6). Data edits for the Eastern Cape, the Free State, Mpumalanga, the Northern and Western Cape Provinces was received. Namhla Mbona and Millicent Dinala ensured that the correction of the required points was done by data editors for the provinces.

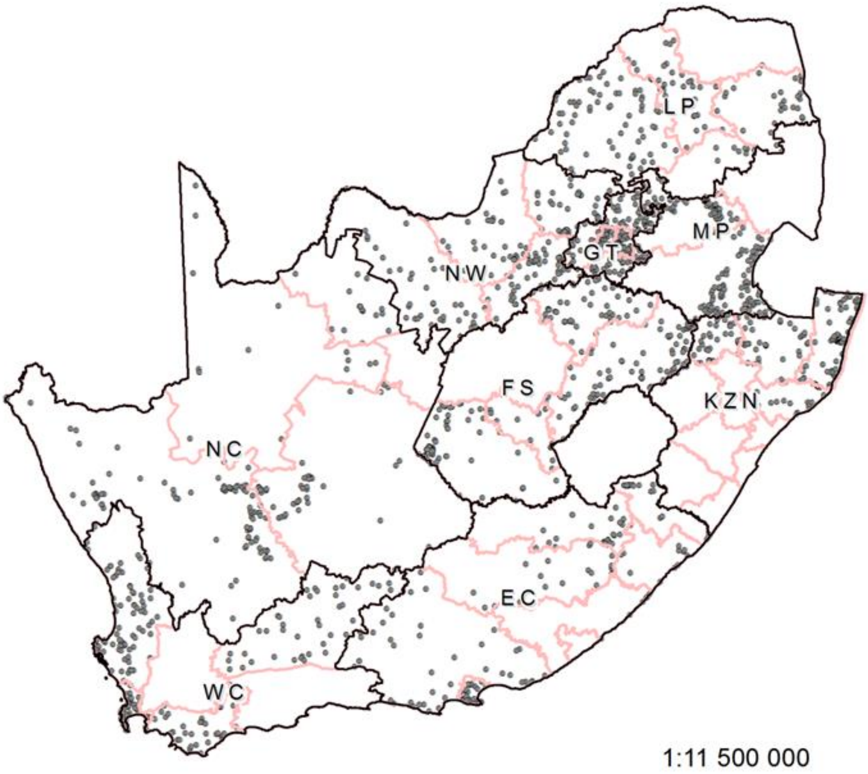


Figure 4.6: Wetland polygons sent for review in the remainder of the provinces.

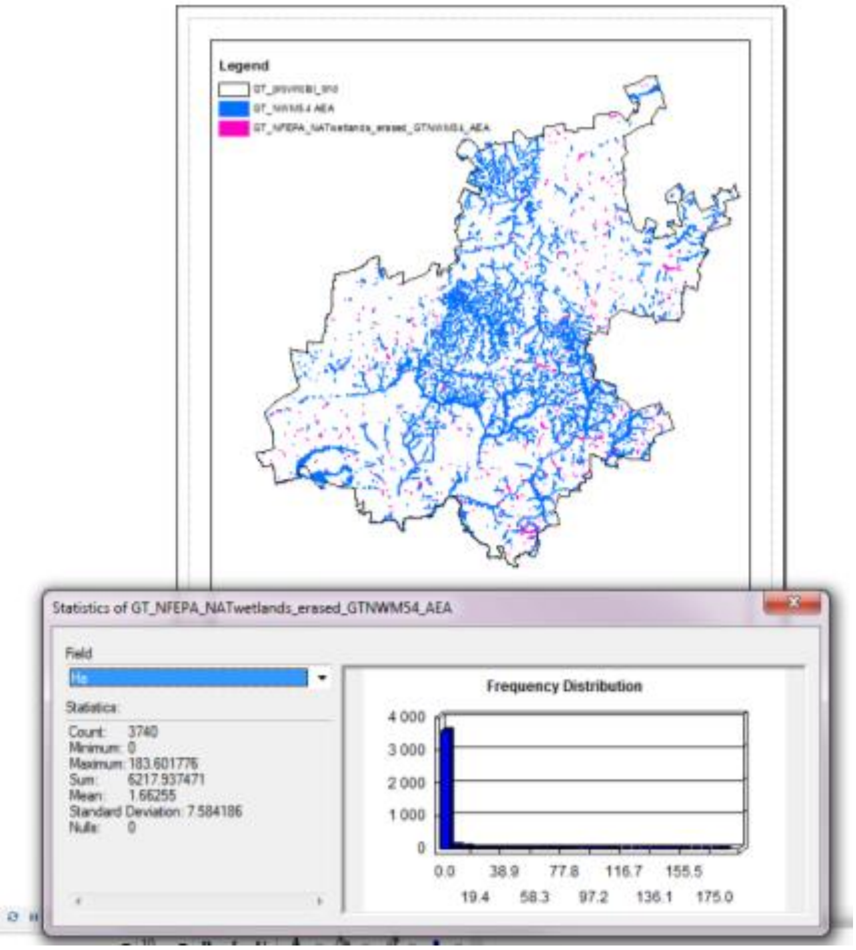
4.7 Assessing whether NWM4 should be added to the fine-scale map version of NWM5

As mentioned in the previous sections, the intention was to first compile a version of NWM5 which is purely fine-scale mapped at a desktop level, and then assess whether there are still areas of the NWM4 polygons which would be useful. In the focus areas, NWM4 were considered during the mapping of wetlands, however in the remainder of the provinces, NWM4 were not included. As such, this section reports the methods and results of the comparison between NWM5.4 and polygons from NWM4 not within NWM5.4. Both the extent and HGM wetland typologies of NWM4 were evaluated to assess whether the extent should be included and the HGM unit be remodelled or manually retyped.

The smallest province, the Gauteng Province, was used for the prototype comparison, assuming that the prevalence of commission and omission errors, generated through the modelling of wetland extent from remote sensing in previous NWMs, may prevail in other provinces.

The following GIS steps were taken in a geodatabase with the outputs indicated after '->' as feature classes:

1. Extract NWM4 for the province - > GT_NFEPA_GeoWGS84 (the latter referring to a naming convention of the province, data set and coordinate system, being unprojected geographic with the WGS84spheroid);
2. Project 'NATURAL' wetlands to the AEA coordinate system for South Africa - > GT_NFEPA_NATwetlands_AEA;
3. ERASE GT_NWM5.4 from the -> GT_NFEPA_NATwetlands_erased_GTNWM54_AEA;
4. Investigate the statistics related to the sizes of the remaining NWM4 polygons (Figure 4.7):
   The results showed the majority (74%) of NWM4 polygons are < 1.7 Ha in size (mean), or a total of 2 760 of 3 740. To assess whether there would be a certain threshold of selection large wetland polygons, the Ha field was sorted from the smallest size to the largest size and then randomly selected and viewed increments of approximately 0.5 and then 1 Ha at a time. Most of the polygons between 0.1 and 18 Ha were found to be commission errors, slivers or polygons on the edges of artificial wetlands. Since a thorough check was not done, it may be that there are some polygons which may be useful, however, the majority were found to be commission errors.
5. Polygons from NWM4 outside NWM5.4 were then selected where the Ha field were >= 18.9 (an arbitrary threshold selected from viewing each polygon below and above this size). The remaining depressions from NWM4 were also omitted, assuming that these were not modelled from the spectra and may still be considered for inclusion. Therefore: "Ha" >=18.9 AND "NWCS_L4" <> 'Depression'. An assumption here was that one would rather like to pick up large wetland systems from NWM4 not present by NWM5.4, rather than the very small polygons which may have resulted from spurious pixels from Landsat in the National Land Cover of 2000. The selection process resulted in 51 polygons which appeared to be useful. This was then entered as a definition query for the layer to minimise the display and these 51 polygons were then inspected one-by-one.



Statistics of GT_NFEPA_NATwetlands_erased_GTNWM54_AEA

Field: Ha

Statistics:

Count: 3740
Minimum: 0
Maximum: 183.601776
Sum: 6217.937471
Mean: 1.66255
Standard Deviation: 7.584186
Nulls: 0

Figure 4.7 NWM5.4 (blue polygons) displayed with NFEPA / NWM4 wetlands (pink) for the Gauteng Province, as well as the statistics of the NWM4 polygon sizes in the graph.

6. Explode polygons to avoid multi-part polygons: Select all polygons from GT_NFEPA_NATwetlands_erased_GTNWM54_AEA and explode; the UPDATE THE HA field.

The depressions remaining from the NWM4 outside NWM5.4 were then investigated from the largest to smallest ones. Most were seeps adjacent to existing depressions from NWM5.4 (Figure 4.8a). In some instances, the depressions were mapped on degraded land or appear to have resulted from interrupted drainage of roads, and an artificial wetland has formed (Figure 4.8b). Others merely represent differences in the extent to which a depression was mapped with different images (Figure 4.8c). It was therefore concluded that these polygons would have to be carefully evaluated before integration with the fine-scale version of NWM5.4 and it was agreed that this should rather be done during the improvement of NWM6.

Figure 4.8: Remaining data from NWM4 after NWM5 was removed: (a) A seep polygon highlighted in yellow from the remaining NWM4 data adjacent to a depression from NWM.54 (blue-filled polygons); (b) artificial wetland mapped in a degraded area; (c) slivers (red outlines) around depressions (blue-filled polygons).

7. Lastly, non-depression HGM wetland types remaining in NWM4 outside the fine-scale version of NWM5.4 were inspected for extent and HGM wetland types -> GT_NFEPA_NATwetlands_erased_GTNWM54_dslv_AEA.
   To evaluate the usefulness of these remaining polygons above 5 Ha, the remaining polygons were classified following visually inspected, according to the following rules:
   - if the majority of the NWM4 polygon falls outside existing data (NWM5.4) and were not considered to be wetland, it was classified as a ‘Commission error’;
   - if the majority of the NWM4 polygon was artificial, it was classified as ‘ART’;
   - if the majority of the polygon was useful but needs to be reshaped, it was classified as ‘Consider’;
   - if the polygon was rather a river, it was classified as a ‘River’; and
   - if the wetland was better represented by the *wetland probability map* (Figure 4.9), then it was classified as ‘*wetland probability map*’.

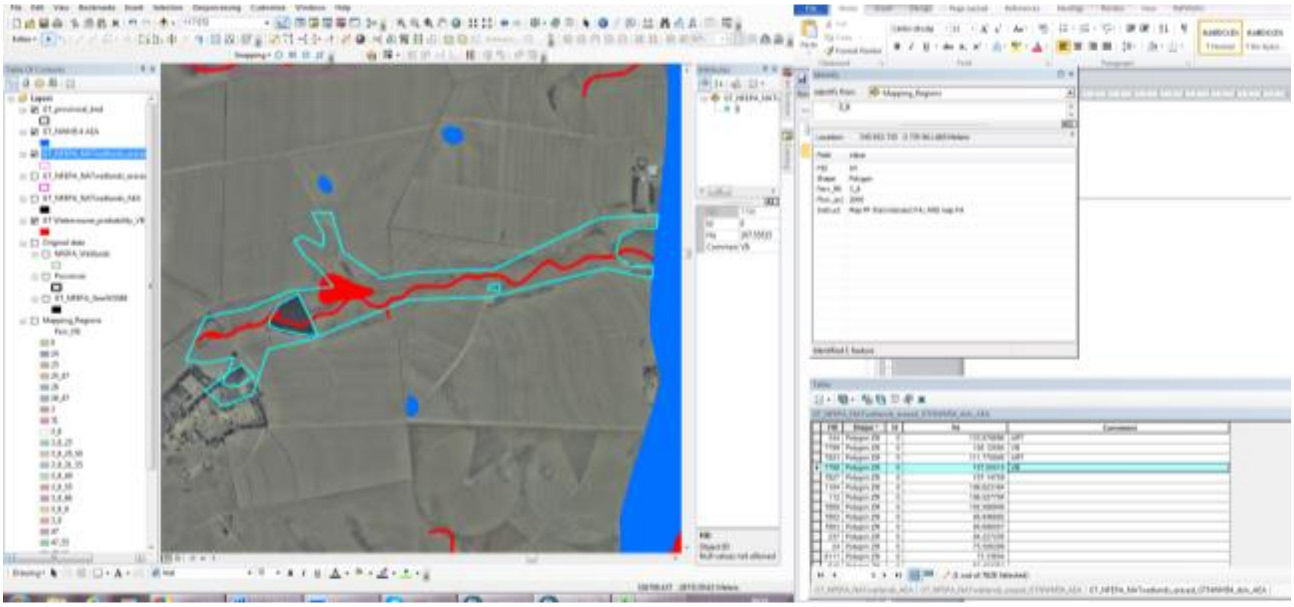


Figure 4.9: Valley-bottom polygon from NWM4 as a turquoise outline displayed with the NWM5.4 wetlands as blue filled polygons and the *wetland probability map* as red-filled polygons (for latter, see Chapter 5).

The majority of the remaining NWM4 wetland types (non-depression wetlands) were found to be slivers or small polygons < 5 Ha in size (33%) or commission errors (32%) (Table 4.6). Less than 1 122 ha (~19%) were considered useful for inclusion into NWM5.4; however most of these polygons would require manual editing to reshaped it to the correct extent and to avoid the inclusion of terrestrial areas (commission errors).

Table 4.6: Results of classes assigned to the remaining, non-depression, wetlands of NWM4 for Gauteng

Category	Number of polygons	Ha	% of total non-depression NWM4 remaining wetlands
Slivers and very small wetlands (<5 Ha)	7 628	1 980.3	33.3
Artificial wetlands	30	699.4	11.8
Commission error	127	1 872.9	31.5
Consider	**31**	**1 121.3**	**18.9**
Watercourse probability map	4	50.3	0.9
River	8	215.8	3.6

The inclusion of the NWM4 polygons outside the NWM5.4 fine-scale wetlands data set was therefore not considered for NWM5, however recommended for consideration during the improvement to NWM6. The size of the polygons that could be considered in Gauteng, ±1 000 ha, could also be added through consideration of large floodplain, valley-bottom and seep systems that could visually be detected and mapped in a quicker way, than by inspecting multiple small polygons. Expert-ID wetlands from the NFEPA wetlands which were natural, however, extracted and integrated into the provincial data set by Ms Namhla Mbona, Ms Millicent Dinala, Dr Andrew Skowno and Dr Heidi van Deventer.

The supplementation of the wetlands probability map to the NWM5 was also considered and is detailed in full in Chapter 6. Owing to a large amount of commission errors in this data set, it was not included into NWM5.

Concurrent to the finalisation of NWM5.4 for each province, Dr Heidi van Deventer (CSIR) and Ms Anisha Daryaram (SANBI) captured large floodplain systems across the country, totalling < 15 systems. All provincial NWM5.4 data sets were reviewed by Dr Heidi van Deventer in January 2018 and sent back to SANBI for final revisions and amendments.

4.8 Integration of provincial data sets into a country-wide National Wetland Map 5 (NWM5)

The improved provincial NWM5.4 versions were received by Dr Heidi van Deventer at the end of March 2018 for final integration. A number of steps have been taken during the final integration to ensure quality of the output file:

- Edge-matching between provinces, giving preference to the extent and HGM wetland typing of polygons where finer-scale data and mapping was available.
- Identification and refinement of the eight limnetic depressions in the country.
- Inclusion of the large floodplain systems.

- Improvements of the HGM wetland types:
    - Floodplain depressions, kept in some provinces separate from the floodplain flats, were correctly attributed at CS_L4B and corrected at CS_L4A and the subtype field to be floodplains. Not all floodplain depressions were included across all the provinces, since many have already been merged by interns into the Level 4A floodplain category. Future updates of the NWM could verify the "lakes" hydrological category of DRDLR:NGI visually to distinguish artificial ponds from floodplain depressions or ox-bow rivers on floodplains. The latter could be included as floodplain depressions into all floodplains of future NWM updates, and attributed to Level 4B of the Classification System. The DRDLR:NGI "lakes" polygons are not inland lakes at all and should not be used for reporting lakes. Only the eight limnetic depressions are lakes. The DRDLR:NGI "lakes" have been converted to a points data set and cleaned up by two interns and points added, to be used potentially in modelling floodplain systems. These required a final check and update by experts before it is used.
    - Wetland flats in most provinces were corrected to Level 4A depressions, except where it originated from data captured by wetland experts, such as the C.A.P.E. fine-scale project. A discussion with the inland aquatic reference committee and a number of wetland experts concluded that these systems are difficult to distinguish at desktop-level, particularly to determine if the source of water is purely groundwater driven, or also from seepage.
- Slivers < 0.125 Ha in size was checked and either merged or deleted. Springs buffered to 2 m resulted in an extent of 0.000313 Ha. These were kept in the data set and can potentially still indicate the origin of inland wetlands. Many other slivers and small polygons remain in the data set which can be considered for deletion. A thinness index can be calculated and a threshold selected to delete slivers, though users should be careful not to delete any polygons before visual inspection, since some may still be valid inland wetlands. The smallest depression mapped, for example, was measured at 0.0031 Ha or 3 m^2.
- Polygons with no HGM wetland type (435) were attributed a landform and HGM wetland type. Other corrections to HGM wetland types were done, particularly in the North West Province where longitudinal systems have been attributed as seeps. Further quality check would be required to ensure that longitudinal systems are correctly attributed.
- Polygons from the KwaZulu-Natal Vegetation Map, where the KZNVEGBIOME was related to wetlands, which were not included in the NWM5.4 version of the KZN Province, were added and typed.
- Other data sets such as those of the Hogsback and Tevredenpan areas, originating from the WRC K5/2545 project on the remote sensing of wetland vegetation (ongoing project, due to complete in the year 2020), as well as the wetlands map from the West Rand District Municipality done by Aurecon (Pty) Ltd (USAID, 2018), was integrated into the NW5.
- Updates to the peatlands data set in 2018, totalling 635 points, required the digitising of about 170 additional polygons which were not in the NWM5. Of these, 33 points were not mapped and will still require further investigating.
- Topology checks in ArcGIS were done several times to ensure no duplicate polygons remained.
- Consistency of all attribute fields, in particular those of CS_L3, CS_L4A and the subtypes field (NWCS_L4A).
- Dissolving the polygons to remove small slivers or divisions of a HGM wetland unit. A dissolve on the national data set containing 169 826 polygons was reduced to 878 records after 5 hours on a laptop and then exploded to 158 240 records again within 15 minutes.

- Assigning Level 2 attributes to CS_L2 for each polygon, as well as adding Bioregion information:
    - An update of the National Vegetation Map (NVM), VEGMAP17_v15_8_210518_AEA, was received from SANBI following updates done in 2018. The update included changes to the Albany Thicket Biome, the amalgamation of certain wetland-related polygons into adjacent vegetation groups, as well as the exclusion of the estuarine and coastal ecosystems mapped for the NBA 2018.
    - Swamp forests from the NVM were attributed to Level 6 (CS_L6) in the attribute fields.
    - The Wetland Vegetation Groups (WVG) (Nel et al., 2011) was re-assigned to the related vegetation types of the NVM. Alluvial vegetation, inland saline, forest and azonal categories were reassigned to adjacent vegetation types. Long linear systems were not split, resulting in potential intrusions of one category onto another. These need to be improved during future updates. The WVG were then dissolved and intersected with the NWM5. Where a polygon was dominated by one WVG, the WVG was assigned to Level 2 (CS_L2). Where more than one WVG was present within a wetland polygon, the dominant WVG was determined in Excel through an INDEX command using the extent (ha) in each WVG, and then attributed to the polygon under Level 2.
    - Bioregions from the NVM update (SANBI, 2018) were derived through dissolving the polygons on the Bioregions field. The ArcGIS Eliminate tool was used to subsume the following categories into adjacent bioregions: Alluvial Vegetation; Azonal Forests; Inland Saline Vegetation and Zonal & Intrazonal Forests. Similar to the WVG, the dominant Bioregion for each polygon was assigned in NWM5.

Owing to time and budget constraints, the names of wetlands present in NWM5.2, were not assigned to the polygons of NWM5.2 again. Although this is not a priority for the NBA 2018, or decision making and planning, names offer key reference points to users. Consideration should also be given to the standardised names and aliases for estuaries and whether these should be adopted by river (lines and polygons).

4.9 Alignment of Inland Aquatic Ecosystems with Estuarine and Coastal Ecosystems

During the investigation of the alignment between the NWM5.2 and the estuaries from the NBA 2011 in the Estuarine Ecosystems Classification Committee workshop March 2017, the estuarine and inland aquatic team noted a number of issues. Polygons mapped by the DRDLR:NGI outside the Estuarine Functional Zone (EFZ) as hydrological features were either inland wetlands, estuarine, coastal or terrestrial in nature. Some of these polygons, for example, included tidal pools, dunes or dune vegetation of which the latter had been captured at a low spatial resolution (lower than 1:10 000). Although it is recognised that all aquatic ecosystem would contribute to biodiversity, and that the ecotone of change is a fuzzy boundary, several steps were taken to ensure alignment of inland wetlands with the estuarine and coastal ecosystem types in the National Wetland Map 5:

- The extent of the Estuarine Functional Zones (EFZs) as well as micro-systems (micro-estuaries, ephemeral coastal streams, coastal seeps and waterfalls into the ocean) were finalised using the first 5 m contour above the shore, as well as vegetation mapped by NMU estuarine experts. These included Dr Lara van Niekerk (CSIR), Dr Fiona McKay (Oceans Research Institute – ORI), Dr Janine Adams, Ms Taryn Ridden and Ms Meredith Fernandez (NMU). EFZs and micro-systems were mapped where seawater surges inland into open waterbodies along the coast and are represented as polygons in the NWM5.

- The extent of the estuarine ecosystems were then aligned with the coastal ecosystem types, mapped by Dr Linda Harris (NMU) at a scale of <1:3 000. The coastal ecosystem types distinguished between the open-water and "floodplain" of the estuaries and the estuarine shores, both part of the EFZs, as well as micro-systems, but excluded outlets and seeps in the map integration. These amendments were then re-incorporated into the NWM5.
- Where an inland wetland exists through the shore as a seep, it was mapped as a point in the outlet data set of the estuarine ecosystems. These outlets will therefore not be reflected as polygons in the NWM5.

Further updates of the NWM should ensure that for each estuarine system, whether EFZ, micro-system or outlet, an inland wetland should be mapped to reflect the connectivity between inland wetlands, estuaries and the coast.

4.10 Creation of an artificial wetlands layer to be used for planning

As part of the development of the national wetland map a data set of artificial water bodies was built using the DRDLR:NGI hydrological features exported from NWM5.2. All non-natural feature types were included in this feature class and were checked for consistency and then integrated by Dr Andrew Skowno (SANBI) with the national 1:50 000 dams map. However, they were also verified or supplemented by data from the dams register of the Department of Water and Sanitation (DWS), which lists approximately 159 dams (DWS, 2015). This formed the foundational layer for the development of the artificial water bodies data set which was exported in the geodatabase as a "Modifications" feature class. The process of development of the map included basic desktop validation of features over 25 ha in extent, and the identification of dams built after 1990 – using the national dams register (DWS, 2015) and a range of remote sensing products. This final step was conducted in order to facilitate the use of the data set in the land cover change analyses. Appendix H contains a technical report covering the development of the artificial water bodies map for South Africa, version 1 (Skowno et al., 2018).

In a second phase of update to the artificial wetlands data layer, Dr Heidi van Deventer (CSIR) refined the extent and names of the 92 large dams monitored in the DWS NEMP. In addition, information from available point shapefiles, including the Aquaculture facilities (DAFF & DEA, 2018) as well as the WTW and WWTW (CSIR, 2015), were attributed to the polygon data set. Not all points had a polygon to attribute the information to (Table 4.7). Some slivers were removed up to an extent of < 0.000313 Ha and some of the adjacent polygons with different but related categories were merged. These include, for example, reservoirs, purification plants, sewerage works and WWTWs which may have been derived from different sources and dates of classification, however were the same facility.

The final map contains just over 200 000 features, covering an area of 598 381 ha, with dams making up the bulk of the artificial water bodies in South Africa (Table 4.7; Figure 4.10).

The accuracy of the underlying DRDLR:NGI hydrological features data dictates the accuracy of this layer to a large degree. Although efforts have been made to eliminate 'gross errors', the large number of features makes a comprehensive, feature by feature, validation process impossible, and many classification and mapping errors are likely to be encountered in the data set. The aim is to iteratively improve this data set through the release of an updated version annually or biennially.

The polygon representing artificial wetlands should be used in association with the Water Treatment Works (WTW), Wastewater Treatment Works (WWTW), invasive species and other data sets for condition modelling and planning processes to obtain a better reflection of the pressures on inland wetlands.

It is furthermore important to note that the current data sets have not been assessed for completeness. Some of the artificial wetland types listed in the Classification System but not in the inventory includes canals, excavations, salt works, aquaculture points and storm water ponds. Future updates should attend to the assessment of the completeness and accuracies of the existing data sets, as well as mapping the point features which are not represented in the Artificial wetlands layer. Furthermore, the full extent of a facility should be captured in the map. The DRDLR:NGI only maps the extent of the hydrological feature, therefore the points or reservoirs, and not the extent of the WTW or WWTW (Figure 4.11). Similarities between categories should be considered and those polygons amalgamated, following finalisation of definitions.

Table 4.7: Total extent and number of artificial water bodies and related features captured in the January 2018 version of the data set

Type	Count	Total extent (Ha)	Percentage of the extent (ha) of all artificial wetlands (%)	Nr of feature represented in polygon data set of total mapped as points
Large dams	97	225 140.0	37.6	
Aquaculture facility	15	372.3	0.1	15 of 265
Bridge	1	0.0	0.0	
Closed reservoir	201	93.4	0.0	
Dam	191 353	360 809.0	60.3	
Fish farm	35	97.4	0.0	
Large reservoir	3 031	894.6	0.1	
Open reservoir	9 140	9 296.7	1.6	
Purification plant	47	62.3	0.0	
Reservoir	3	8.4	0.0	
Sewerage works	335	337.0	0.1	
Slimes dam	1	5.0	0.0	
Water tank	373	44.2	0.0	
Waterworks	3	0.2	0.0	
Weir	3	0.7	0.0	
WTW (CSIR)	11	326.7	0.1	11 of 630
WWTW (CSIR)	243	852.3	0.1	243 of 780
Total	**204 892**	**598 380.6**		

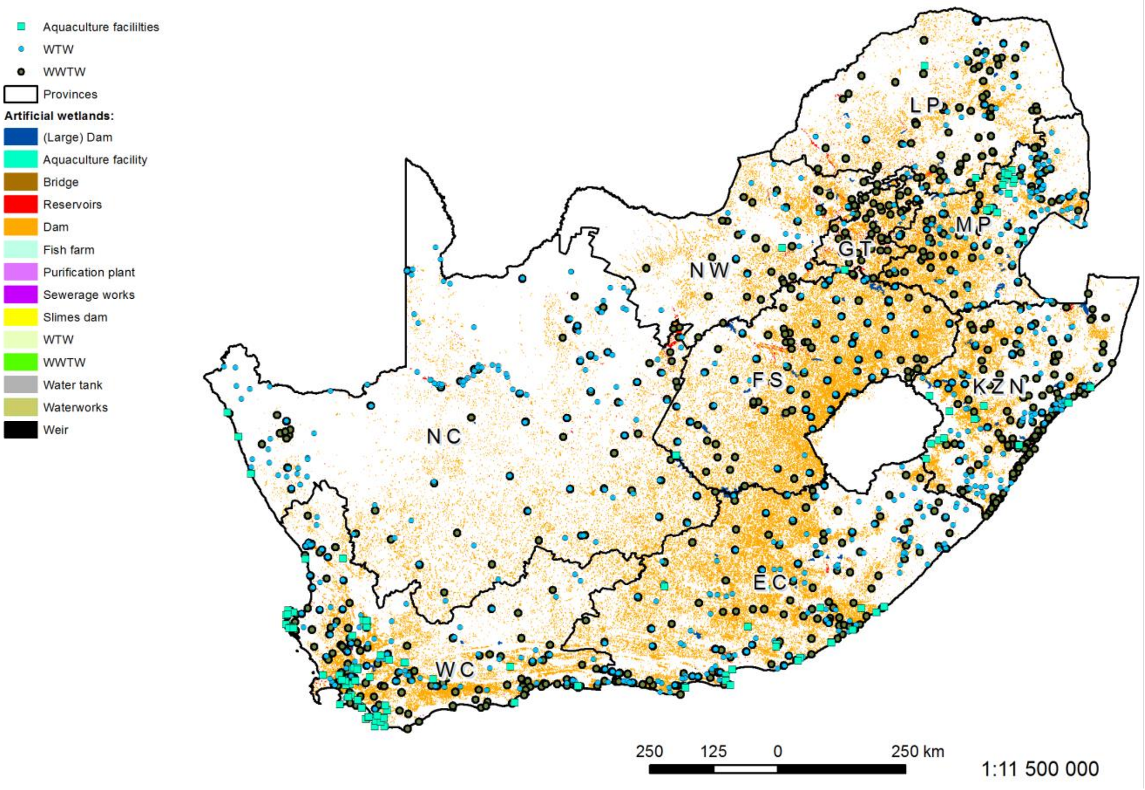


Figure 4.10: Artificial wetlands in the South African Inventory of Inland Aquatic Ecosystems.

Figure 4.11: The extent of Waste Water Treatment Works (WWTW) as mapped by DRDLR:NGI.

4.11 Results of the improvement of NWM5

4.11.1 Results of NWM5 for country

The final National Wetland Map version 5 (NWM5) shows the distribution of the estuaries and inland wetland HGM types across South Africa (Figure 4.12). Not only has the number of data sets represented in the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) increased, but also the number of ecosystem types within the NWM5: we now have Estuarine Functional Zones (EFZs), estuarine micro-systems, inland wetlands and rivers included, totalling **nearly 4 million hectares (ha) of aquatic ecosystems** which cover 3.3% of the surface area of South Africa (Table 4.8; Figure 4.13). Various categories of artificial wetlands are also now mapped, totalling almost 600 000 ha in a separate data layer.

NWM5 shows an increase of 123% of inland wetlands mapped compared to the NFEPA natural inland wetlands. **A total of 2.6 million ha of inland wetlands have been mapped in NWM5** and typed to HGM wetland types, making up 2.2% of the surface area of South Africa (Table 4.8; Figure 4.13). A total amount of 201 381 ha of estuaries have been added and > 1 million ha of river channels.

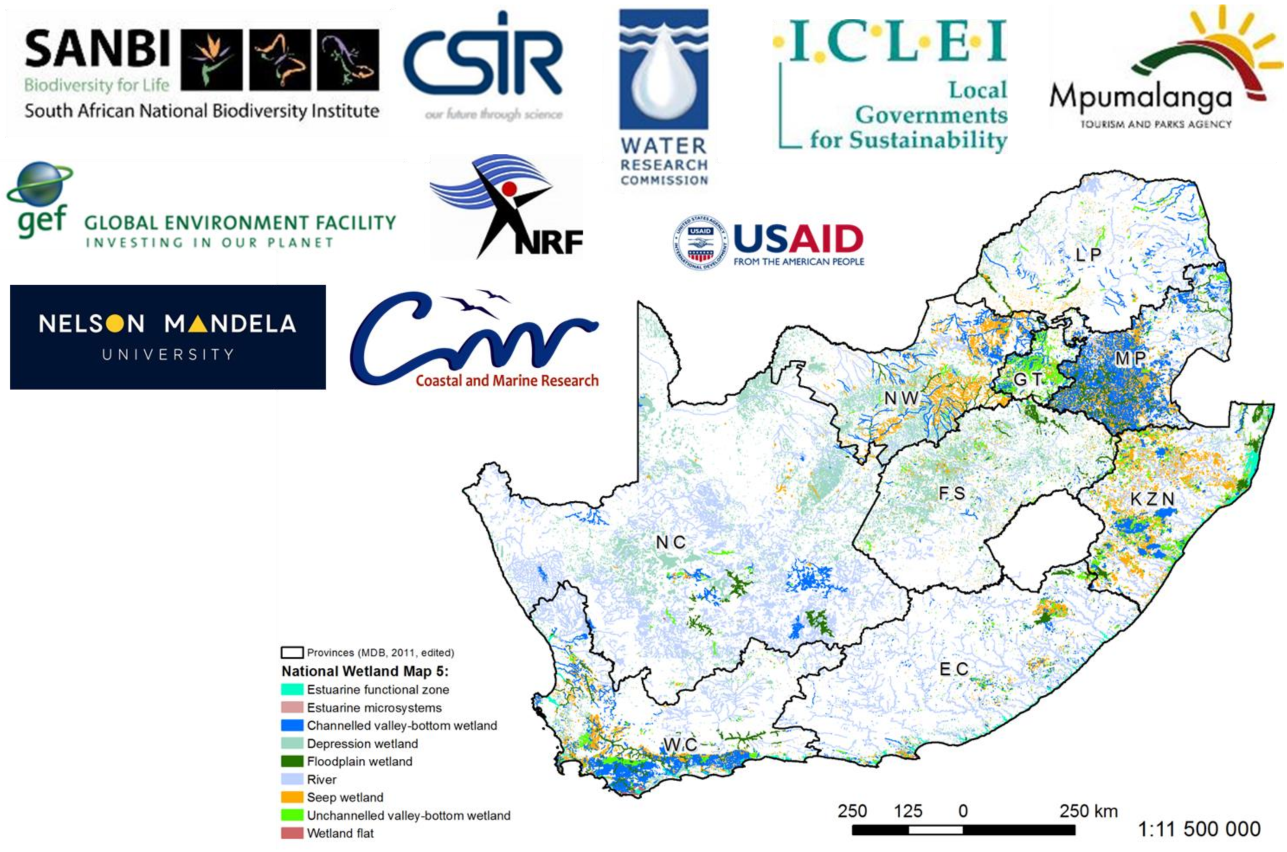


Figure 4.12: Representation of the estuaries and hydrogeomorphic wetland types of National Wetland Map 5. Logos of the funding organisations are included.

Table 4.8: Statistics for Aquatic Ecosystems* represented in the National Wetland Map 5

National Wetland Map version (across)/ Realm types	NWM1 (2006)	NWM2 (2007)	NWM3 (2008)	NWM4 (2011)	NWM5 (2018)
Estuarine Functional Zone (EFZ)				165 934.1	200 820.6
Estuarine microsystems (micro-estuaries)					560.7
Artificial wetlands - large dams (92 of NEMP)					225 140.0
Artificial wetlands - other	-	321 114.2	528 067.3	528 187.3	373 240.5
Rivers					1 146 232.1
Wetlands (not typed)	1 961 948.5				
Total extent of inland wetlands mapped for SA:		**1 575 683.3**	**1 527 607.4**	**2 152 104.3**	**2 649 914.8**
Wetland and waterbodies	1 961 948.5	1 575 683.3	1 527 607.4		
Channelled valley-bottom				494 380.8	681 065.6
Depression				734 042.0	764 243.9
Wetland flat				151 573.0	15 266.6
Floodplain				452 838.6	547 108.4
Seeps (including Hillslope seeps)				238 232.7	454 217.0
Unchannelled valley-bottom				81 037.2	188 013.3
Total extent of estuaries	-	-	-	165 934.1	201 381.3
Total extent of inland wetlands	1 961 948.5	1 575 683.3	1 527 607.4	2 152 104.3	2 649 914.8
Total extent of rivers	-	-	-	-	1 146 232.1
Total extent of all wetlands	1 961 948.5	1 575 683.3	1 527 607.4	2 318 038.4	2 851 296.1
Total extent of Aquatic Ecosystems	1 961 948.5	1 575 683.3	1 527 607.4	2 318 038.4	3 997 528.2
Extent of estuaries as % of SA				0.14	0.17
Extent of inland wetlands as % of SA	1.61	1.29	1.25	1.76	2.17
Extent of all wetlands as % of SA (estuaries and inland wetlands)	1.61	1.29	1.25	1.90	2.34
Extent of all Aquatic Ecosystems as % of SA (estuaries, inland wetlands and rivers)	1.61	1.29	1.25	1.90	3.28

** Shallow marine systems are included in Aquatic Ecosystems but will be documented by the Coastal Ecosystem.*

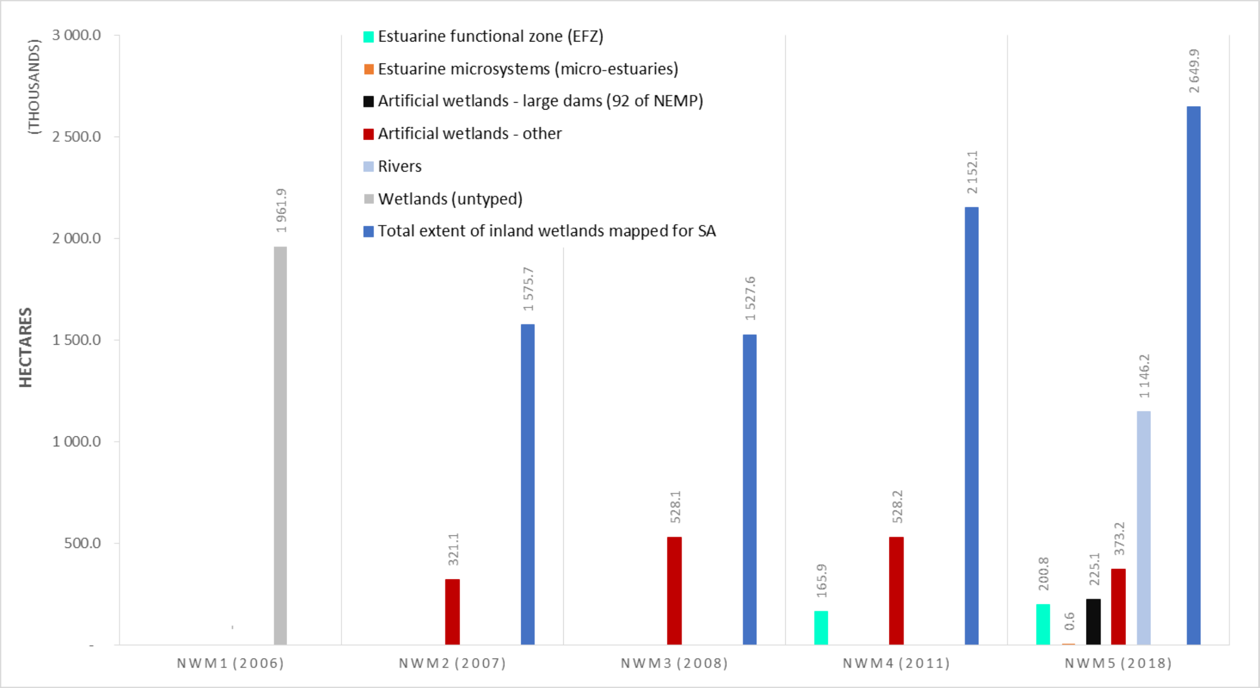


Figure 4.13: Increase of area (hectares) being mapped for the inland aquatic and estuarine ecosystems in National Wetland Map version 5 (NWM5).

NWM5 shows an increase in the extent for the majority of HGM wetland types compared to the NFEPA natural wetlands (Figure 4.14). The over estimation of the extent of wetland flats modelled in the NFEPA natural wetlands data set, has been reduced to reflect only wetland flats mapped in fine-scale data sets, such as the C.A.P.E. project. Depression wetlands show a minor increase from the NFEPA natural wetlands to the NWM5 data set. Depressions were not modelled in the NFEPA wetlands, but incorporated from the DRDLR:NGI data from 2006. Similarly, NWM5 used both the 2006 and 2016 depressions from DRDLR:NGI, though supplemented it with fine-scale mapped data which included additional depressions. An increase in extent of > 120% of wetlands mapped in NFEPA, is observed for the other HGM wetland types, including the floodplains, seeps and valley-bottoms.

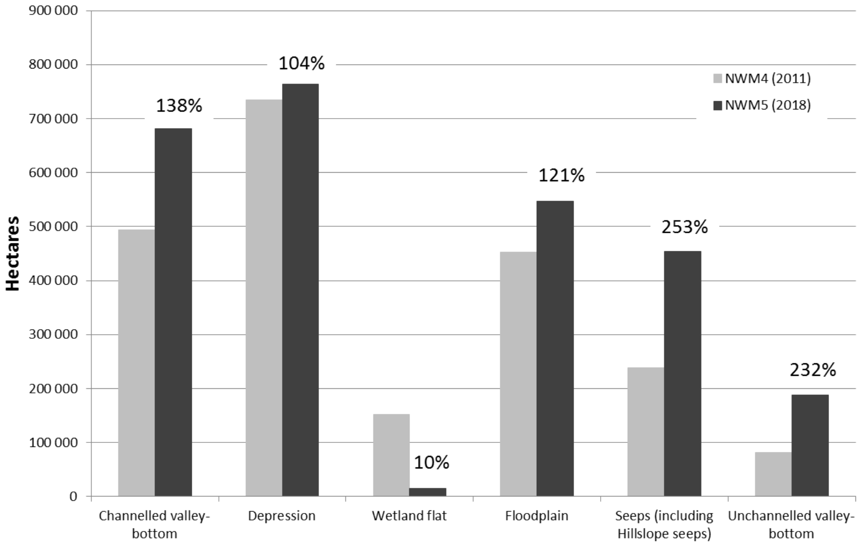


Figure 4.14: Improvement in National Wetland Map 5 per hydrogeomorphic wetland type.

In total we estimate that more 31 data editors distributed across > 10 organisations have been involved in the data mapping, integration and finalisation of the inland wetlands and estuarine ecosystem represented in NWM5. The cost of generating NWM5 is estimated at > R7 million during a period of only two years.

4.11.2 Results of NWM5 for the focus areas

NWM5 showed an increase in the extent of HGM wetland types for seven of the nine focus areas where inland wetlands had been mapped (Figure 4.15). In three of these focus areas, the extent increase by > 150% of the inland wetland extent mapped in the NFEPA wetlands, including the Umgungundlovu, Vhembe, Ehlanzeni Districts. In three of the focus areas, namely the Buffalo City, Lejweleputshwa and Frances Baard Districts, a reduction in the extent of inland wetlands was observed when NWM5 was compared to the NFEPA natural wetlands. All three of these districts are in more arid regions. Some of these had been attributed to commission errors in the NFEPA wetlands that had been removed, as well as expert knowledge from Dr Nacelle Collins on inactive paleo river systems in the north-western part of the Free State Province, which now had been removed in NWM5.

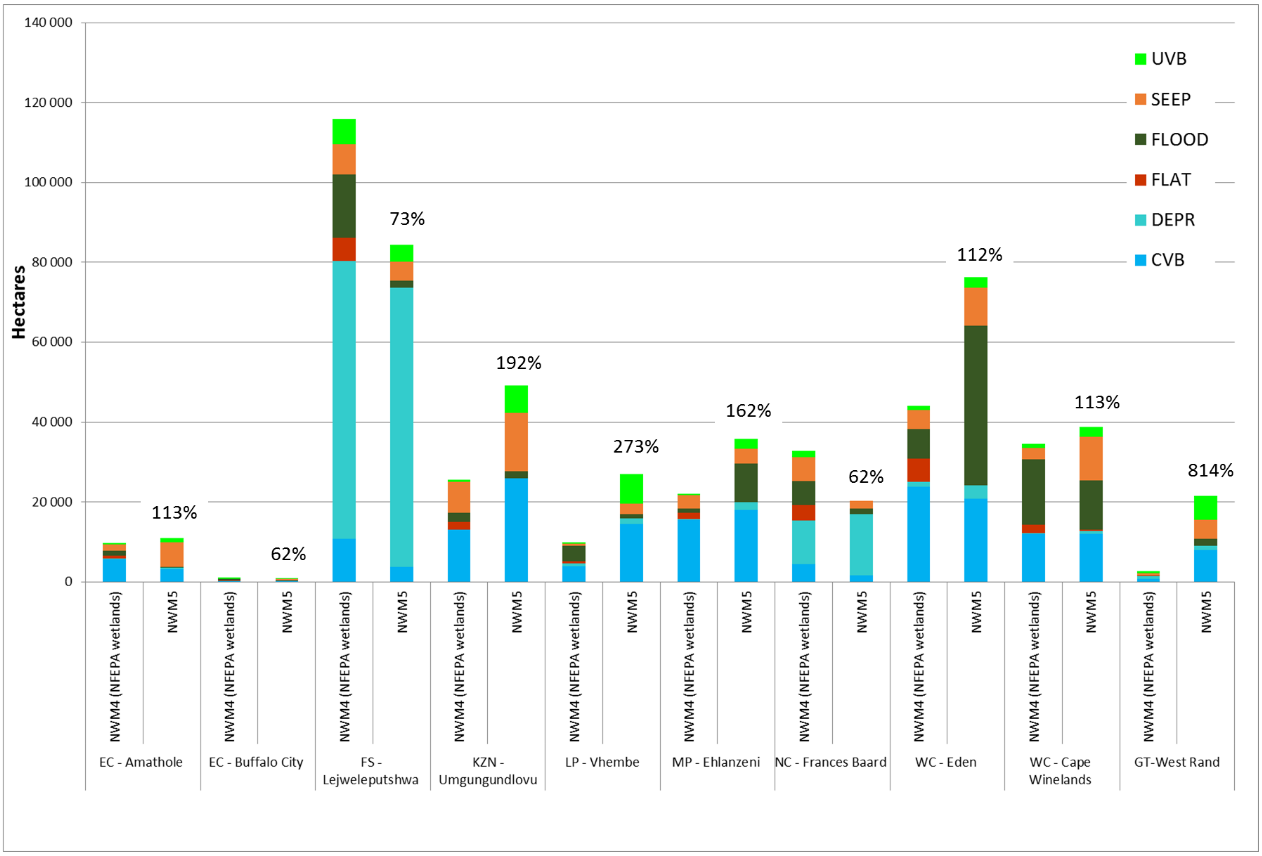


Figure 4.15: Extent (ha) of hydrogeomorphic wetland types represented in the NFEPA natural wetlands and NWM5 for the nine focus areas and the West Rand District Municipality (USAID, 2018).

It was quite interesting to note that the extent of inland wetlands for the West Rand District Municipality in Gauteng had increased by >800%! The increase followed the supplementation of NWM5.4 of the Gauteng Province with the *wetlands probability map* (Chapter 6), as well as the reshaping and HGM typing of the inland wetlands by Dr Joseph Mulders and Dr Heidi van Deventer. The NWM5.3 for the Gauteng Province, prior to the supplementation of the *wetlands probability map*, showed a 314% improvement of the extent of the inland wetlands compared to the NFEPA natural wetlands map, whereas the *wetlands probability map* added another 500% improvement compared to the NFEPA data. While the integration of more than 9 data sets for the Gauteng Province into NWM5.3 took quite some time, the supplementation, reshaping of extent and typing of the wetlands of the *wetlands probability map* took less than two weeks by the two experienced personnel.

4.12 Comparison between the NWM5 and the National Wetland Vegetation Database

A comparison was done between the NWM5 and 5 137 relevés of the National Wetland Vegetation Database (NWVD) of Sieben (2015). Nearly 60% of the relevés of the NWVD had no polygons represented in NWM5 (Table 4.9), which emphasize that there remain a large underrepresentation of inland wetlands, regardless of the improvements. Twenty-two percent of the relevés had polygons in the NWM5 which were congruent in HGM wetland types. Another 6% of the relevés had polygons in NWM5 however showed discrepancies in the HGM wetland types. Further investigation showed that multiple relevés were taken within one large inland wetland unit represented by one polygon, and if the HGM wetland unit different, this was detected as multiple differences. In addition, HGM wetland types of floodplains, for example, was typed in the NWVD at Level 4 B of the classification system as “depressions” which occurred on floodplains. Comparisons with Level 4A appeared as discrepancies, but were however similar HGM wetland types. Some relevés within the estuarine ecosystems were also typed as inland wetlands, which may reflect a gradual transition from one system to another, and is not necessarily incorrect in either of the two data sets, but merely that different criteria and scales have been used in the typing of the aquatic system.

The HGM wetland type assigned to approximately 291 relevés (5% of the total number of relevés) could potentially be updated, however since NWM5 received fine-scale typed data sets from various wetland experts, the changes of these polygons require a process of verifying the type against the source and review points before it is changed. Owing to time and budget constraints, the team decided to leave these points for further investigation and improvement in NWM6.

Table 4.9: Comparison between NWM5 and the National Wetland Vegetation Database (Sieben, 2015)

Category	Number of points	% of total inland wetlands matching with the NWVD and mapped in NWM5	% of total number of relevés
Comparable / congruent	1223	53.4	21.9
Not congruent with the NWVD	330	14.4	5.9
Consider changing in NWM6	291	12.7	5.2
Not mapped in NWM5	3293		59.0

4.13 Confidence map

A confidence map was compiled to identify areas where the extent and HGM wetland types attained a higher level of certainty compared to other areas. For the purpose of this first version of the SAIIAE, higher levels of certainty are associated with areas that have been visited in-field by a wetland specialist(s) over multiple seasons and cycles of the hydroperiod of a wetland, and accurately represented in the data set. Accuracy, on the other hand, reflects the degree to which the spatial boundaries and/or attributes of the wetlands match those in the real world (Pascual, 2011). A higher confidence score would imply an increase in accuracy, assuming that the spatial boundaries of a wetland had been informed by water, soil and vegetation indicators, and recorded with differential GPSs. Low confidence scores would imply the inverse.

A number of confidence ratings have been developed for the inland wetlands included in the NWM5 (Table 4.10). These have been primarily derived from the data received for the SAIIAE (Van Deventer et al., 2018). Confidence ratings have been assigned to the sub-quaternary catchments (SQ4s) of South Africa (Figure 4.16). The majority of the country (69%) has a Low confidence rating for NWM5, where the data is a cross-walk of DRDLR:NGI hydrological features to the HGM wetland types. For 24% of the country, interns trained by wetland specialists, have mapped the extent and HGM wetland types at a desktop level, resulting in a Low to Medium rating of confidence. For 7% of the country, desktop mapping was done by wetland specialists, resulting in a Medium confidence. For a very few number of SQ4s, or parts thereof, in-field verification was used to modify the extent and HGM wetland types of polygons in the NWM5. None of the SQ4s had studies which considered the long-term hydrological cycles of the inland wetlands, and therefore no part of the country had a confidence rating of High.

The confidence rating map should always be consulted to assess whether the NWM5 is fit for purpose. The confidence of estuarine and coastal ecosystems is not reflected in this confidence map (Figure 4.16). In general, areas mapped as a Low confidence, is likely to still have a 50% omission error, though the commission error may have been reduced to < 10% compared to the previous versions of the NWMs. The appropriate scale of use would be 1:50 000. Where the confidence rating is Low to Medium, Medium and Medium to High, we estimated the omission error to be <30% and the commission error < 10%. The appropriate scale of use would be 1:10 000.

Table 4.10: Confidence ratings assigned to sub-quaternary catchments based for inland wetlands

Rating	Description
1 – Low	Desktop mapping of the extent of inland wetlands was done by non-wetland specialists for a part of, or the full extent of the SQ4.
2 – Low to Medium	Desktop mapping of the extent of inland wetlands was done by interns trained by wetland specialists for the full extent of the SQ4.
3 – Medium	Desktop mapping of the extent of inland wetlands and HGM typing was done by wetland specialists for the full extent of the SQ4.
4 – Medium to High	Desktop mapping of the extent of inland wetlands and HGM typing as well as field verification and revision by experts was completed for the full extent of the SQ4.
5 - High	Inland wetlands have been mapped and verified for a period of > 10 years over multiple hydrological cycles for the full extent of the SQ4. Verification may include field observations as well as soil and/or vegetation surveys.

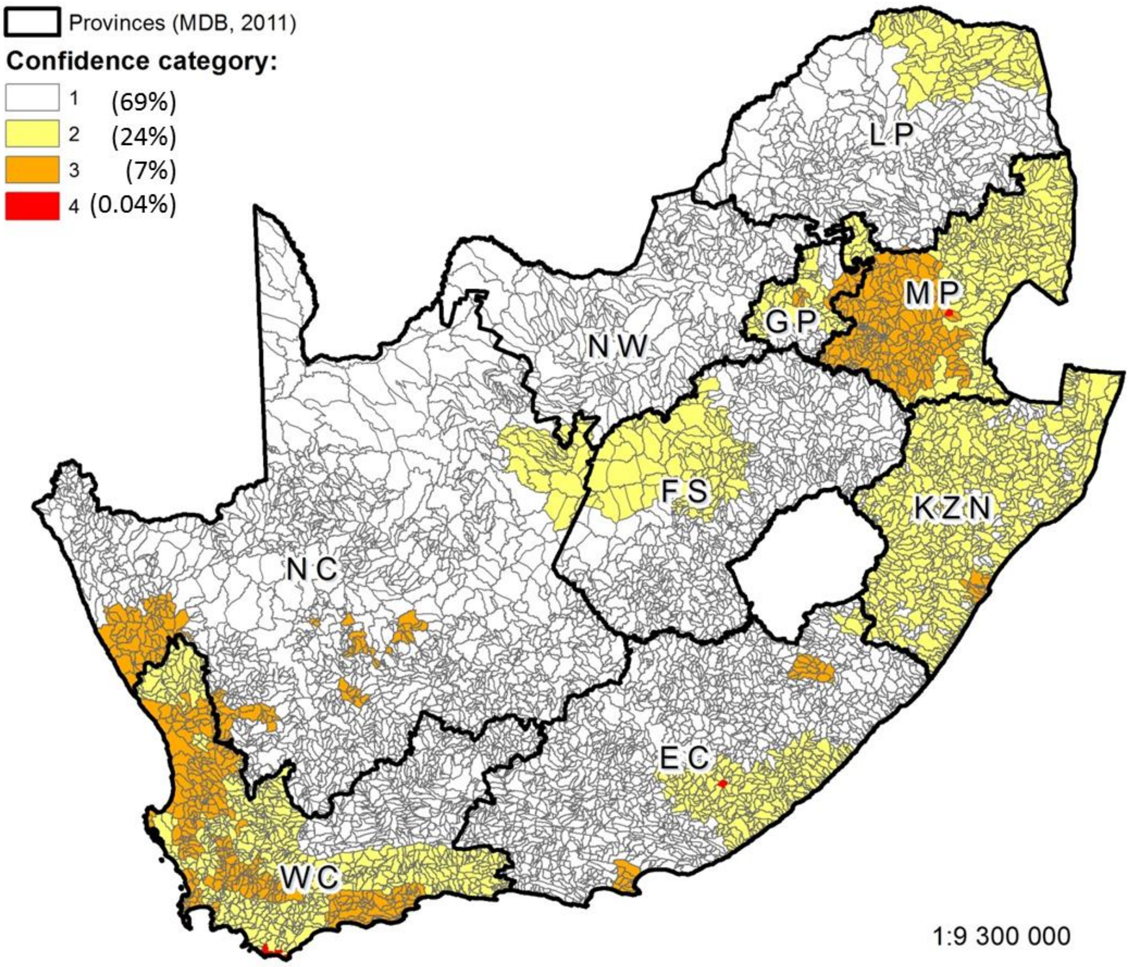


Figure 4.16: Extent of areas with various ranks of confidence for the extent and hydrogeomorphic typing of inland wetlands in the country. Table 4.9 provides definitions of the various ratings of confidence.

4.14 Recommendations of future updates

During the course of the finalisation of the NWM5, Ms Nancy Job has been appointed as the Programme Manager of the Freshwater Biodiversity Unit at SANBI (1 February 2018). This unit will further address the strategy of updating NWM6 and the identification of priority areas and approaches in doing so.

We provide herewith a summary of recommendations for future updates of the NWMs for the consideration not only by this unit of SANBI, but many other stakeholders who have interest in the improvement of the NWM.

Adopt the principles in data capturing:

- The original extent of the wetland should always be captured.
- The maximum extent of a wetland should always be captured. Multi-temporal imagery across hydrological cycles should be used to determine the maximum inundated extent of a wetland across hydrological cycles.
- The HGM wetland types and condition assigned in fine-scale wetlands data sets received from wetland experts should always be retained.

Improvements to the extent of the NWM5:

- Aim for immediate improvement of 75% of the country to at least confidence level 2 (Low to Medium) within the next 5 years. Immediate updates of the FEPAs are illogical while the majority (69%) of the country's inlands wetlands are mapped at a low confidence with an estimated 50% omission error. Collaboration in reaching this target is crucial.
- Desktop reshaping and typing of polygons from the *wetland probability map* appears to be a very quick and effective way of addressing omission errors in the NWM5.
- Desktop mapping wetlands for the remaining peatlands points and relevé points not captured in NWM5. These should be a quick exercise since there are < 350 polygons to map.
- Reintegrate the river channels of the DRDLR:NGI into the NWM to remove 'commission errors' of inland wetlands which should be in fact rivers.
- Desktop verification of small polygons mapped in NWM5 as inland wetlands, but also appear in the Artificial wetlands layer as farm dams.
- The improvement of definitions, categories and desktop mapping of artificial wetlands. These systems are important for assessing hydrological regime impacts on wetlands and rivers, fragmentation and planning. Similar to the inland wetlands, a confidence map should be developed for the artificial wetlands, as improvements are progressively done across the country.
- Closing polygons where a dam are or have been within the inland wetland. These improve the original extent of the inland wetland ecosystem types for NBAs. The artificial wetlands can always be used with the NWM for planning purposes.
- Large floodplain and valley-bottom wetlands not mapped in NWM5 can be easily detected and supplemented from the alluvial categories of the 1:250 000 geology and NVM, if not already integrated from the *wetland probability map*.

Improvements to the NWM that are of secondary importance:

- Removing slivers using a thinness threshold. This may be a time-consuming process with minor impact on the extent of inland wetland ecosystem types represented and assessed. This should not be done as a top priority.
- Names of wetlands were lost from NWM5.2 to NWM5.4. Spend time assigning names to inland wetlands again. It makes the map user friendly and serves as search facility and common reference.
- Do a desktop cleaning of the oxbow rivers (polygons and point data set). Both these data sets can be valuable for use in the typing of the HGM types. The point data set could facilitate improved modelling of inland wetlands in modelled data sets, such as the *wetlands probability map*. The polygon data set can facilitate the division of a floodplain into the floodplain flat and floodplain depression subcomponents.

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5. CHAPTER 5: MODELLING OF PROBABLE WETLAND EXTENT

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This chapter provides an overview of the method used to procedure to create a map of predicted wetland extent.

5.1 Introduction

An objective of the National Biodiversity Assessment 2018 (NBA 2018) process was to improve on some of the existing national spatial data sets available at the time. The poor spatial accuracy of the national wetlands layer has been a long time concern and was identified as a priority layer for improvement.

Methods previously employed for mapping wetlands have not produced satisfactory results. Some casual observations have estimated that in certain regions the wetland features of the National Freshwater Ecosystem Priority Areas (NFEPA) wetlands layer, which is informed by National Wetlands Map 3 (NWM3), account for only ±20% of the wetlands in certain regions. Not all wetlands are mapped equally poorly, with wetlands of the valley floor landscape unit being of particular concern. In-field mapping of wetlands by Mbona et al. (2015) showed that 68% of wetlands mapped in the Mpumalanga Highveld were located on valley floors, which when considering the above, explains findings that the more recent and improved National Wetland Map 4 (NWM4) is estimated to account for less than 54 % of the wetlands found at the fine-scale level (Mbona, et al., 2015; van Deventer H. , 2016). The results of these studies also showed hydrogeomorphic (HGM) type classification and the wetland condition assigned to the wetlands to be inaccurate in NWM4 (van Deventer, et al., 2016).

Low mapping accuracies of NWM4 are also expected for the rest of the country (Mbona, et al., 2015). According to Mbona et al. (2015) these widespread weaknesses are considered to be of sufficient severity to warrant investment in the improvement of the National Wetland Map as a matter of urgency, hence the efforts of the NBA 2018 process to improve on this layer. In addition to presence/absence inaccuracies the NWM4 also suffers from poor contiguity of inland aquatic systems within and between individual wetlands.

The NBA 2018 process therefore set out to improve on NWM4 by creating National Wetlands Map 3 (NWM5). Two approaches to improve the NWM5 were pursued, these being (van Deventer H. , 2016):

- A fine-scale wetlands map to be created by heads-up digitising from imagery with inclusion of data from the Department of Rural Development and Land Reform: National Geo-spatial Information (DRDLR:NGI) as well as newly acquired fine-scale data.
- A data set of modelled (predicted) wetland extent.

This chapter reports on the technical procedure to create the map of predicted wetland extent.

5.2 Background

The South African national wetland inventory has seen several improvements over the past decade. Numerous improvements have been enacted on the original wetlands map and the latest release is the NWM4. NWM4 has recently received some criticism, specifically the spatial accuracy, the latter referring to both wetland representation and boundary delineation. Wetlands associated with the valley floor landscape unit in particular are considered to be poorly mapped. Considering the fact that previous image based approaches have not produced satisfactory results, alternative methods for mapping wetlands were investigated.

A Digital Elevation Model (DEM) based approached was considered as a possible alternative. It is a desktop approach which, considering the extent of the study area (RSA), is considered to be a practical and appropriate solution. The DEM-based approached stems from the landscape position criterion of the indicators and criteria for identifying and delineating wetlands (DWAF, 2005) and is based on the logical assumption that water will accumulate within the lowest position of the landscape which therefore represent areas of highest probability for wetland[1] development. The low lying areas are watercourses per the National Water Act and include amongst others rivers, springs, natural areas in which water flows regularly or intermittently, wetlands, lakes and dams (DWAF, 2005). It follows that although wetlands are most likely to develop within these low-lying areas, that features other than wetlands are also present. It is also possible that many of the watercourse areas do not contain any wetlands at all as wetland development does not only require the presence of low lying areas, but also depends of other factors, e.g. mean annual precipitation, slope, soil depth, etc. The aim was therefore to map the valley floor areas, but to limit the valley floor areas mapped to those that are considered to be wetland as subjectively identified from imagery. Depending on a number of factors the areas mapped in the final output may or may not be wetland, and considering the fact that it is a desktop approach using remote sensed data, there is no certainty as to the likelihood of the mapped areas actually being wetland or not. The output of the mapping process is therefore referred to as a '*wetland probability map*'.

There are a number of tools available in Geographical Information Systems (GISs) with which to identify and map the valley floor landscape unit from Digital Elevation Model (DEMs). Probably the best known is the Topographical Position Index (TPI) tool (Jenness, 2013). The TPI tool determines landscape position by comparing differences in elevation of a cell with the average elevation of surrounding cells. The degree to which elevation and slope of the target and surrounding cells differ are used to assign cells to different landscape position categories. For example, cells that are significantly higher than the surrounding cells and that are located on a flat surface are likely to be ridgetops or hilltops, whereas cells that are on a flat location and at or near the bottom are most probably valley floors. The number of values surrounding the target cell considered is determined by the user by specifying the size of a moving window where the elevation of the target cell (the cell in middle of the window) is compared with the elevation of the cells within the remainder of the moving window.

The TPI tool was used during initial attempts at mapping valley floor areas and although the outputs were subjectively considered to be not satisfactory, they did represent a minimum level of improvement on previous attempts at mapping wetlands. Perceived inaccuracies of the TPI tool relate to mapping wetland occurrence and extent. Relief can change over very short distances and areas of different relief require different TPI tool parameters, specifically different moving window sizes. Suitable parameters are

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[1] Watercourses include wetlands, but not all watercourses are wetlands (DWA, 1998).

determined by trial and error and the area of which the valley floors were satisfactory mapped for a specific set of parameters are determined as a post mapping exercise. New parameters need to be set for the ‘not so accurately mapped’ areas which again will only accurately map certain areas while new parameters will have to be determined of the remainder of the areas for which the current parameters do not apply. To map wetlands in different landscape positions within the same area will also require different parameters, specifically different moving window sizes. It follows that a set of parameters will map some of the wetlands within an area while a new set of parameters are required to map other wetlands of the same area. Similarly the wetlands of other areas will again require new parameters. Because the accuracy with which the valley floor areas are mapped can only be determined after the tool finished a run, the TPI tool cannot be applied in a systematic manner to consistently map wetlands of all landscape positions in all areas and was therefore considered not suitable for mapping the valley floors of an area the size of South Africa. In addition to the latter the output of the TPI tool is a single continuous feature which in reality may consist of different HGM units. This is undesirable as the mapped feature (valley floors) will at a later stage have to be typed per Ollis et al. (2013). This will be problematic if wetlands of potentially different HGM type are not mapped as separate features.

While the TPI tool maps all terrain units (ridges, upper slopes, middle slopes, flat slopes, lower slopes and valleys), other tools are dedicated to mapping valley floor areas only, e.g. the ‘Extract Valleys’ tools in Whitebox GIS. Other tools are also available, e.g. the Topographical Wetness Index (TWI) as available in both SAGA and Whitebox GIS which attempts to map the ‘wetness’ of an area based on the upstream contributing area and slope.

Unlike the TPI tool many of the above-mentioned tools are not able to map the extent of the valley floor areas, i.e. the identified valley floor is mapped as a single line rather than as an area (polygon). Another limitation is that some of the tools, similarly to the TPI tool, require different parameters to accurately map the valley floors of different areas, or different wetlands within the same area, due to differences in e.g. topography. Similarly the areas accurately mapped can only be identified at the end of the run. Applying these tools for mapping wetland extent therefore require continuous adjustment to accurately account for different areas and different wetland ecosystems, particularly when applying them at a country-wide scale. Their application is therefore mostly a ‘trial and error’ approach which inevitably becomes very time consuming and cumbersome.

It was subjectively concluded that none of the investigated tools were deemed suitable for improving NWM4 by way of modelling. Requirements for a new method for creating an improved wetland map included the ability for it to:

- map the extent of valley floor areas;
- reflect the contiguity of inland wetland ecosystems;
- be applied to all regions of the study area (South Africa);
- be rapid while still producing results suitable for (1:50 000) country-wide application; and
- have minimum data and budget requirements.

Considering the limitation of the TPI and other existing tools, as well as the above-stated requirements, modelling the extent of wetlands from a country-wide Digital Elevation Model was considered the most suitable alternative approach for creating a new and improved wetland map.

5.3 Aim

The aim of this part of the study was to develop a method for creating an improved wetland map for South Africa that will satisfy the above-stated requirements.

5.4 Materials and methods

5.4.1 Introduction

Of the different tools and methods considered, an approach of combining outputs of the 'Percentile filter' tool of Whitebox GIS (Lindsay, 2014) and flow accumulation maps of ArcGIS 10.5.1 (ESRI, 1999-2017) were considered to be most suitable at achieving the stated objectives. Whitebox GIS was used to create percentile filter maps as this or a similar tool is not available in ArcGIS. Whitebox GIS also offers DEM preparation tools that are superior to those of ArcGIS (Section 5.4.5).

Implementation of the method required the following data:

- Imagery:
  The 2013 SPOT 5 national mosaic coverage obtained from the South African National Space Agency (SANSA) was used for identifying wetland ecosystems. Most of the imagery was for the period between 2013/01/10 and 2013/12/31. Due to some technical issues three image footprints had to be patched with acquisitions taken on 2014/01/11, 2014/01/16, and 2014/01/23 (Figure 5.1). The 2013 SPOT 5 mosaic was created from pseudo-colour pan-sharpened scenes, which were derived from panchromatic and multispectral pairs (SANSA, 2013).
- A Digital Elevation Model (DEM):
  The DEM used was the 30 meter Shuttle Radar Topology Mission (SRTM) layer (NASA, 2000).

A number of python scripts were developed to facilitate the mapping process. Python (Python Software Foundation) is the preferred ArcGIS scripting language that allows for automation of GIS related tasks. Python 2.7 is automatically installed with every ArcGIS installation and is therefore easily accessible and freely available to all ArcGIS users. In addition to providing access to the standard ArcGIS tools, Python also provides additional functionality without which automating certain aspects of the mapping process would not have been possible, e.g. branching (if-then-else statement), the use of lists and dictionaries, etc. The scripts are run from the standard ArcMap and ArcCatalog interfaces and automate many of the required processes, e.g. creating the mapping regions (Section 5.4.3). The scripts also automate the process of converting user defined mapping parameters (Section 5.4.6) to the *wetland probability map*. It is important to note that the mapping process *per se* is not automated, but that the scripts merely automate some of the geoprocessing tasks required for creating the *wetland probability map*.

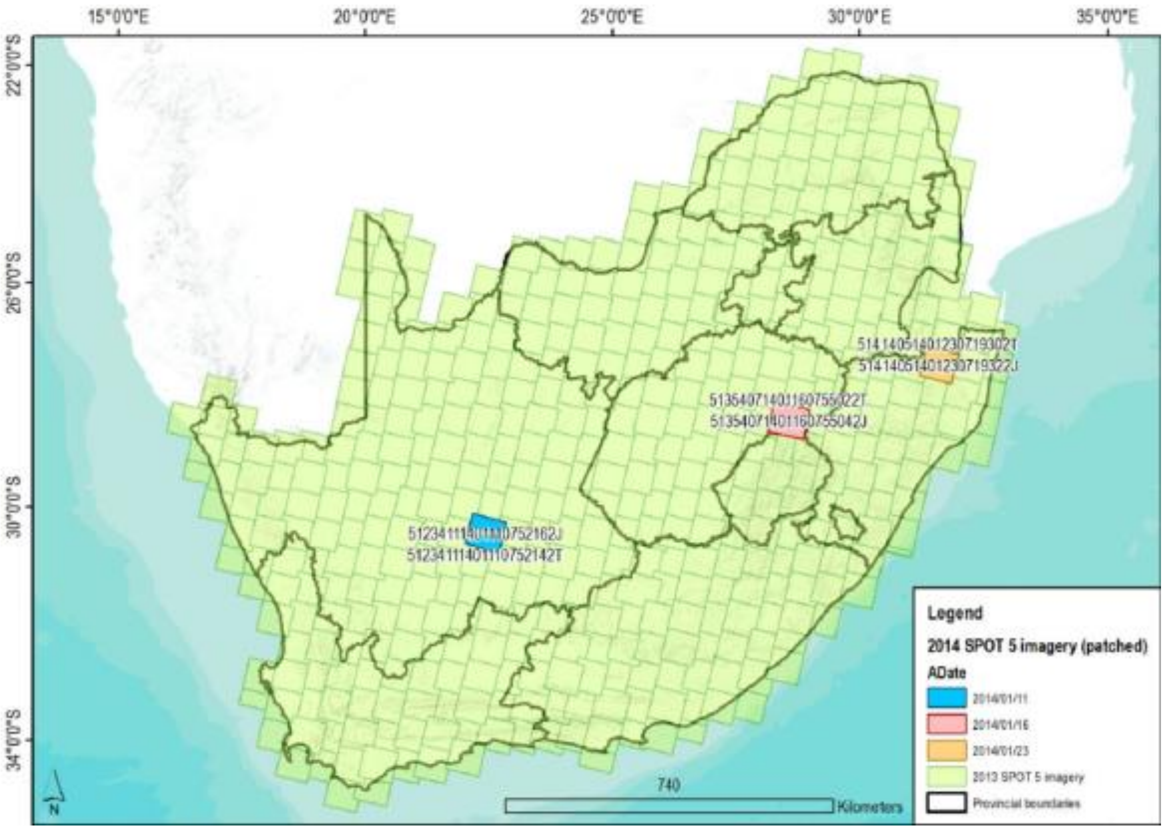


Figure 5.1: Three tiles from the 2014 SPOT 5 images were included due to technical issues with 2013 images. The remainder of the images are from the period 2013/01/10 and 2013/12/31 **(SANSA, 2013).**

The mapping process can be summarised as follows:

- The study area (South Africa) was subdivided to account for computer processing limitations (Section 5.4.2).
- The divisions were further subdivided into mapping regions (Section 5.4.3) which serve as the mapping units for which percentile filter and flow accumulation thresholds were determined (Section 5.4.3).
- Percentile filter maps of varying moving window sizes were created for each of the divisions (Section 5.4.4).
- Flow accumulation maps were created for each of the divisions (Section 5.4.5).
- For each of the divisions:
  - the mapping regions were displayed over the SPOT 2013 imagery.
  - percentile filter and flow accumulation mapping thresholds were determined for each of the mapping regions (Section 5.4.6):
  - wetlands not sufficiently accounted for by the percentile filter and/or flow accumulation maps were captured manually and included as ancillary data (Section 5.4.7).
  - the wetlands, as informed by the percentile filter and flow accumulation thresholds and ancillary data, were mapped (Section 5.4.8).

The method used to create the *wetland probability map* is therefore not an automated process. It can be considered to be similar to onscreen mapping but differs in that whereas with standard onscreen mapping each wetland identified from imagery is mapped individually, the modelled approach simultaneously maps all wetlands identified from imagery within a mapping region using an 'overall best fit' approach. The user determines a set of mapping thresholds which when applied to the percentile filter and flow accumulation maps gives the best approximation of wetland extent on valley floor areas within the mapping region.

5.4.2 Subdividing the study area

To overcome computational limitation imposed by the size of the study area the latter was subdivided according to existing provincial boundaries. Provincial boundaries used are those per the South African Municipal Demarcation Board (MDB). Due to its size the Northern Cape Province was further subdivided into four regions, these being the Northern Cape East (NC_E), Northern Cape North (NC_N), Northern Cape South (NC_S) and Northern Cape West (NC_W) (Figure 5.2). The division boundaries of the Northern Cape Province follow those of secondary catchment areas (refer to Table 5.1 for an explanation of the abbreviations).

Figure 5.2: Divisions of the study area (South Africa). Abbreviations are explained in Table 5.1.

5.4.3 Creating the mapping regions

Because no single set of mapping thresholds are suitable for all areas of a division, the latter were further subdivided into 'mapping regions'. The mapping regions are a first approximately of areas considered to be homogenous in terms of the variables that were subjectively considered to be most influential at determining wetland development, these being relief, mean annual precipitation and generalised geology. They therefore represent areas in which a certain set of parameters (the mapping thresholds) should theoretically be able to consistently map the wetlands of the valley floor areas.

Relief

Relief was determined by creating a grid of 1 000 ha hexagons for each of the divisions after which the standard deviation of elevating for each hexagon was calculated using the ArcGIS 'Zonal Statistics as Table' tool. Elevation data were derived from the 30 m DEM. The standard deviation of elevation is considered to be a quantitative expression of the relief of the terrain underlying each hexagon (Figure 5.3 A). The map was subsequently simplified by grouping the standard deviation values. Grouping was achieved by displaying the output of the Zonal Statistics tool in ArcMap with symbology set to quantity, 5 classes and natural breaks (Jenks) as the classification method. The indicated Jenks break values were used to define the borders for the 5 categories according to which they were grouped. The output is therefore a map with 5 zones of relief (Figure 5.3 B).

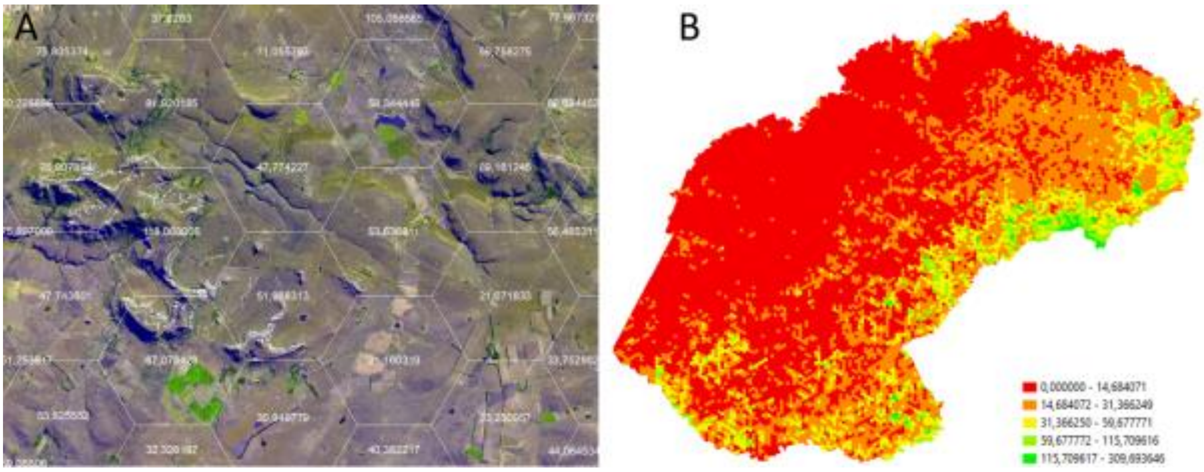


Figure 5.3: The standard deviation in elevation was calculated per 1 000 ha hexagons to quantitatively express relief (A) after which they were grouped per the Jenks natural breaks, using the Free State an example (B).

Generalised geology

The geological data used is a simplified version of the 1:1 million Geological Data of the Council for Geoscience's RSA Geological Data Set (Council for Geoscience, 1997) (Figure 5.4).

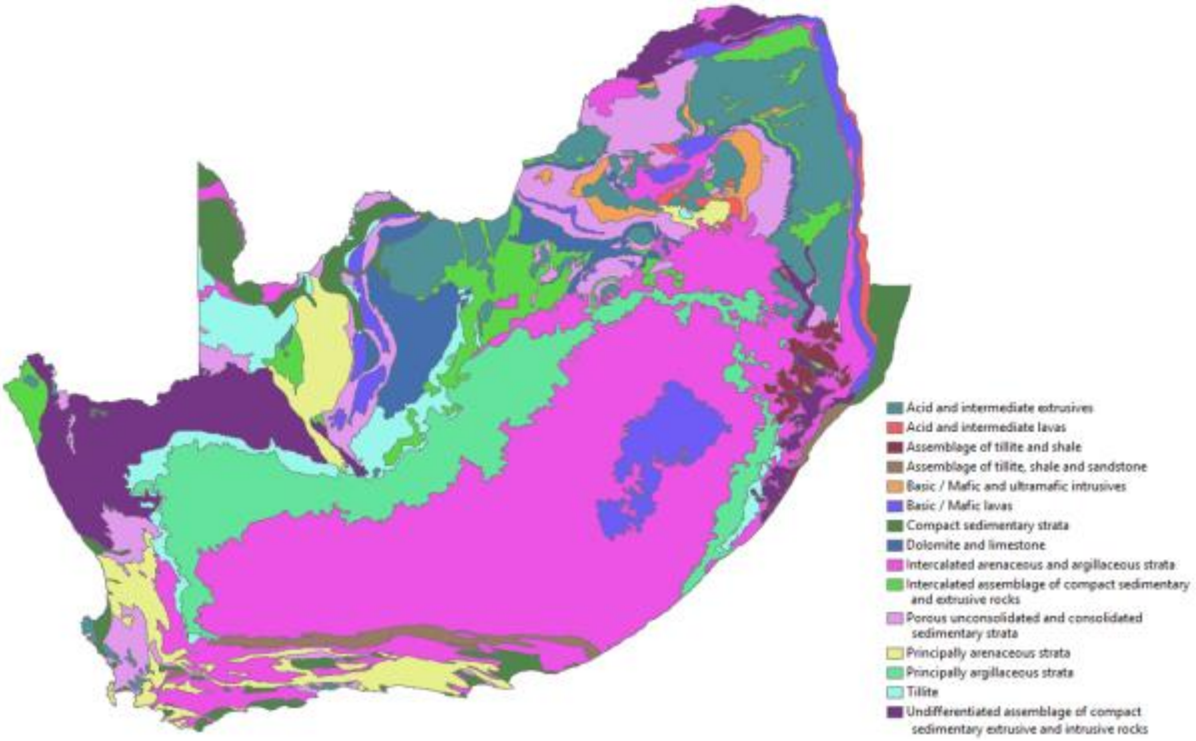


Figure 5.4: Simplified version of the 1:1 million geological map used to inform creation of the mapping regions.

Mean annual precipitation (MAP)

While relief and the generalised geology relate to the extent to which the percentile filter maps will be able to consistently map valley floor areas within different mapping regions, the mapping regions also need to account for the environmental variables that influence the probability of the mapped valley floor areas actually being wetland. There may, for example, be differences in the likelihood of wetlands occurring within regions of similar relief but which are characterised by differences in MAP. As wetlands are predominantly a function of rainfall, the MAP is expected to be an important modifier that needs to be accounted for (Hiesterman & Rivers-Moore, 2015). MAP data were sourced from the Water Research Commission (Lynch & Schulze, 2000) and was categorised into 100 mm intervals (Figure 5.5). The output is therefore a mean annual precipitation map with zones of 100 mm interval.

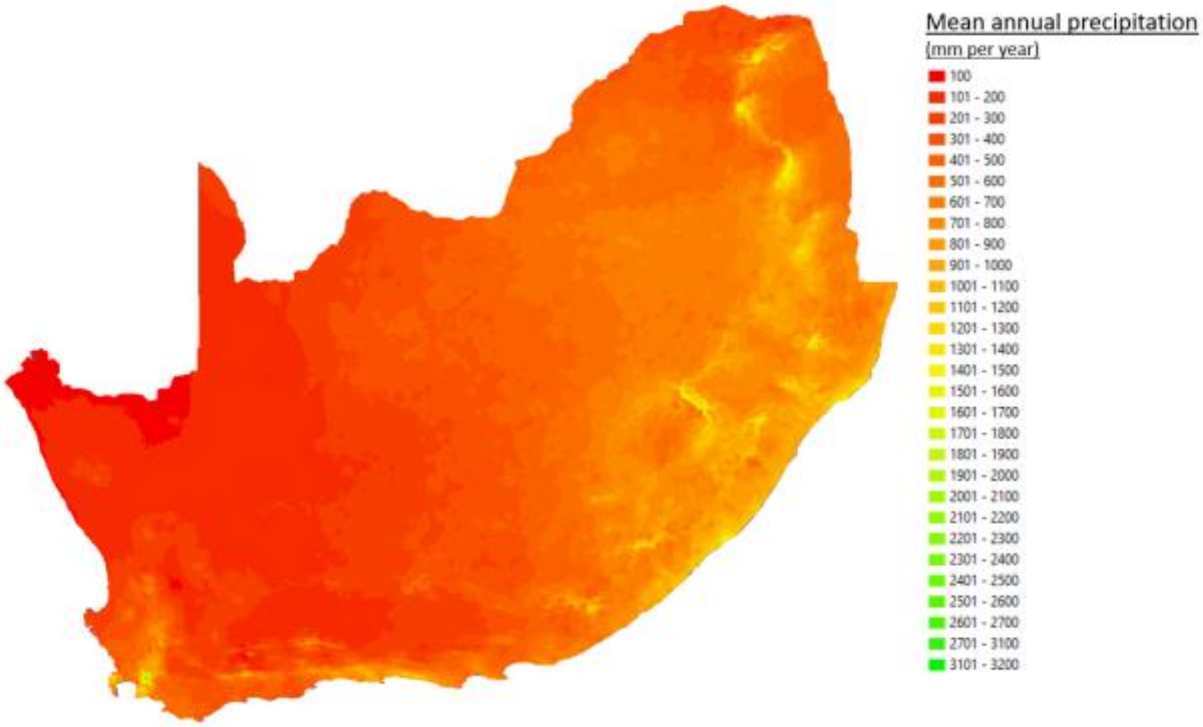


Figure 5.5: Mean annual precipitation (MAP) of the South Africa mapped at 100 mm intervals which was used to inform creation of the mapping regions.

Mapping regions for each division were obtained by creating a union of the relief (the 5 category zones), generalised geology and MAP (the 100 mm interval zones) using the ArcGIS 'Union' tool (Figure 5.13). Mapping regions smaller than 40 km^2 were dissolved into neighbouring features using the ArcGIS 'Eliminate' tool (with the Eliminate by border parameter checked). Mapping regions were added during the process of assigning mapping thresholds by manually subdividing mapping regions to account for situations where the wetlands in a mapping region could not be adequately accounted for by any set of percentile filter and flow accumulation map thresholds.

5.4.4 Percentile filter maps

Percentile filter maps were used to map the broader valley floor areas where typically floodplain and channelled and unchannelled valley-bottom wetlands would occur.

Percentile filter maps were created using the 'Percentile filter' tool of Whitebox GIS (Lindsay, 2014). As the name of the tool suggests it performs a percentile filter analysis on a raster image. The tool expresses the value of each cell as a percentile (0% - 100%) of the range of values within a moving window. Because cell values of a DEM represents elevation, the percentile value assigned to each target cell (the cell in the centre of the moving window) is therefore a quantitative expression of its elevation relative to the elevation of the surrounding cells, specifically the cells covered by the moving window. Once the percentile for a target cell has been calculated, e.g. target cell A of Figure 5.6, the tool moves the target as well as the moving window to the neighbouring cell, e.g. target cell B and moving window B of Figure 5.6 respectively. As was for target cell A, a percentile value is calculated for target cell B by expressing its value as a percentage of the range of values of all the other cells that are covered by the moving window at its new location. This process is repeated until a percentile value has been calculated for all cells.

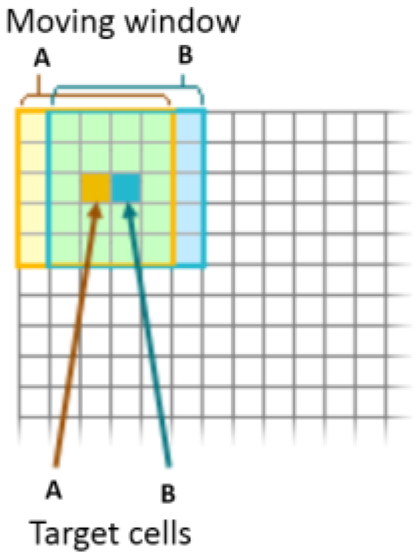


Figure 5.6: The percentile filter tool analyses a raster on a cell-by-cell basis as illustrated by target cells A and B and the accompanying moving windows which follow the target cell. The value of the target cell is expressed as a percentage of the value of all cells that are covered by the moving window.

The size of the moving window is adjustable, i.e. the size of the neighbourhood against which the value of the target cell is being evaluated can be changed. This feature is of particular use and allows for the percentile filter tool to be applied to areas of different relief. For example, a small moving window (9x9 cells) was found to be appropriate for mapping valley floors in areas of high relief while a larger moving window (81x81 cells) was found to be more suitable in areas with a relative flat topography (low relief). In Figure 5.7 A the 9x9 moving window size is unable to detect the valley-floor areas as the entire window is located within the valley-floor as opposed to the 81x81 window of Figure 5.7 B which, because the window extends beyond the valley-floor, is able to detect it. Both the 9x9 and 81x81 windows in the high relief areas of image A and image B are able to detect the valley floors but, because of the different window sizes, will require different percentile values (percentile thresholds) to display them (e.g. the 10th percentile of the 81x81 window of B will represent a larger portion of the valley floor than the 10th percentile of the 9x9 window of A because the former includes a larger range of numbers of which most are of higher elevation than the latter).

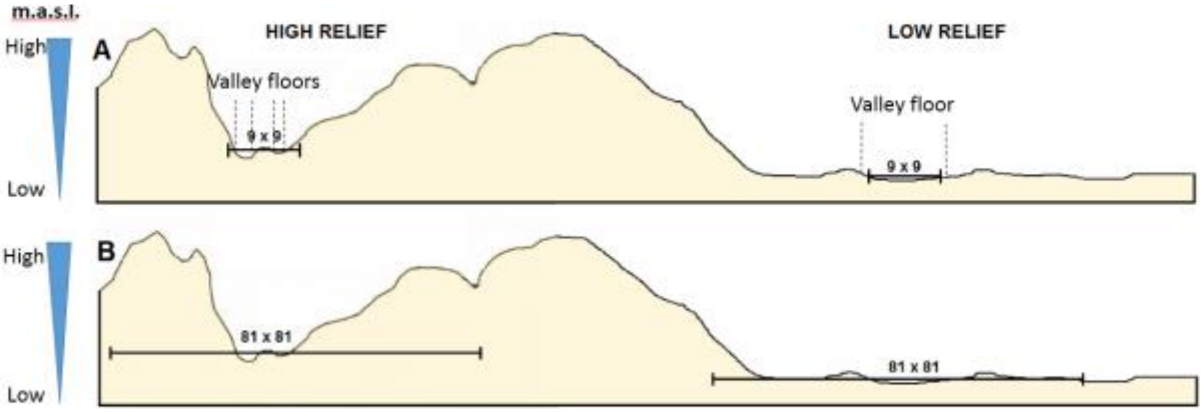


Figure 5.7: Areas of low relief require larger moving window sizes to detect the valley-floor areas while smaller moving window sizes are more suitable for areas of high relief.

For mapping purposes percentile filter maps with moving window sizes of 9x9, 15x15, 21x21, 31x31, 51x51 and 81x81 were created for each of the divisions. These are referred to as the base percentile filter maps.

The extent of area mapped by a percentile filter map is controlled by specifying a percentile threshold. A threshold of e.g. 10% means that only the cells of which their elevation is 10% or less of the elevation of all cells in the moving window will be mapped, i.e. the cells at the lower end of the elevation (the valley floors). Similarly a percentile threshold of 50% means that all cells with a value that is halfway between the cell with lowest elevation and the cell with highest elevation will be mapped.

5.4.5 Flow accumulation maps

The flow accumulation maps were used to map the narrower wetland systems that typically connect the broader floodplain and valley-bottom wetlands (those mapped by the percentile filter maps) as well as those on the adjacent slopes. These are typically rivers or seeps that occur along channels or within the valley-floor landscape unit, but can also be narrow occurrences of other HGM types.

Creating flow accumulation maps has become standard practice in hydrological modelling processes. To create flow accumulation maps the DEM first needs to be hydrologically corrected, a process also referred to as DEM pre-processing which involves removing sinks from the DEM. In addition to the standard fill tools, Whitebox GIS also includes tools to create hydrologically corrected DEMs by way of breaching the sinks instead of filling them as the standard ArcGIS ‘Fill’ tool does. Whereas the standard fill method simply raises the elevation within depressions, breaching ‘carves’ a channel through the sinks. The advantage of this approach is clearly visible in (Figure 5.8, blue lines) where the outcome of the flow accumulation derived from a DEM pre-processed with the ‘breach’ tool results in lines which reflect a ‘natural’ path that water would follow in the landscape. In contrast, the result of flow accumulation derived from a traditional fill operation (Figure 5.8, red lines) result in illogical and unnatural straight lines running through the fills.

DEM pre-processing was done by first subjecting the DEM to the ‘Breach Depressions’ tool of Whitebox GIS, of which the output was used as input for the ‘Breach Depressions (Fast)’ tool (also from Whitebox GIS). The output was subsequently exported to ArcGIS and used as input to create flow direction maps using the ‘Flow Direction’ tool. The latter informed the flow accumulation maps which was created using the ArcGIS ‘Flow Accumulation’ tool.

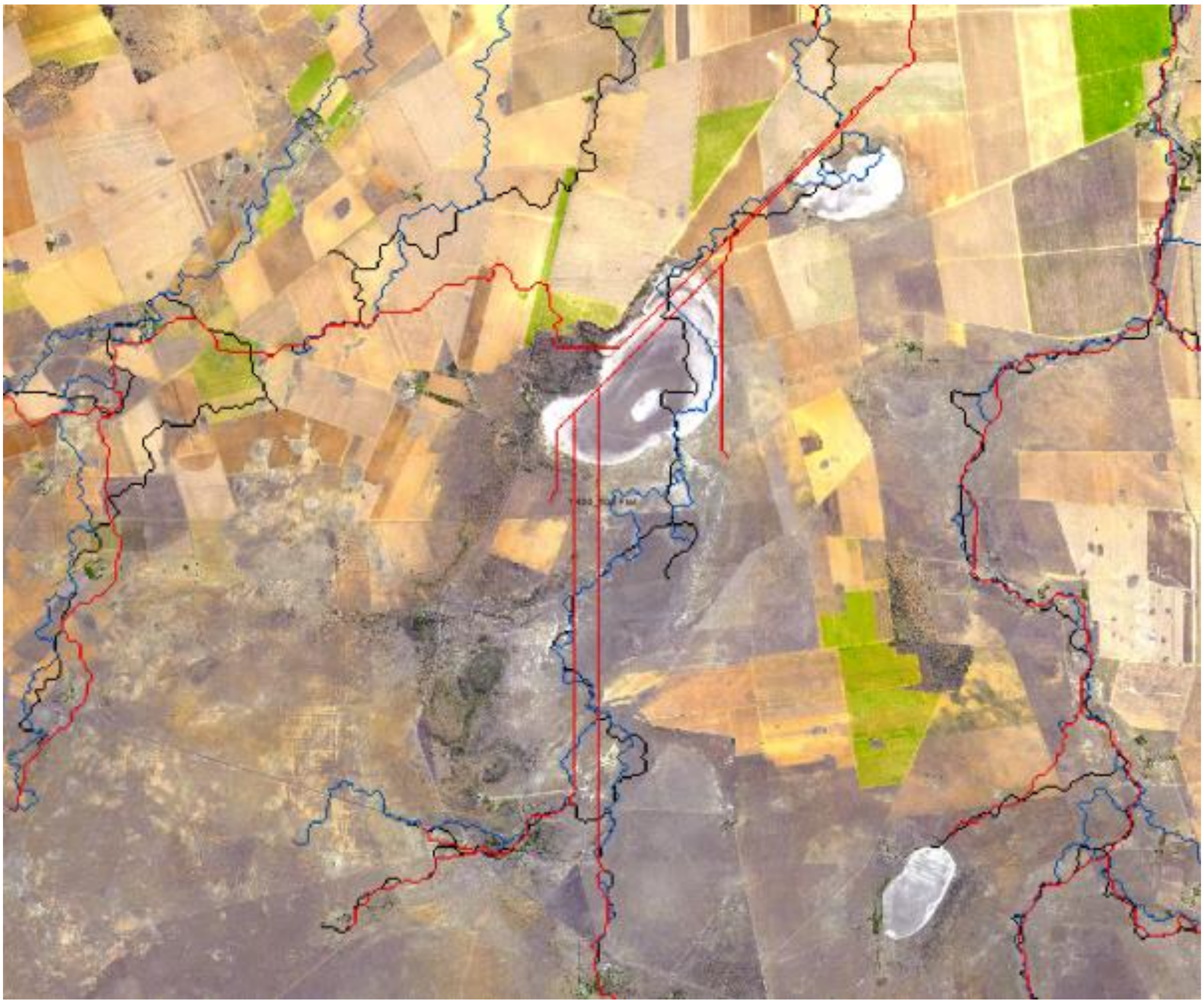


Figure 5.8: Comparison of flow accumulation outputs as derived from DEMs that were subjected to different methods of pre-processing. Red lines are flow accumulation derived from first applying the ArcGIS fill and then the flow direction and flow accumulation tools. Blue lines indicate flow accumulation derived from the Whitebox breach fast only tool with ArcGIS-derived flow direction and flow accumulation. Black lines indicate flow accumulation derived from the ‘breach’ and subsequently ‘breach fast’ tools in Whitebox GIS.

5.4.6 Determining mapping thresholds

All the mapping regions of a division occur as separate features (rows) within the mapping region attribute table. The attribute table contains fields in which the percentile filter and the flow accumulation threshold considered to best map the wetlands of the mapping regions are recorded.

Percentile filter thresholds

It follows from Section 5.4.4 that it is highly unlikely that a single percentile filter map will be suitable to accurately map the valley floor areas for all mapping regions of a division. The user therefore the needs to make a judgement on the appropriate moving percentile base map and percentile threshold for different mapping regions.

In many instances the accuracy of the base percentile filter maps can be improved by iteratively expanding and shrinking cells or vice versa. The process of creating the modified percentile maps is an iterative one which is not done as a separate task but as part of the process for determining which percentile filter maps and thresholds are best for mapping the visually identified wetlands of a mapping region. Percentile filter thresholds were determined by first subjectively deciding on a base percentile filter map and a percentile threshold which was considered to be suitable for the mapping region. Depending on whether the chosen percentile threshold was found to accurately represent the identified wetlands or not, different base maps with the same or other threshold, or a different threshold using the same base map were tested. It may become evident at this time that the accuracy of the base map for a given threshold may be improved with some modification. The base percentile filter map was modified in such instances.

Modification involves reclassifying the base map so that only values (percentiles) that satisfy the subjectively chosen threshold are retained (assigned a value of 1) while the remainder of the cells are discarded (assigned 'NoData'; A of Figure 5.9). The remaining cells (those with value 1) can then at the discretion of the user be repeatedly expanded and/or shrunk so that the end result is improved representation of the identifiable wetlands (B of Figure 5.9). The benefits of such modifications are clearly visible from Figure 5.9 where A is a base percentile filter map (81x81 moving window) with a threshold of 30 percentile, while Figure B is the same percentile filter map (81x81 moving window) which was also reclassified to the same percentile threshold (30) after which it was modified by first shrinking it with 1 cell, then expanding it by 5 cells and then again shrinking it by 8 cells.

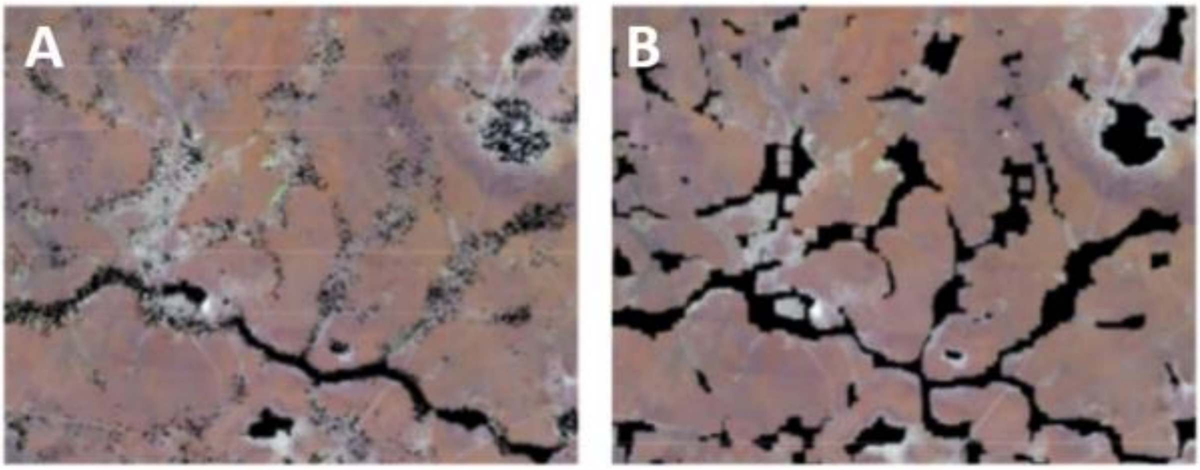


Figure 5.9: Comparison of the extent to which the accuracy of the base percentile filter maps with set threshold can be improved.

Subsequent to having created the different modified percentile filter maps, the process of assigning percentile thresholds to a mapping region involved (i) testing different percentile filter base maps and thresholds, (ii) creating modified percentile filter maps where the base maps are found to be unsuitable or (ii) determining which of the already created modified percentile filter maps are best at covering the wetlands (this only after modified percentile filter maps have been created for previously assessed mapping regions). What is referred to as the percentile threshold for a mapping region is therefore actually a map which is the culmination of a process involving identifying a suitable base percentile filter map, reclassifying it to the determined percentile threshold and applying the modification per the above explanation.

It follows from the above that the percentile filter tool provides an almost endless number of permutations that can be created by:

a) using different moving window sizes (the base maps);
b) applying different thresholds to the base maps; and
c) applying a number of additional modifications to the reclassified base maps

It is mostly the modified percentile filter maps that were used to inform mapping and not the base percentile filter maps. The latter were only used for mapping areas where the modified maps did not increase mapping accuracy. The process of creating the modified percentile filter maps is simplified and automated by a script developed specifically for this purpose. The output is a new map with a unique name that incorporates all these modification and it is this map that is recorded in the appropriate field of the mapping region attribute (the name of the map is entered to inform the mapping tool to use this modified map to map the wetlands of the valley floor areas for the mapping region; section 5.4.8). The neighbouring mapping region may require the use of a different combination of base map, threshold and modifications. In such instances, as for the previous mapping region, the script was used to apply the reclassification and modifications to the base map and to again create a new modified percentile filter map with a different name. This newly created modified percentile filter map was then listed as the map to inform wetland mapping for that mapping region. In addition to creating the modified percentile filter maps, the script also creates a text file which lists the base percentile filter, the threshold (used for reclassifying the base map) and the expand and shrink operations used to create the modified percentile filter map. This text file is automatically saved to disk for record keeping purposes.

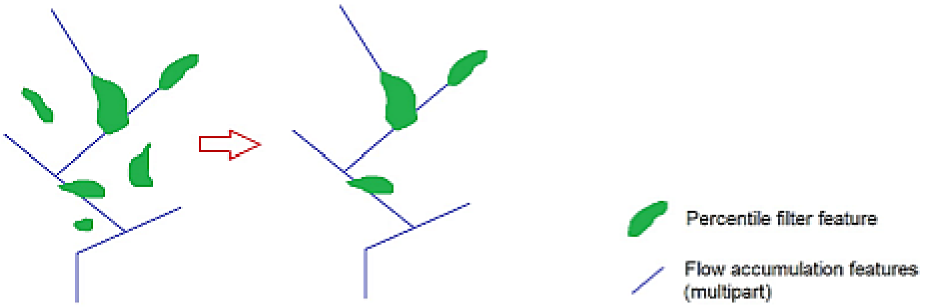
For many mapping regions more than one modified percentile filter map is required to account for all the wetlands visually identified from the image. This is common for mapping regions that contain wetlands of very dissimilar shape, specifically where they contain large and flat wetlands while also containing wetlands that are long and narrow. All modified percentile filter maps necessary to map all of these wetlands can be entered into the mapping region attribute table (separated by an underscore).

Flow accumulation thresholds

Determining the mapping threshold for the flow accumulation maps followed a similar process whereby the most appropriate threshold was determined by trial and error on account of what was subjectively considered to give the best representation of the visually identifiable wetlands. However, unlike the percentile filter maps, the flow accumulation maps were not modified. The thresholds value represents the number of cells of which their surface water will flow towards a particular cell. It follows that if the flow accumulation threshold is set to 1 then all but the outer cells at the top of the catchment of the flow accumulation map will be mapped as they have the surface water of at least 1 cell flowing towards it. A threshold of 1 000 means that only cells which receive surface water from 1 000 cells or more will be mapped. Flow accumulation thresholds were recorded in the appropriate field of the mapping regions attribute table.

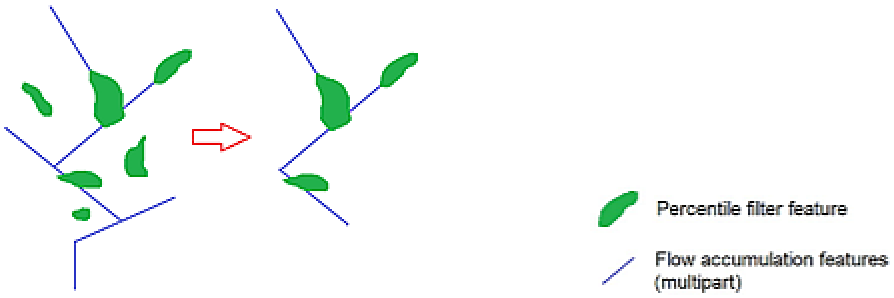
While determining the most appropriate maps and thresholds for each mapping region, the most appropriate mapping relationship between the percentile filter and flow accumulation features were also determined. As for the percentile filter and flow accumulation thresholds, the attribute table of the mapping regions also contains a field in which the user can specify the mapping relation between the percentile filter and flow accumulation features. A number of options exist where features are retained or omitted in the final output depending on the content of this field. These mapping options are set individually for each mapping region and are:

- Option 1: Select and map the percentile filter features that intersect the flow accumulation features, *AND* map *all* the flow accumulation features (all the flow accumulation features are mapped, irrespective of whether they intersect percentile filter features or not).

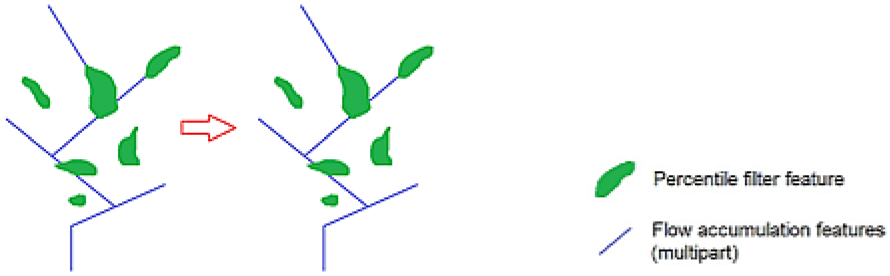


- Option 2: Select and map the percentile filter features that intersect the flow accumulation features, but do *NOT* map the flow accumulation features (none of the flow accumulation features are mapped, irrespective of whether they intersect percentile filter features or not).

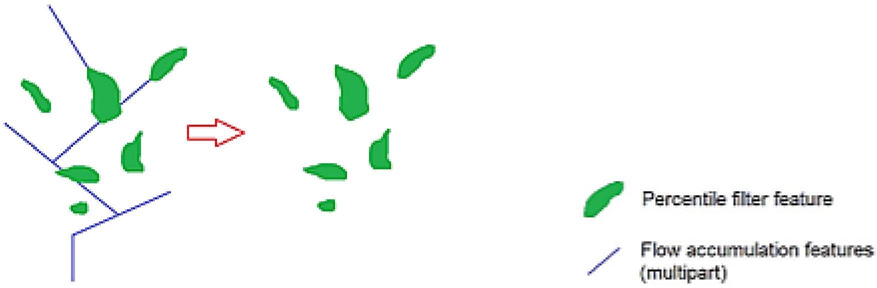
- Option 3: Select and map the percentile filter features that intersect the flow accumulation features, *AND* only map the *intersecting* flow accumulation features. Oonly flow accumulation features that intersect the percentile filter features are mapped; depending on the user defined selection the flow accumulation features are either multipart or singlepart (Figure 5.24), i.e. all or only sections of the flow accumulation features that intersect percentile filter features are mapped respectively.



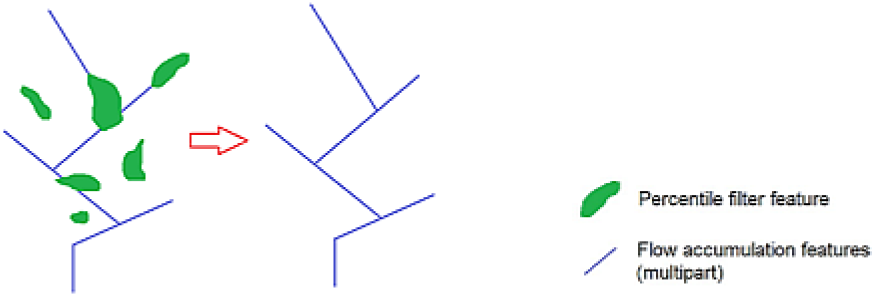
- Option 4: Map all percentile filter *AND all* flow accumulation features, irrespective of whether they intersect each other or not.



- Option 5: Map only the percentile filter features (all percentile filter features are mapped, irrespective of whether they intersect flow accumulation features or not). All ancillary data are mapped along with the percentile filter features, i.e. the output will be all the percentile filter features as well as all the features contained in the vector and raster ancillary data.



- Option 6: Map only the flow accumulation features (all the flow accumulation features are mapped, irrespective of whether they intersect percentile filter features or not). All ancillary data are mapped along with all the flow accumulation features, i.e. the output will be the flow accumulation features as well as all the features contained in the vector and raster ancillary data.



- Option 7: No features are mapped, i.e. the mapping region does not contain any wetlands.

Except where indicated otherwise, in all of the above options the ancillary data are mapped per the mapping options of section 5.4.7.

In all of the above stated options the flow direction lines are of the singlepart type. The ArcGIS tool that creates the final *wetland probability map* (Figure 5.23) includes the options to view and apply all flow accumulation features as multipart features (parameter 'For "Map PF that intersect FA; map intersecting FA only"; use multipart FA'). This option only applies to mapping regions for which the mapping relationship is set to Option 3 ('Select and map the percentile filter features that intersect the flow accumulation features, *AND* only map the *intersecting* flow accumulation features'). If the option to use multipart flow accumulation features is enabled, then the flow accumulation lines included in the final *wetland probability map* will be based on a multipart feature selection, i.e. all sections that are connected to any part of the flow accumulation features that intersects a percentile filter features will be selected and will be mapped Figure 5.10 A). However, if the option is not enabled then the flow accumulation features will be considered to be singlepart, i.e. only those sections of the flow accumulation feature that intersects the percentile filter feature will be selected and mapped, while those that do not intersect any percentile filter feature will not be selected and therefore not be included in the final *wetland probability map* (Figure 5.10 B). For the purpose of creating the *wetland probability map*, this option was enabled, i.e. flow accumulation lines were multipart.

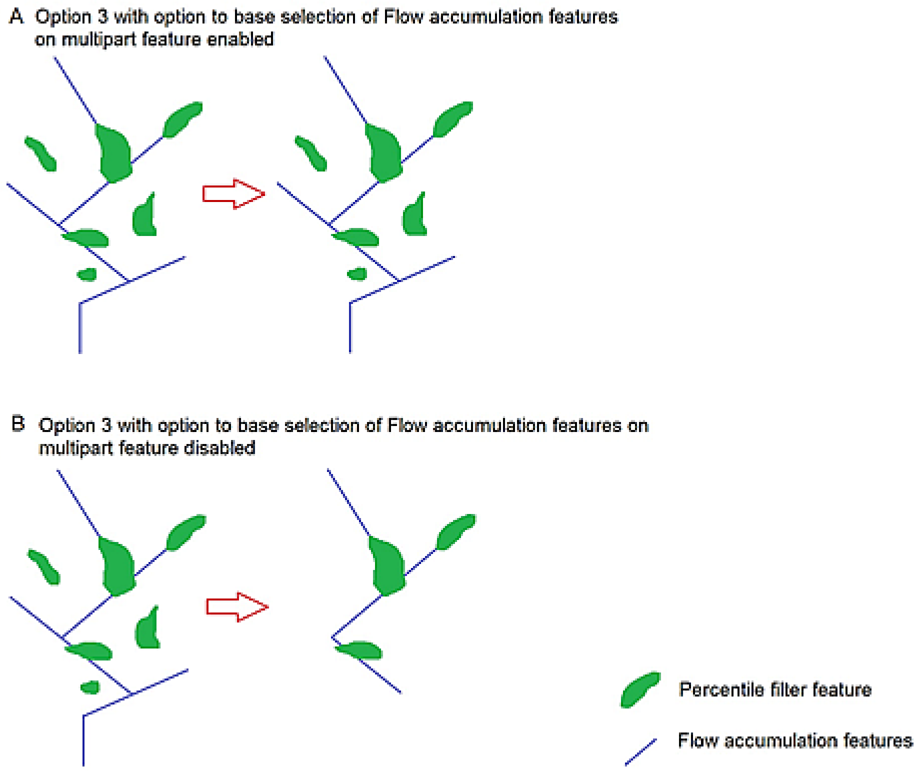


Figure 5.10: Comparison of the output for Option 3 with the option to base selection of the flow accumulation features on it being multipart (A) and singlepart (B).

In some instances it may be found that no combination of percentile filter and/or flow accumulation maps are able to consistently map all wetlands within the mapping region. In such instances the mapping region was manually subdivided and separate percentile filter and flow accumulation thresholds are assigned for the two newly created mapping regions.

5.4.7 Incorporating ancillary data into the output probability map

In addition to having wetland presence and extent predicted through the percentile filter and flow accumulation maps, wetlands which cannot be adequately accounted for using these tools can be captured by way of manual on-screen digitizing. The script that performs the mapping (Figure 5.23) allows for such ancillary data to be listed as inputs to supplement the percentile filter and flow accumulation data. Similarly vector and/or raster wetland data from other existing sources can be added to the list of ancillary data to be included in the final output. Although available, limited use was made of this option as it contradicts the rapid mapping objective of the method. Ancillary data can be incorporated during the mapping process according to the following options (setting for both vector and raster ancillary data can be set individually for each mapping region):

- Map all the vector ancillary data irrespective of whether they intersect the percentile filter or flow accumulation features or not. This was the default option used during the mapping process (A of Figure 5.11).
- Map only the vector ancillary data that intersects the percentile filter or flow accumulation features while excluding the ancillary features that do not intersect the percentile filter or flow accumulation features (B of Figure 5.11).
- Map all the raster ancillary data irrespective of whether they intersect the percentile filter or flow accumulation features or not.
- Map only the raster ancillary data that intersects the percentile filter or flow accumulation features while excluding the ancillary features that do not intersect the percentile filter or flow accumulation features.

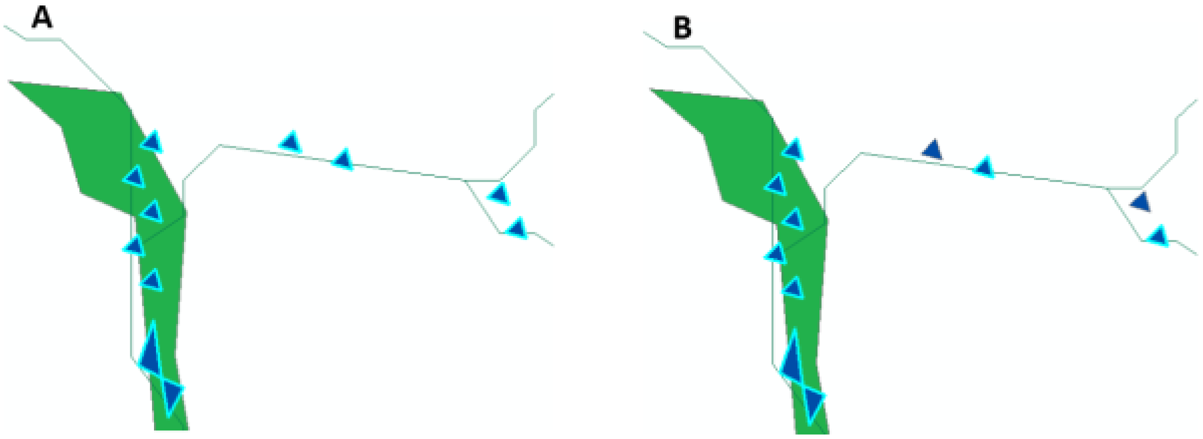


Figure 5.11: The user has the option to include all ancillary data (blue polygons) irrespective of whether they intersect the percentile filter (green polygons) or the flow accumulation features (green lines) or not (A), or to only include ancillary data that intersect either the percentile filter or the flow accumulation features (blue polygons with cyan border of B).

5.4.8 *Producing the wetland probability map*

The *wetland probability map* can be created for a division once the mapping thresholds of all mapping regions have been determined and captured. This is accomplished by combining the percentile filter and flow accumulation data per the thresholds as captured in the mapping region attribute table, as well as all indicated ancillary data. The process of combining these data sources is facilitated by an ArcGIS tool (python script) which creates the predicted wetlands maps for each division. Processes performed by the scrip are (not necessarily in this order):

A. The tool loops through the mapping regions one-by-one (records of the mapping region attribute table) and performs the following tasks for each mapping region before moving on to the next:
    a) The tool reads the percentile filer and flow accumulation thresholds from the mapping regions attribute table.
    b) The mapping region is buffered by 150 meters. All subsequent clipping and selections are per the buffered extent of the mapping region to allow for seamless integration of features of neighbouring mapping regions.

c) The flow accumulation map is clipped to the buffered mapping region extent.
d) The clipped flow accumulation map is reclassified according to the flow accumulation threshold [only flow accumulation cells with value larger or equal to the threshold are retained (assigned value 1) while the rest are discarded (assigned value 'NoData')].
e) The flow accumulation raster is converted to a line feature.
f) The modified percentile filter maps per the attribute table per the attribute table are clipped to the buffered mapping region extent.
g) Raster ancillary data, if listed, are clipped to the buffered mapping region extent.
h) Vector ancillary data, if listed, are clipped to the buffered mapping region extent.
i) The flow accumulation lines are buffered by a standard 10 meters (top left of Figure 5.12).
j) The mapping relation instruction is applies, i.e. percentile filter and flow accumulation data are selected and retained or discarded depending on whether they intersect each other or not. The option to have flow accumulation be treated as multipart or singlepart is applied during this process.

B. The tool starts the process of combining the features of the different mapping regions.

k) The flow accumulation polygons of all mapping regions are merged.
l) Overlapping features in the merged flow accumulation output are dissolved to establish a smooth transition of the features over mapping region boundaries.
m) The percentile filter rasters are 'merged' to a single raster.
n) The merged percentile filter rasters are modified to fill voids (donut holes) that may be present.
o) The raster percentile filter data are converted to vector format.
p) All vector ancillary data are merged.
q) All raster ancillary data are 'merged' and converted to vector format.
r) Depending on the ancillary data setting all or only the ancillary features that intersect either the percentile of flow accumulation data are selected.
s) The ancillary data are merged with the vector percentile filter data.
t) The buffered flow accumulation features and the percentile filter features are smoothed.
u) All features obtained from the flow accumulation maps are selected and assigned a value 'ST' in the attribute table.
v) All features obtained from the percentile filter maps are selected and assigned a value 'VB' in the attribute table.
w) The percentile filter features are used as erase feature to remove portions of the buffered flow accumulation features that overlap with the percentile filter features (Figure 5.12 B).
x) The remaining flow accumulation features are merged with the percentile filter features to create a single continuous *wetland probability layer* for the division.
y) A simplification and cleaning process is applied to remove voids (donut holes) and other undesirable features to produce a single seamless *wetland probability layer* for the division (Figure 5.12 C, blue features).

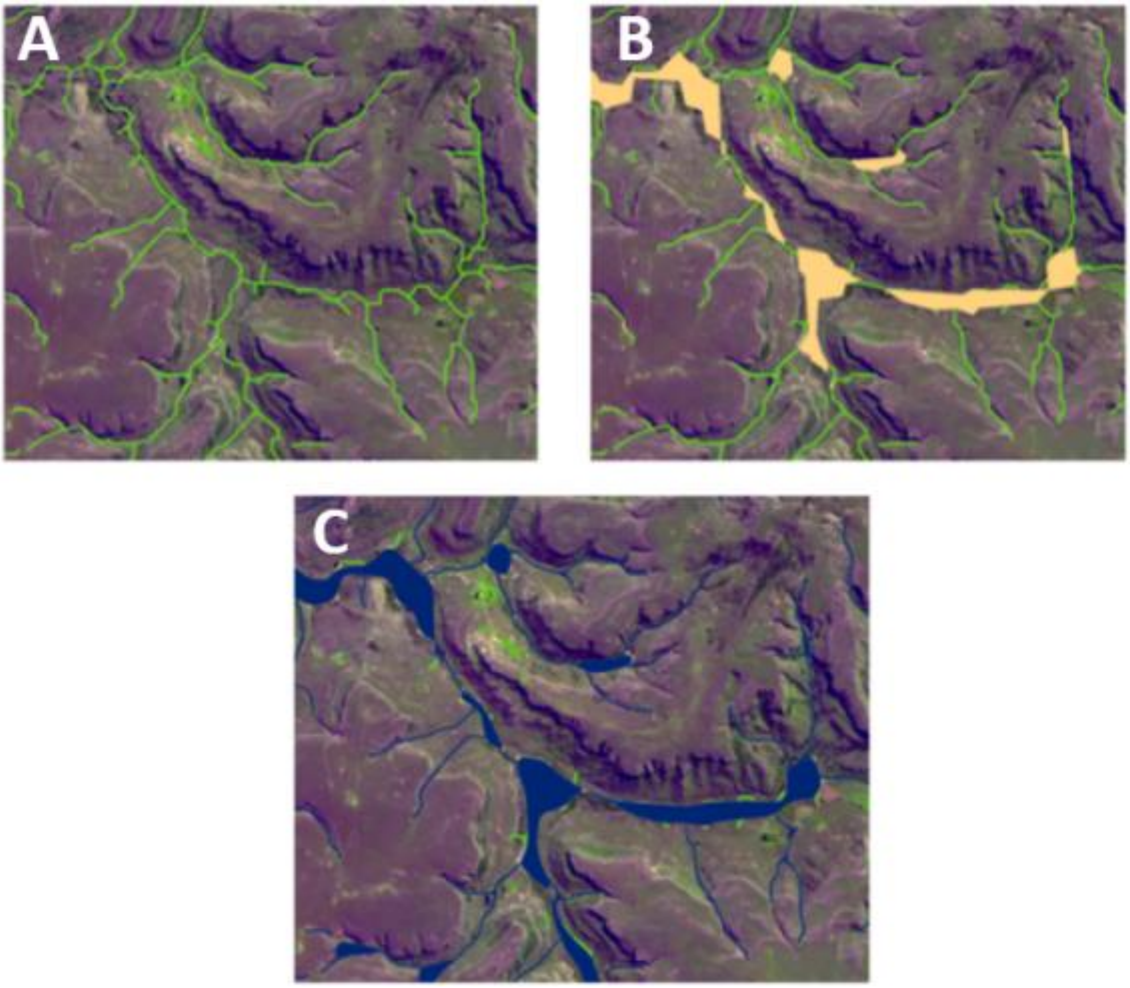


Figure 5.12: Creating the final *wetland probability map* requires the percentile filter, flow accumulation and ancillary data to be combined to create a single seamless map for the division. A: the results of the flow accumulation features which have been buffered by 10 m. B: the percentile filter features (peach polygons) displayed on top of the flow accumulation features (green polygons). C: the final results (blue polygons) include the merged flow accumulation and percentile filter features to create a single seamless *wetland probability map* for the division. The protruding portions of the flow accumulation map (green polygons) were removed during the simplifying and cleaning processes.

To create a single seamless *wetland probability map* for the study area the maps of all divisions are merged and then dissolved on account of the field containing the values indicating the source of the feature, i.e. 'ST' for features derived from the flow accumulation maps or 'VB' for features derived from the percentile filter maps.

5.5 Results

The result of subdividing the study area and creating the mapping regions are presented in Figure 5.13, while Table 5.1 provides a summary of the total number of mapping regions per division.

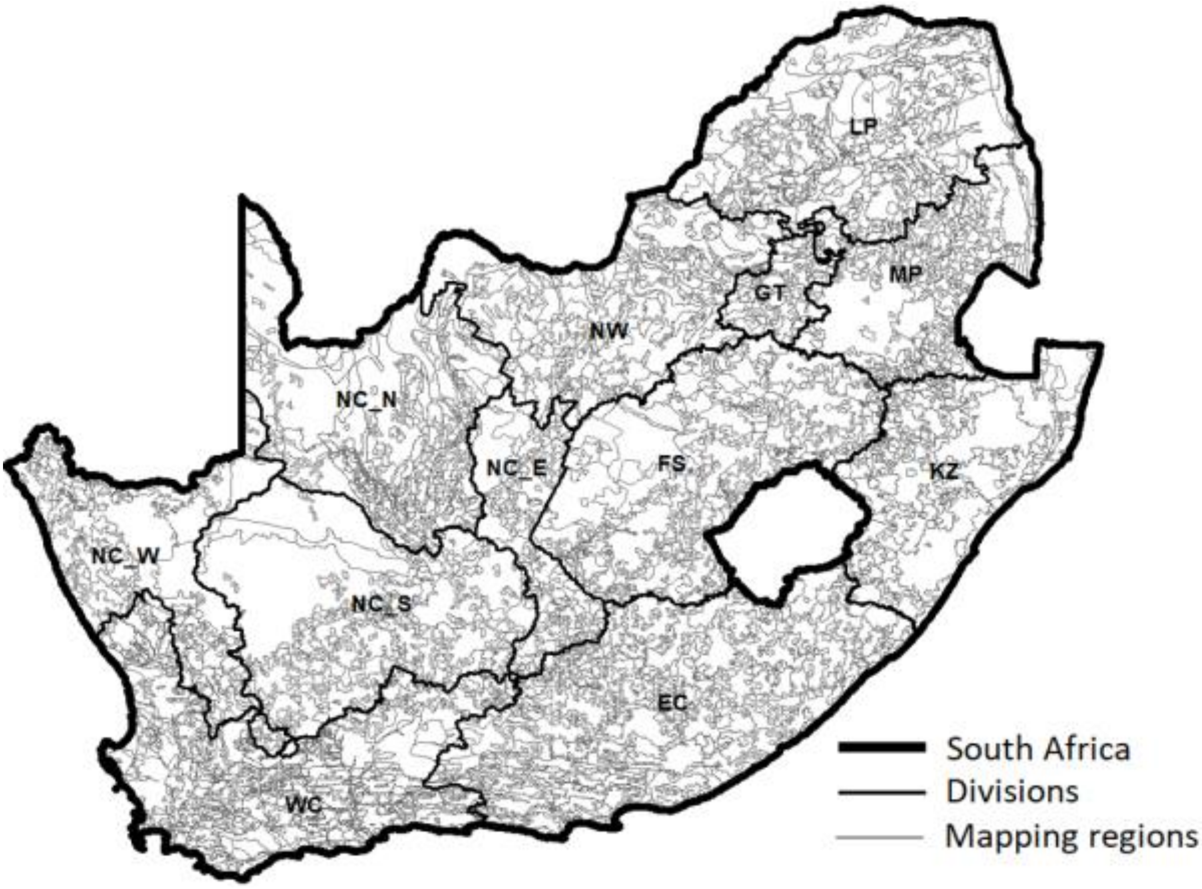


Figure 5.13: Divisions and mapping regions of the study area (South Africa). Mapping regions smaller than 40 km2 were dissolved into neighbouring features.

Table 5.1: The number of mapping regions for each of the divisions. The indicated value includes mapping regions manually added during the process of determining mapping thresholds.

Division name	Number of mapping regions
Eastern Cape Province (EC)	948
Free State Province (FS)	537
Gauteng Province (GT)	162
KwaZulu-Natal Province (KZ)	372
Limpopo Province (LP)	630
Mpumalanga Province (MP)	379
Northern Cape East (NC_E)	263
Northern Cape North (NC_N)	463
Northern Cape South (NC_S)	278
Northern Cape West (NC_W)	364
North West Province (NW)	406
Western Cape Province (WC)	1 437
Total	**6 239**

A visual comparison was done as a first estimation of whether the DEM-based approach provides any improvement on NWM4. A comparison of the area covered by each as well as a quantitative comparison was also done to gain more insight into improvements, if any, offered by the DEM-based approach. Comparisons were limited to mesic areas of high relief in the eastern regions of South Africa as both the

DEM-based and the imagery-based method used for creating NWM4 are expected to perform optimally in such areas (Figure 5.14).

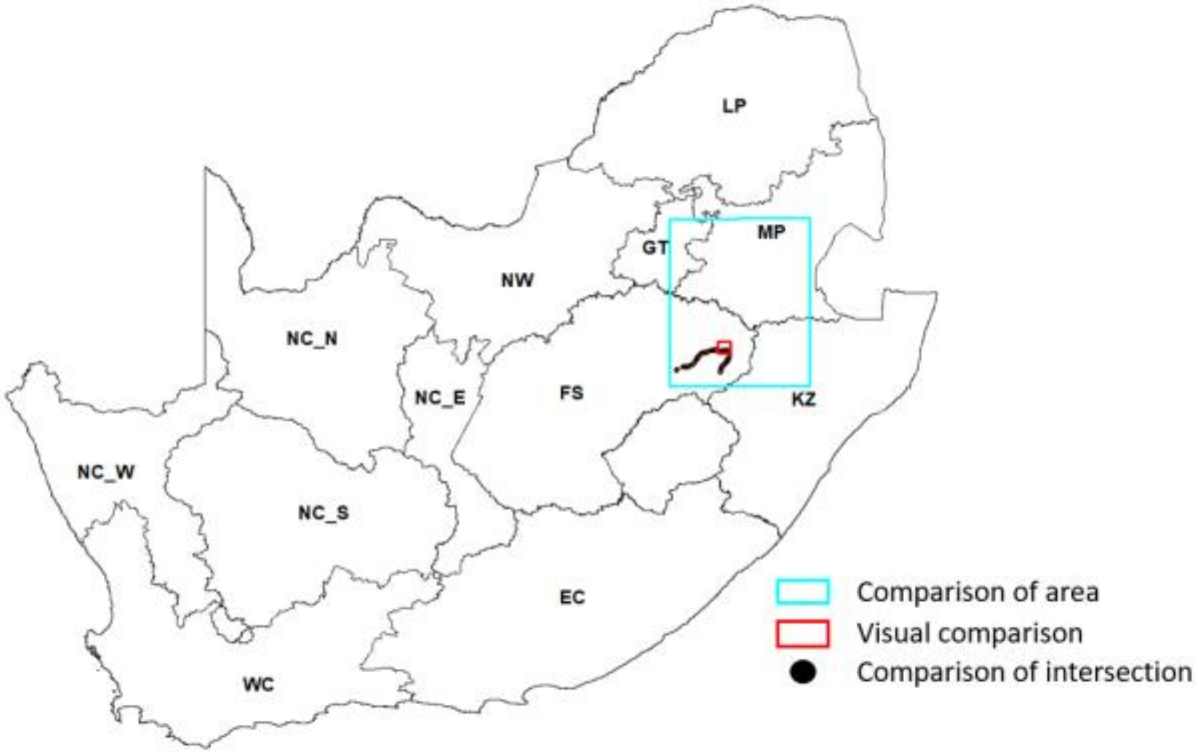


Figure 5.14: All comparisons between the *wetland probability map* and NWM4 were limited to mesic areas of high relief in the eastern regions of South Africa. A visual and quantitative comparison was done for areas in the north eastern Free State (red square and points respectively) while a comparison of surface area was done for an area transecting the GT, MP, FS and KZ divisions (cyan square).

The visual comparison (Figure 5.15; 27° 48' 39.17''S; 29° 11' 29.88''E) revealed significant differences between the two maps. The contiguity and extent of valley-floor wetlands can be estimated from the sinuous features in the landscape of Figure 5.15 A. It can be seen that NWM4 has poor representation of the valley floor wetlands with most of the NWM4 features being farm dams (red features in Figure 5.15 B). The *wetland probability map* shows a marked increase in representation of wetland extent for this area (cyan in Figure 5.15 B).

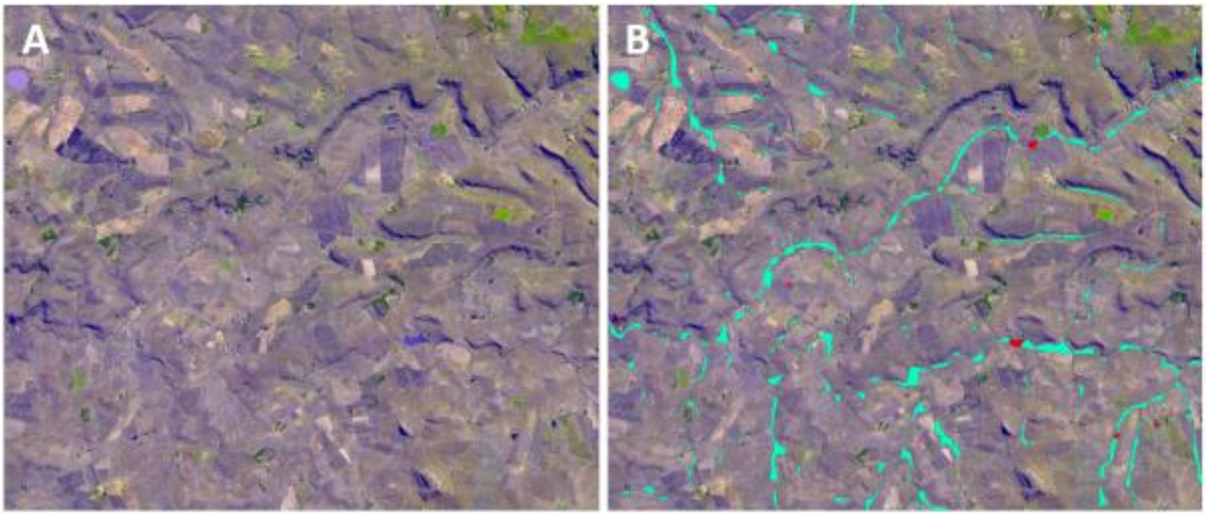


Figure 5.15: The potential presence and extent of wetlands can be estimated from A while B shows the improved wetland representation of the *wetland probability map* (cyan features) compared with that of NWM4 (red features).

To obtain a more quantitative estimation of the observed differences the area (km^2) covered by the different maps were compared (cyan square of Figure 5.14 and Figure 5.16). A visual comparison of the areas cover by the respective maps is presented in Figure 5.16 while Table 5.2 presents a quantitative comparison.

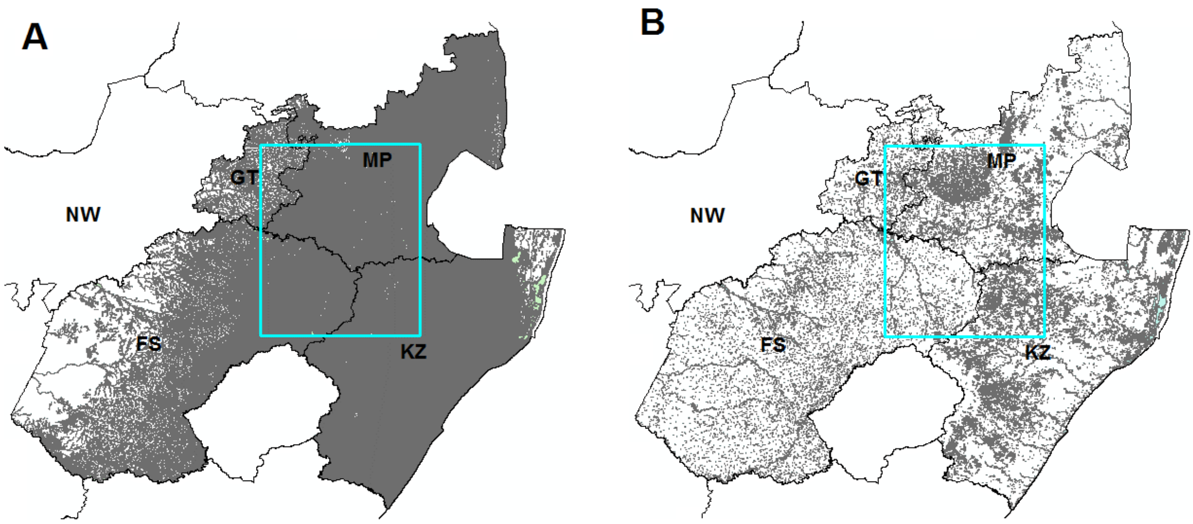


Figure 5.16: Differences between the *wetland probability map* (A) and NWM4 (B) are clearly visible when comparing divisions GT, MP, FS and KZ. A comparison of area (Table 5.2) was done for features located within the area indicated by the cyan square.

Table 5.2: Comparison of surface area (km^2) of the *wetland probability map* and NWM4 for the wetlands located within the cyan square per Figure 5.16.

Sample area (km2)	*Wetland Probability Map* total area (km2)	NWM4 total area (km2)	Difference (km2)	% increase
76799	7085	3524	3561	201

According to Table 5.2 the DEM-based method resulted in a 201 % increase in wetland area compared to NWM4.

To gain more insight as to whether the DEM-based approach offers better accuracy of wetland presence, the ability of each to indicate actual wetland occurrence was tested. A total of 93 points of confirmed wetland occurrence were collected along a route of 150 kilometres by driving along a road in the north eastern Free State (points per Figure 5.15). The number of points that intersect the *wetland probability map* as well as NWM4 were subsequently determined and expressed as a percentage of the total number of points (Table 5.3). To account for mapping errors all points were buffered by increments of 30 meters to a maximum of 210 meters. Similarly as for the original point data sets the number of points of the different buffer widths that intersect the *wetland probability map* as well as NWM4 were determined and expressed as a percentage. A 30 m incremental buffer was chosen on account of the 30 m resolution of the DEM used during the DEM-based mapping process (Table 5.3).

Table 5.3: Comparison of the number and percentage of features of both the *wetland probability map* and NWM4 that intersect points of known wetland location. Buffer: Buffer (meters) around each point; Cells: DEM cell equivalent of buffer width; Intersect: The number of points the intersect wetland features; Percentage: The number of points the intersect wetland features expressed as a percentage of the total number of points

		Wetland probability map		**NWM4**	
Buffer (m)	**Cells (n)**	**Intersect**	**Percentage**	**Intersect**	**Percentage**
0	0	31	34	2	2
30	1	51	55	2	2
60	2	67	72	5	5
90	3	74	80	8	9
120	4	78	84	9	10
150	5	81	87	13	14
180	6	82	88	16	17
210	7	87	94	18	19

The results suggest that the *wetland probability map* offers a significant wetland presence accuracy advantage over NWM4. Most notable from Table 5.3 is the fact the *wetland probability map* intersects more none-buffered points (31 points; 34%) than 210 meter buffered points intersected by NWM4 (18 points, 19%). These results would suggest that the *wetland probability map* provides improved coverage for wetlands in this and other areas of similar environmental characteristics. However, one must remain conscious of the fact that these findings are not the result of an accuracy assessment, but of a comparative analysis, i.e. if all of the Free State was mapped as wetlands then 100% of the *wetland probability map* would have intersected the reference points, which is an obvious false representation of accuracy. A proper accuracy assessment should in addition to 'confirmed wetland' reference points also include 'non-wetland' reference points so that both omission and commission errors are reported and considered.

A visual comparison of accuracy in other regions was less favourable for the DEM-based approach. Initial indications are that the DEM-based approach had low accuracy in arid regions as well as regions of low relief. Regions that are characterised by these constrains are expected to have lowest accuracy. The eastern region of the Northern Cape Province (division NC_E) is arid but also of high relief. Figure 5.17 (30° 39' 03.41''S; 25° 16' 17.07''E) shows modelled wetlands features (cyan) as well as wetlands from NWM4 (red). As for Figure 5.15 the NWM4 features accounts mostly for farm dams whereas the *wetland probability map* (cyan features) includes the farm dams but also the watercourses that drain to and from the farm dams. However, unlike Figure 5.15 where the *wetland probability map* covers areas with high certainty of them being wetland, this is not the case for the features of this area. While the wetland probability features of Figure 5.17 covers some of the watercourses, numerous watercourses not covered by the map are evident (indicated by the blue arrows). There is high certainty that the areas covered by the features of Figure 5.17 are watercourses, however, there is also high uncertainty as to whether they represent actual wetlands or not. The same applies to the watercourses indicated by the blue arrows. Of the indicators for identifying wetlands it is only the vegetation indicator that can be detected with some degree of reliability from imagery. The uncertainty whether the valley floor areas are wetlands or not, therefore stems from the fact that these features are without vegetation. The fact that some of the watercourses are mapped and others are not is the result of a conscious decision to indicate selected areas of the watercourses as possible wetland, while excluding other areas from this possibility. In this case that rationale was that there is uncertainty all around as to whether any of the valley floor areas are actually wetland, but that the most lower parts of the valley floor areas have the highest likelihood of being wetland, and were therefore mapped. It is important to note that exclusion of the remainder of the valley floor areas, whether rightly or wrongly so, is a result of conscious decisions taken by the user and not a failure on account of the method (i.e. these areas would have been mapped if they were considered to be wetland). Different users, depending on what they consider to be wetland from the imagery, will therefore produce different results and it is in instances like this where the expert knowledge of the user is key to producing an accurate map.

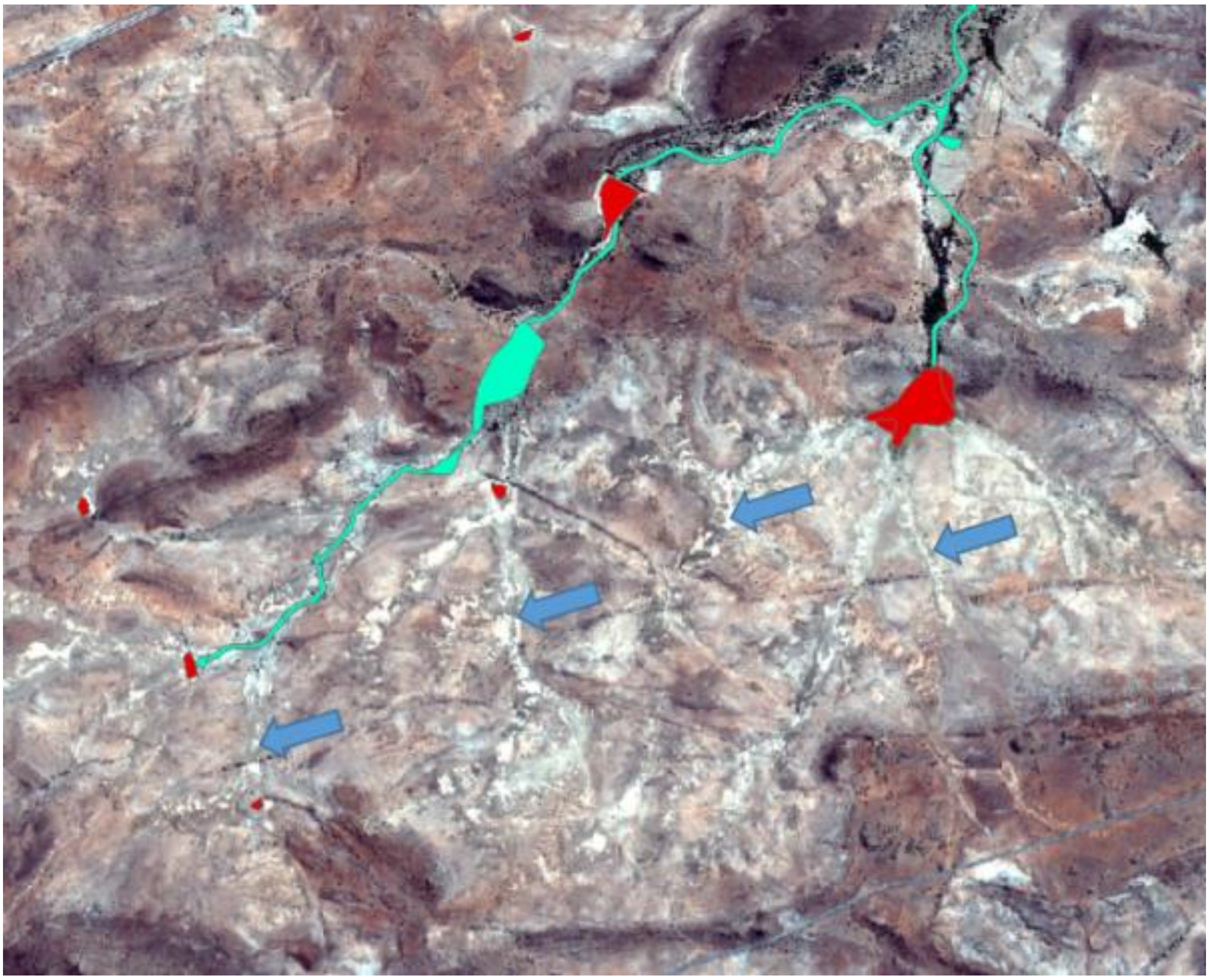


Figure 5.17: Valley floor areas in an arid area of high relief of which some portions of the valley floors were indicated to be possible wetland (cyan features) while others were not (blue arrow). The absence of vegetation from the valley floor areas requires the user to rely on expert knowledge on which areas, if any, are to be mapped as wetlands.

A common feature of the Northern Cape Province is what is commonly referred to as washes (black arrow of Figure 5.18). These are low lying areas towards which surface water flows during high rainfall events. It is clear from Figure 5.18 that these areas are water affected, but it is not clear whether they are wetlands or not as they, similar to the valley floor areas of Figure 5.17, are often without vegetation. A challenge experienced during the mapping process is that when deciding that, e.g. the area indicated by the blue arrow is a wetland, is to then motivate why any one of the other valley floor areas (all valley floors of Figure 5.18) are not wetland since these, similarly to the valley floor indicated by the blue arrow, are equally likely/unlikely to satisfy the indicators and criteria for identifying and delineating wetlands. Because it is a desktop based method assumptions had to be made. When following this rational then all of the visually identifiable valley floors should or should not be mapped as wetland. This conundrum applies to all valley floor areas in arid regions and highlights the subjective nature of the mapping process. However, this limitation of mapping wetlands in arid regions does not only apply to the DEM-based method but also to other method applied previously as is evident from the NWM4 features (red features of Figure 5.18). The DEM-based approach, however, will allow for the mapping of these areas should it be established that they are wetland or if the objective is to map all watercourses, whereas an imagery based approach will most probably fail.

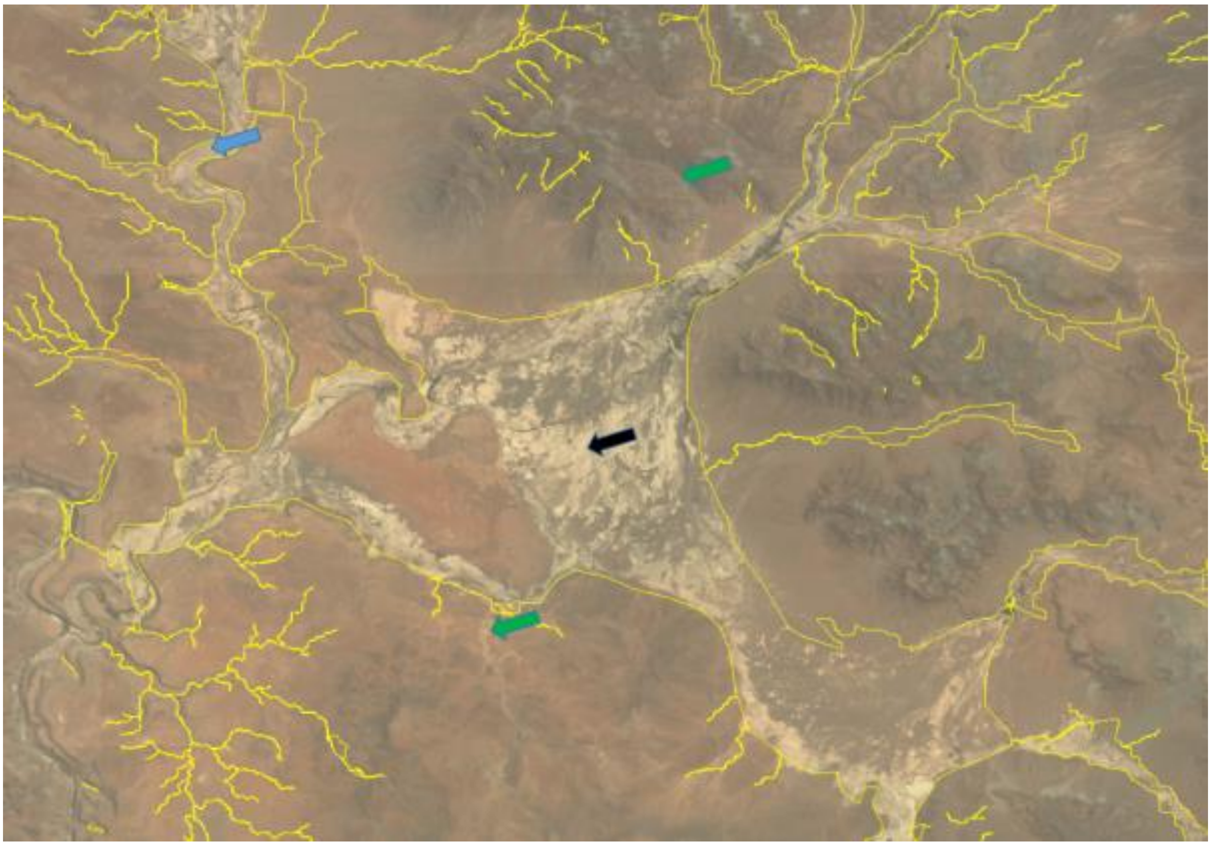


Figure 5.18: Because there is no vegetation in the valley floor areas, assumptions have to be made on whether they represent wetland or not. Rightly or wrongly so, these washes (areas indicated by all areas) were not considered to be wetland. All areas indicated by the yellow outline were mapped as wetland for the *wetland probability map*.

It is subjectively concluded from the above assessments that areas for which low accuracies are expected are those of low MAP (MAP < 500 mm) and low relief (standard deviation of elevation less than 10 m). While low relief relates to difficulties at accurately mapping the valley floors and wetland extent, low MAP relates to difficulties at identifying and recognizing wetlands from imagery. Ratings of mapping confidence were assigned to areas on account of MAP and relief (Figure 5.19).

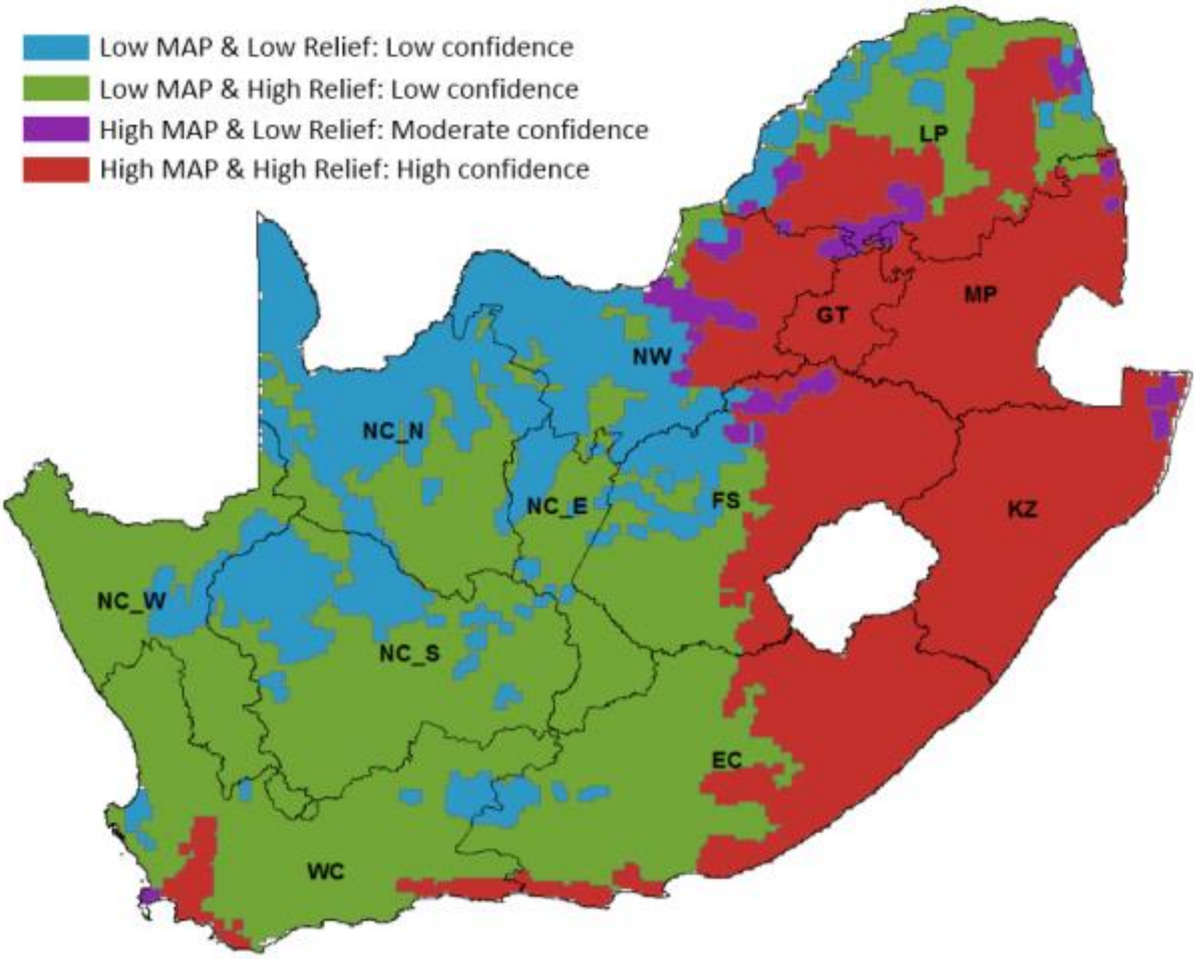


Figure 5.19: Ratings of mapping confidence for regions based on MAP and relief. Regions with an MAP <=500 mm are considered to have a low MAP while regions with a standard deviation in elevation <=10 are considered to have low relief.

The categories of confidence rating are relative, i.e. a confidence rating of high does not imply that the wetlands of these areas are necessarily accurately mapped, but rather that they are considered to be more accurately mapped than regions with a lower confidence rating. High confidence therefore refers to mapping accuracy within the constraints and limitation of the DEM-based method as discussed in Section 5.6.

The confidence rating per Figure 5.19 is a very simplistic representation and does not account for factors other than MAP and relief. Regions of low MAP and sparse vegetation were found to be more problematic than regions of similar MAP but which are better vegetated. Wetlands located within the grasslands of the low confidence regions are therefore expected to be better mapped then e.g. areas of desert or Karroo in the same low confidence region. The converse is also true, i.e. certain vegetation types in the high confidence region are not conducive to the DEM-based approach and wetlands of these areas will be mapped at lower accuracy than the wetlands of other vegetation types. The confidence ratings also do not account for other environmental drivers such as seasonality of rainfall. Differences in mapping accuracy were also reported for the high relief (>10 standard deviation) category. In some regions wetlands at the lower end of this category were found to be reasonably well mapped while wetlands at the upper end of this category (i.e. areas of very high relief) were found to be poorly mapped.

Criticism of the existing national wetland map (NWM4) includes amongst others the lack of contiguity amongst and within wetland ecosystems. The DEM-based method was designed to address these shortcomings and the results indicate that the method has to some extent succeeded therein. The isolated and disconnected nature of features in the NWM4 Map (red in A & B of Figure 5.19) is clearly visible as opposed to the modelled *wetland probability map* (blue), which to a large extent overcomes this defect (B).

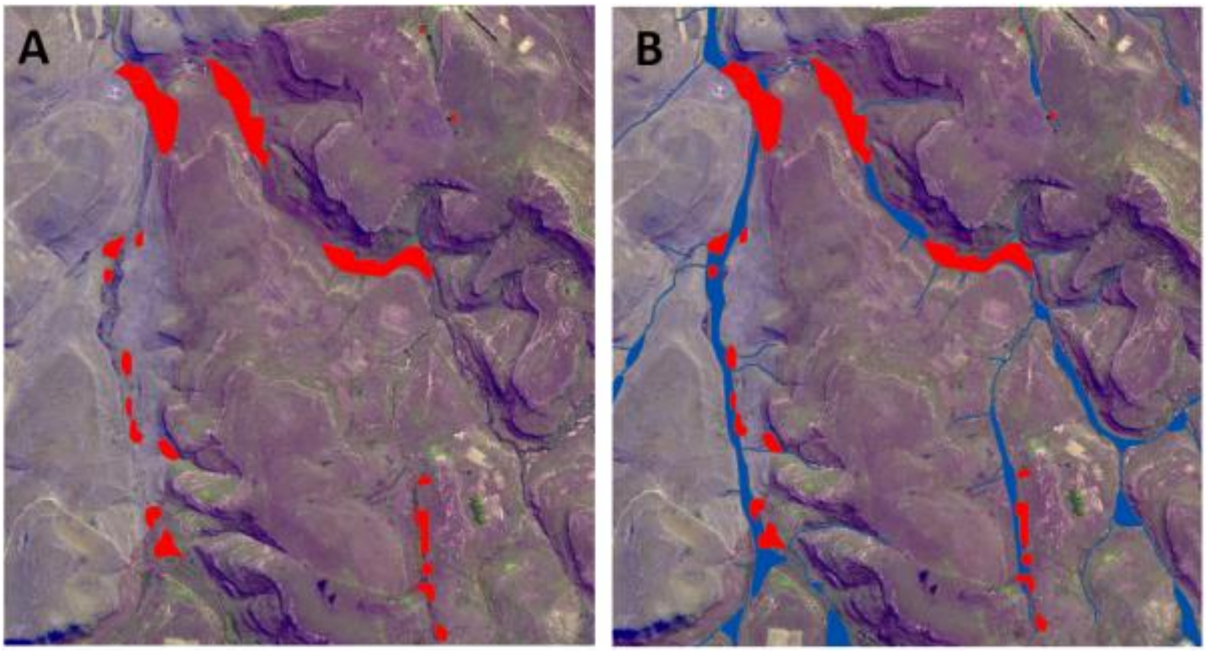


Figure 5.20: The DEM-based approach (blue features) was to a large extent able to overcome the poor contiguity of NWM4 (red features).

A comparison of spatial accuracy also allowed for the comparison of other technical aspects. Manually mapped polygons, as is required for mapping wetlands, typically suffer from a number of mapping errors such as gaps between features, unintended overlaps, switchbacks, knots and loops. It is evident from casual observations of the *wetland probability map* that the automated process has to a large extent negated the occurrence of such errors in the *wetland probability map*.

An objective when developing the DEM-based approach was for it to be able to rapidly map extensive areas with minimum data, skill and cost requirements. Imagery and DEMs were freely available while it took a single person on average approximately 7-9 working days to determine and capture the mapping thresholds for all mapping regions of a division (excluding the time for data preparation, e.g. creating the percentile filter and flow accumulation maps). Although it is acknowledges that the results have suffered from the fact that all mapping was done by a single user, it was possible for a single person to map the entire South Africa within reasonable time at cost. Development of the Python scripts did require skills not common amongst most whom in future will be mapping wetlands. However, once the scripts are made available the mapping of wetlands following the DEM-based approach will require minimum GIS skills of the user. An added advantage of this benefit is that users who have detailed knowledge of wetlands in a particular region will in future be able to easily improve on the results of the mapping exercise using the same method, something that was not possible with previous mapping method.

Although the percentile filter and flow accumulation features are combined to create a single seamless *wetland probability map*, these remain as individual features within the final output (Figure 5.20). The fact that they are mapped as separate features allows for the possibility of automating HGM typing of these features per Ollis et al. (2013) which would not have been possible if all percentile filter and flow accumulation features were dissolved into a single feature. The fact that the features are mapped individually is considered to be a distinct advantage for the initial creation of a wetland map that will allow for the assessment of other wetlands attributes, e.g. wetland function and wetland health, which in turn are required to prioritize wetlands. Wetland priority is a key factor to be included in tools and systems that inform wetland conservation and management decisions such as provincial biodiversity plans.

Figure 5.21: Individual wetland ecosystems are reflected in different colours. Symbology was set to the feature unique identifier (field OBJECTID) to assign each individual features (potentially a different HGM wetland type than the adjoining feature) a unique colour.

Wetlands are a key component of provincial biodiversity plans. For most provinces the wetland component of their biodiversity plans are informed by the NFEPA of which the spatial component is informed by NWM4. If the finding that the NWM4 accounts for less than 50 % of the wetlands associated with the valley floor landscape unit is accurate, then it means that priority wetlands were identified without having considered half of the wetlands. NFEPA priority wetlands may therefore in actual fact not be the priority wetlands, implying the Critical Biodiversity Areas (CBAs) that are selected on account of important wetlands may have been incorrectly identified as such. The *wetland probability map* may to some extent contribute towards the spatial component of future wetland priority assessments and therefore contribute towards improved confidence of such processes.

Wetlands are defined as areas which in 'normal circumstances supports or would support vegetation typically adapted to life in saturated soil' (DWA, 1998). Methods employed during previous attempts at creating a national wetland map used multispectral imagery with which to detect wetlands. Only wetlands that displayed sufficient reflectance were mapped which, amongst others, resulted in the poor contiguity of wetlands per NWM4. It follows that the wetlands of which the hydrology has been altered and therefore no longer supports hydrophytic vegetation, but which under normal circumstances would, were not mapped and are therefore not included in NWM4. The DEM-based method assumes such areas to be wetland and is therefore more compliant with mapping wetlands as per the South African Water Act. It is therefore also more suitable for mapping original wetland extent which if combined with wetlands identified from multispectral imagery, allows for determining wetland loss.

5.6 Limitations

5.6.1 Image limitations

In-field identification and delineation of wetlands are informed by the indicators and criteria as contained in the field procedure for the identification and delineation of wetlands and riparian areas (DWAF, 2005). Of the indicators it is only the soil wetness indicator that is considered to be diagnostic[2]. Although soil maps can be included as ancillary data, the method relies mostly on the visual observation of wetlands from remote-sensed images. This is considered to be problematic, especially so in arid regions where neither the soils nor the vegetation of valley floor areas satisfy any of the wetland indicators.

The ability to identify wetlands from imagery differs from one region to the next as areas with different vegetation structure, moisture regime, topography, *et cetera*, present different conditions for wetland development and has different reflectance properties. The extent to which vegetation expresses the presence of a wetland therefore differs between mapping regions so that the accuracy with which wetlands are mapped will differ, even if mapped by the same user. Similarly, areas that are frequently inundated within a mapping region are more readily identified as wetland as opposed to areas in the same mapping region that are inundated less frequently. Depending on the quality of the imagery, on-site disturbances and experience of the user, the drier wetlands may or may not be identified as wetland (Figure 5.21). A certain amount of error is therefore an inherent part of the mapping process.

Deriving wetlands from imagery should ideally be informed by images from different years and seasons to account for environmental and temporal variability. All of the mapping performed was informed by identifying wetlands from satellite imagery of a single season of (2013; see Section 5.4.1). It is can be seen from Figure 5.22 that the three years preceding 2013 received mostly above average annual rainfall (indicated by the red line), with the preceding year received below average rainfall (South African Weather Service, 2016). The dry year preceding the imagery used for mapping is not considered to be ideal and may contribute towards omission errors.

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[2] Although the presence of hydrophytic vegetation is considered to be diagnostic, the absence of such vegetation does not necessarily indicate the absence of wetlands as other indicators such as soil form or soil wetness may confirm wetland presence in the absence of this indicator. It is acknowledged that certain soil forms do indicate the presence of a wetland and they are considered to be diagnostic. However, some soil form may or may not indicate wetlands presence. The soil form indicator is therefore not considered to be diagnostic.

Figure 5.22: Different reflectance properties of wetlands may affect the outcome of the mapping process. Clearly discernible wetlands are indicated by the blue outlines, while those demarcated in red are less obvious wetlands. Different users may include the wetlands demarcated by the red outline while others users may exclude them (Note: the above image is for demonstration purposes only and is not considered to be a complete and accurate delineation of wetlands).

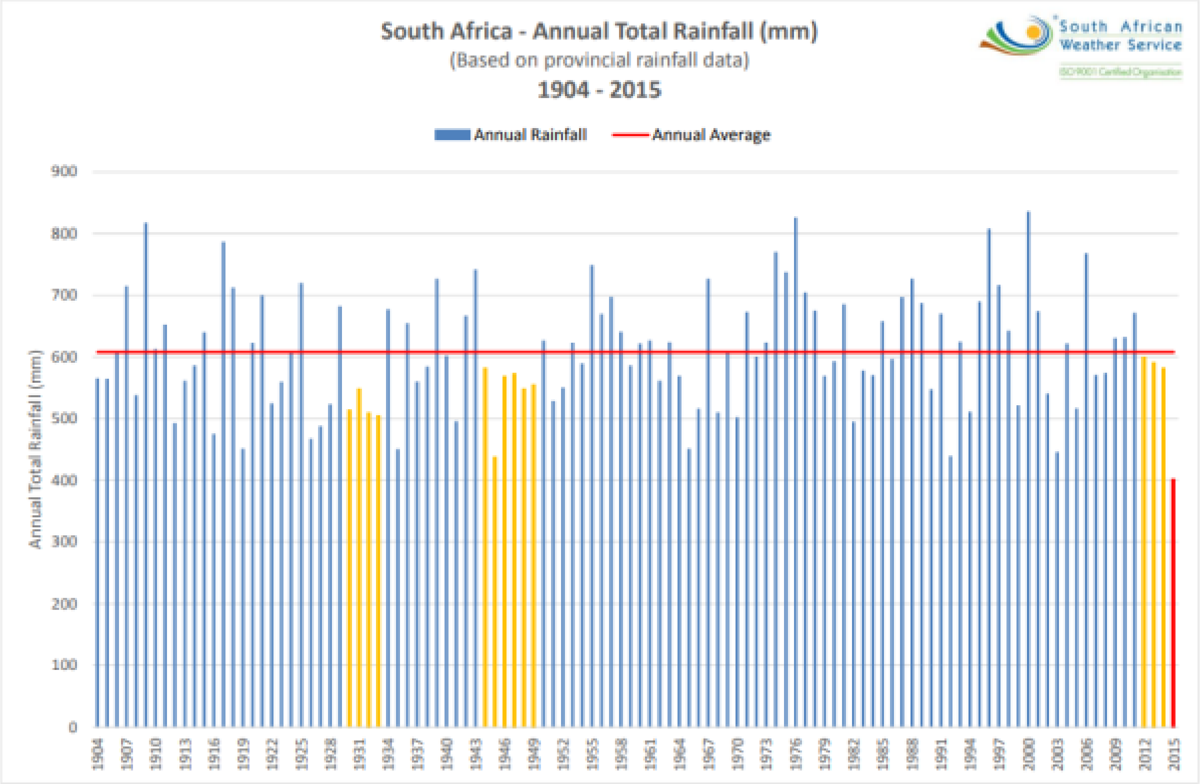


Figure 5.23: Annual total rainfall for the period 1904 to 2015 in South Africa.

5.6.2 DEM limitations

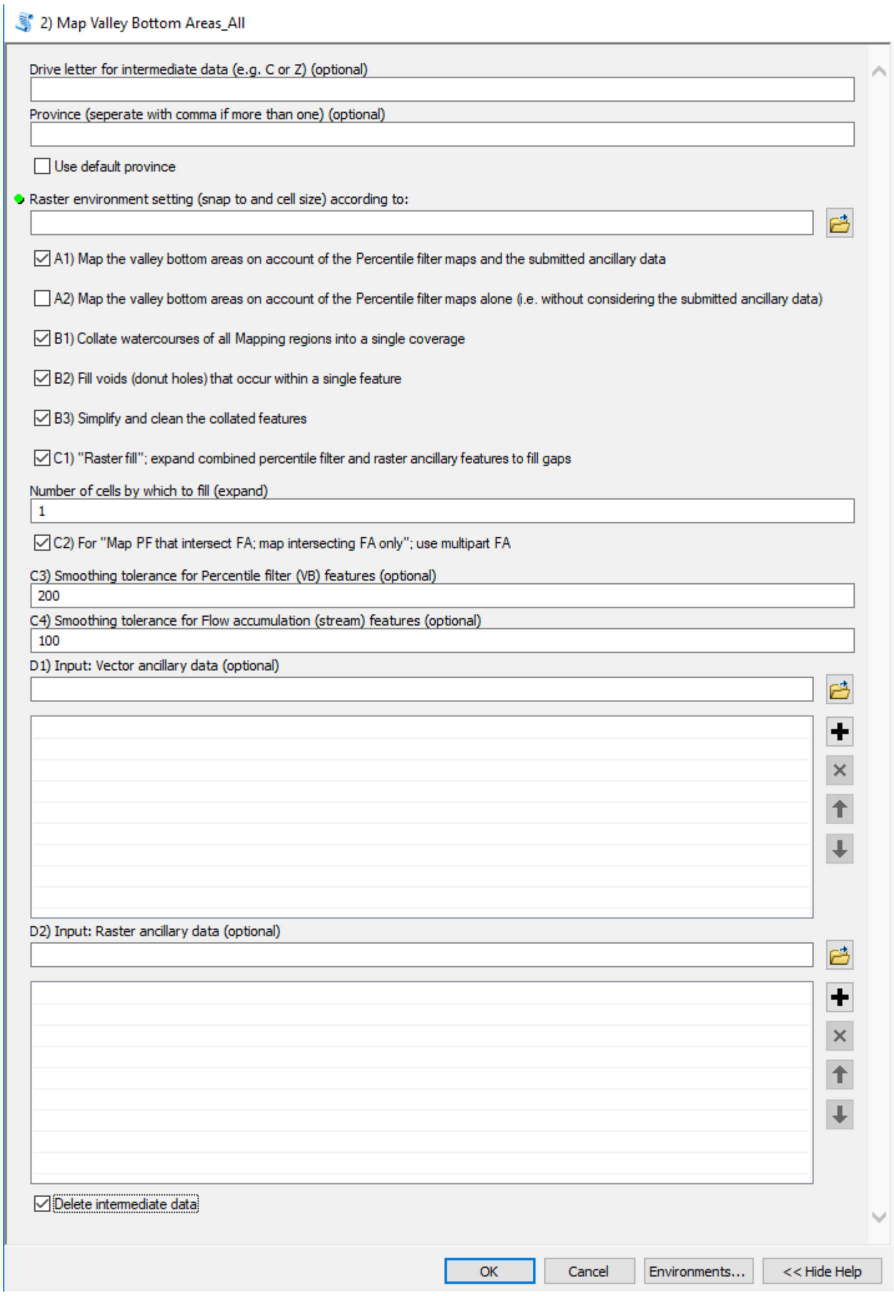
The ability of the percentile filter tool to distinguish valley floors from surrounding slopes diminishes in areas of low relief. The accuracy with which wetland presence and boundaries could be predicted is therefore assumed to be low in flat areas, and more so where these occur in arid regions. Increased accuracy is expected in areas of higher relief and rainfall (Figure 5.19).

Another limitation of the DEM-based approach is that it does not perform well at mapping very large expanses of valley-floor landscape units. The full extent of such areas is often not fully mapped and they are more prone to having voids (donut holes) in the final output.

5.6.3 Other technical limitations

The mapping tool (Figure 5.23) offers various options which, in general, are expected to improve the output. They may, however, have unintended consequences which in some instances may result in mapping errors.

The option to fill voids (parameter 'Fill voids (donut holes) that occur within a single feature' in Figure 5.23) will fill all voids located within a features (Figure 5.24 B). Often the filling of voids is desirable as many of them are the result of the percentile filter and ancillary maps not covering the full extent of the visually identified wetland, especially in extensive wetland systems. However, this option may result in non-wetland areas being filled and therefore incorrectly mapped as wetland (Figure 5.25 B).



2) Map Valley Bottom Areas_All

Drive letter for intermediate data (e.g. C or Z) (optional)

Province (seperate with comma if more than one) (optional)

☐ Use default province

● Raster environment setting (snap to and cell size) according to:

☑ A1) Map the valley bottom areas on account of the Percentile filter maps and the submitted ancillary data

☐ A2) Map the valley bottom areas on account of the Percentile filter maps alone (i.e. without considering the submitted ancillary data)

☑ B1) Collate watercourses of all Mapping regions into a single coverage

☑ B2) Fill voids (donut holes) that occur within a single feature

☑ B3) Simplify and clean the collated features

☑ C1) "Raster fill"; expand combined percentile filter and raster ancillary features to fill gaps

Number of cells by which to fill (expand)
1

☑ C2) For "Map PF that intersect FA; map intersecting FA only"; use multipart FA

C3) Smoothing tolerance for Percentile filter (VB) features (optional)
200

C4) Smoothing tolerance for Flow accumulation (stream) features (optional)
100

D1) Input: Vector ancillary data (optional)

D2) Input: Raster ancillary data (optional)

☑ Delete intermediate data

Figure 5.24: User interface of the mapping tool. The tool offers the user a number of mapping options as well as the opportunity to list both vector and raster ancillary data.

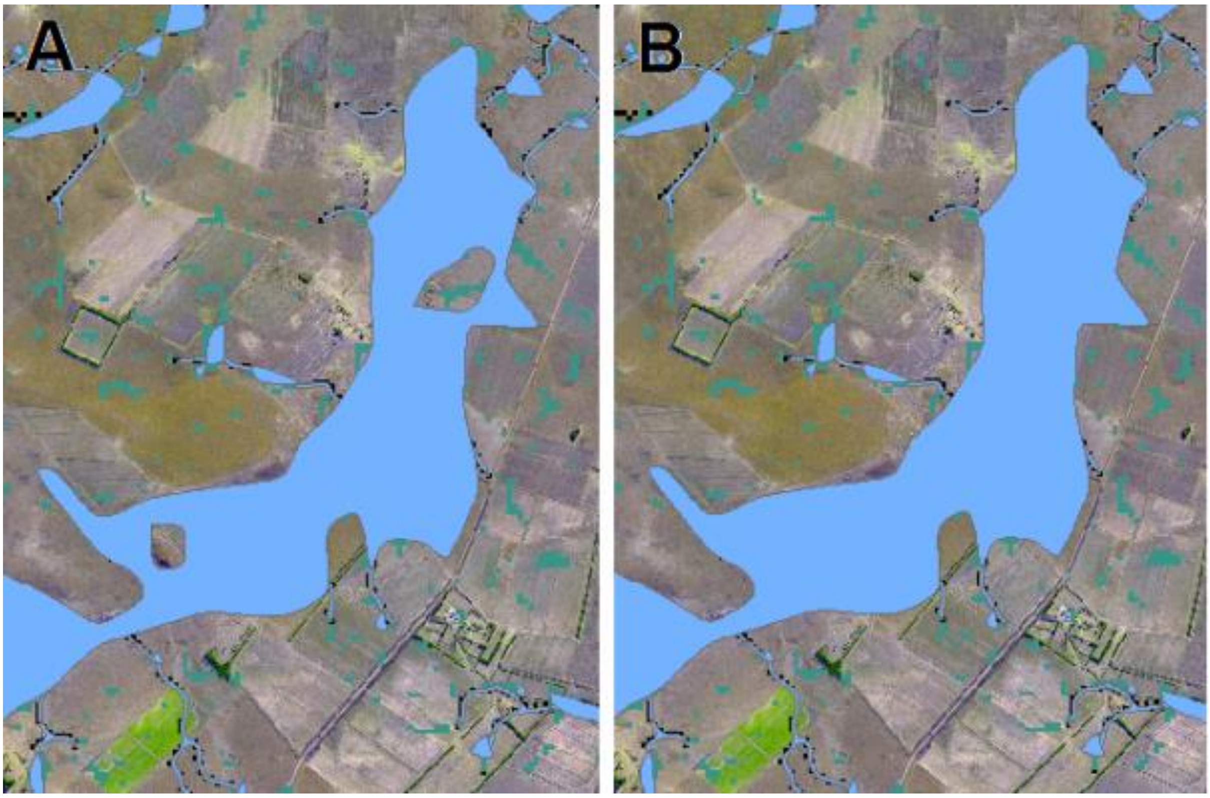


Figure 5.25: Comparison of results with the 'Fill voids (donut holes) that occur within a single feature' option not enabled (A) as opposed to it being enabled (B).

Another limitation of this option is that voids that contain islands of isolated features are not considered to be empty and are therefore not filled (Figure 5.26). Contrary to the example of Figure 5.25 such areas of wetland are incorrectly mapped as non-wetland.

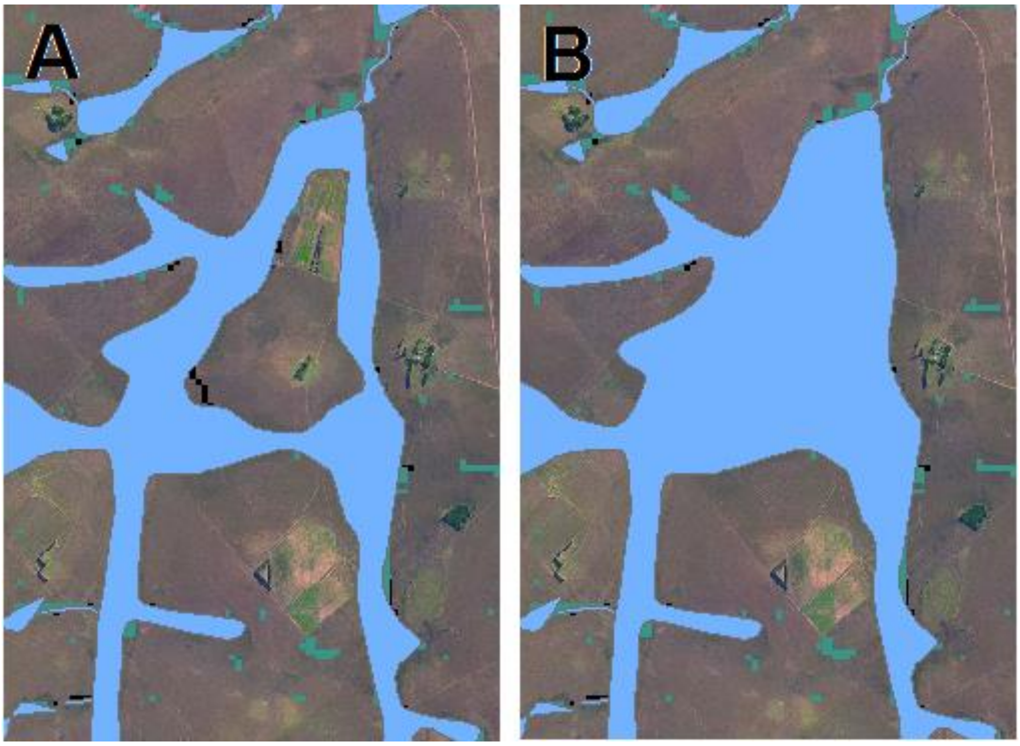


Figure 5.26: Unintended consequences of having an area which is not wetland (A) filled and thereof incorrectly mapped as wetland (B).

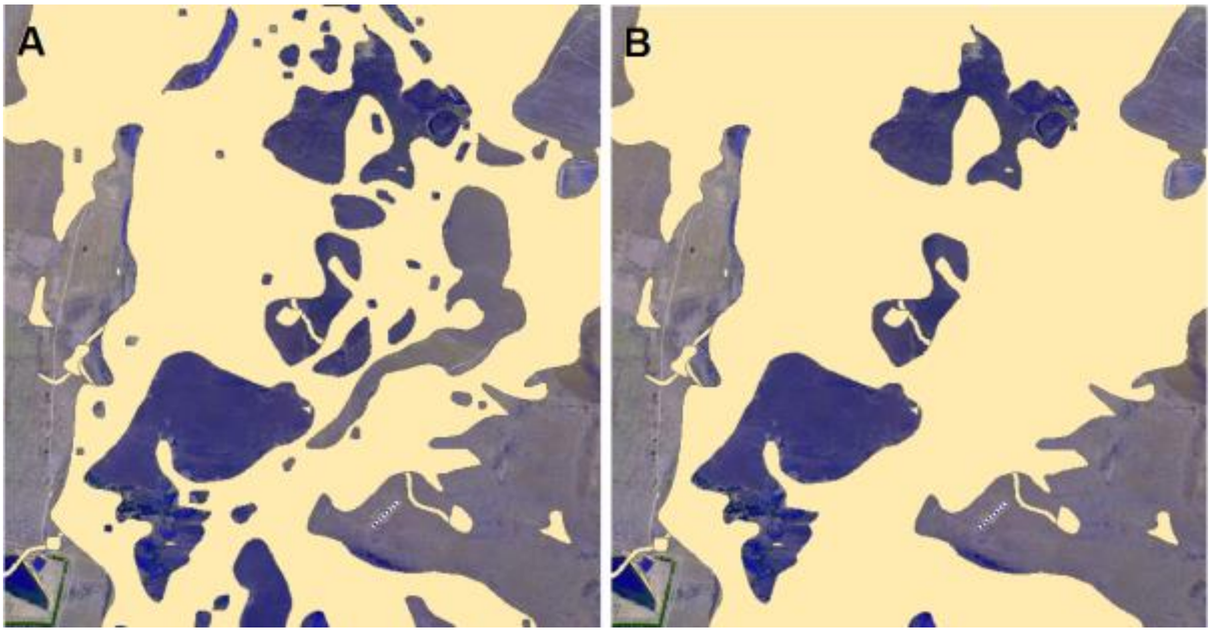


Figure 5.27: A indicates all voids before filling compared to B which indicates the voids after filling. Voids that contain features are not filled thereby resulting in wetlands areas being incorrectly mapped as non-wetland (B).

Although the method is aimed at mapping wetlands which are primarily associated with the valley-floor landscape position, it inevitably predicted wetlands of other HGM types, specifically depression wetlands. For the purpose of creating a single wetland layer for South Africa containing wetlands of all HGM wetland types, the latter is considered to be more of an inconvenience as opposed to an error. Ideally the output of a *wetland probability map* would be able to predict different HGM wetland types, or alternatively an output containing only wetlands that are associated with the valley floor-landscape unit. The use of the percentile filter tool, however, predicts valley-floor-related HGM wetland types such as channelled and unchannelled valley-bottom wetlands, but also includes HGM wetland types found on plains, such as depression wetlands. Further investigations are required to determine whether depressions can be excluded.

As mentioned previously the mapping thresholds represent a best average for all wetlands within a mapping region. Although this allows for the rapid assessment of wetlands, it does imply that wetland occurrence and extent (boundary) of almost none of the wetlands will be 100% spatially accurate. The final output will therefore always to a certain degree be an approximation of wetland occurrence and extent.

It is important to keep in mind that the DEM-based method only maps wetlands of the valley floor landscape position. To create a national wetland map that includes wetlands of all HGM types the wetlands of other landscape units will need to be obtained from alternative sources.

5.7 Recommendations for improvement

The 10 m buffer applied is a subjectively chosen width that was considered to represent a suitable average for wetlands of the flow accumulation maps. Wetlands located in the upper catchments are typically narrower than those of the lowlands. The possibility of applying a stream-order analysis to quantitatively inform buffer allocations should be investigated.

Inclusion of a *wetland probability map* determined by way of e.g. Bayesian statistics or logistic regression (Hiesterman & Rivers-Moore, 2015) will greatly contribute towards and should ideally be available during mapping. The use of multiple imagery (different years and seasons) as well as images derived from other sensors will also allow for improved detection of wetlands to inform the process of setting mapping thresholds. Data from non-imagery related sources to confirm wetland presence/absence should also be considered, e.g. relevé data from the national vegetation database where vegetation and soil data can confirm the presence or absence of wetland ecosystems.

Although initial testing did not suggest that DEMs of courser resolution (e.g. 90 m and 500 m) provide any advantage over and above those provided by the 30 m DEM, the ability of coarser DEMs to possibly overcome the limitation of mapping extensive wetland systems requires further investigation.

The method relies heavily on the ability of the user to visually identify wetlands from imagery using the vegetation indicator. Vegetation, however is absent in most parts of the arid regions. Research of the valley floor areas of the arid regions to better understand their ecology will greatly improve decision making as to whether these areas should be mapped as wetlands or watercourses.

5.8 Conclusion

Development of the method and its application were done simultaneously. Time to collect alternative data sources for indicating wetland absence and presence was therefore limited. However, in spite of this and other limitations it is concluded that the method does show promise for improving on existing wetland spatial data, more so for some regions than others. Although it was not possible to do a detailed accuracy assessment, the *wetland probability map* is considered to represent an improvement on the existing NWM4 in mesic regions of high relief. The worth of the results in arid regions, especially in regions of low relief, will need to be reviewed. In the absence of a detailed accuracy assessment the use of the results from such areas to inform conservation and management decisions is not recommended. Areas of which the results are subjectively considered to be not suitable for general use are those from regions that receive on average less than 500 mm rainfall per year and / or that have a standard deviation in elevation of 10 meters or less.

For the remaining areas the results are considered to be an improvement on existing alternatives. Although the accuracy with which wetland extent was mapped in these areas could be improved, the results do indicate wetland presence where many of the alternatives do not. From this perspective the results of these regions are considered to be useful to inform decision making at various levels (areas of high confidence per Figure 5.19).

The accuracy of the outputs are very much dependant on the effort. Depending on time constraints the user can decide how much effort to increase accuracy can be afforded. Such efforts will include more percentile filter base maps of different DEM resolutions and different moving window sizes, of DEMs with improved horizontal and vertical accuracy, spending more time testing different modification options to arrive at the best modified percentile filter map, using other environmental variables to inform the mapping regions, obtaining other sources of known wetland location to use as 'training features' during the process of determining mapping thresholds, obtaining more imagery as well as imagery from other sensors and manual subdivision of mapping regions. All of these, along with an improved understanding of what constitutes wetland may result in greatly improved mapping results. Although many of the above stated recommendation will improve accuracy, many of them will result in severe time penalties and the user will need to determine the trade-off between increased accuracy and mapping effort.

Irrespective of the accuracy of the *wetland probability map*, the logic and rationale on which it is founded is considered to be sound. Mapping errors are mostly the result of DEM resolution, horizontal accuracy of the DEM, time constraints, insufficient scientific data to distinguish wetlands from watercourses in the arid regions, etc. Although these have resulted in unsatisfactory mapping accuracy in the regions mentioned above, future improvements to these current limitations may still prove the approach to be useful in such areas.

Although the *wetland probability map* is at present being viewed as being the final output of a wetland mapping exercise, its use to support other mapping processing should be considered. Multispectral approaches often use masks to 'filter' out errors of spectral confusion. A map of valley floor areas can be used to distinguish between wetland reflectance values that are likely to be wetland (i.e. those within the valley floor areas), and those that are unlikely to be wetland (i.e. this not in valley floor areas). The method can therefore in future be used to create landscape data to support and inform other mapping process.

5.9 References

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6. CHAPTER 6: EVALUTATION OF THE WETLAND PROBABILITY MAP FOR SUPPLEMENTING THE NATIONAL WETLAND MAP

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This chapter provides information on the comparison between fine-scale mapped wetlands and modelled wetlands for a number of areas in South Africa. At least three country-wide modelled wetland data sets were compared for four catchments, one district and three metropolitan municipalities. Recommendations are provided on the use of these data sets for NWMs.

6.1 Introduction

Omission errors in NWM5 remain a concern and are difficult to quantify at a country-wide scale. Where reference data sets exist, a comparison of agreement, omission and commission errors can be done to evaluate the quality and completeness of a NWM. At a finer scale, and where expenses for fieldwork can be made, the level of agreement, omission and commission can be assessed for a corridor along transects, similar to those done by Werner (2004-2005).

Supplementation of a NWM with modelled wetlands data has been considered previously (Chapter 1), and likewise, we have also considered the supplementation of NWM5 with wetlands data modelled at a country-wide scale.

This chapter has two objectives:

i) to evaluate the agreement, omission and commission errors of NWM5 in comparison to reference data; and
ii) to assess whether wetland data modelled at a country-wide scale could be used to address omission errors of NWM5 without introducing more commission errors.

6.2 Methods

NWM5 was evaluated against three fine-scale wetlands data sets (reference data sets), mapped by Wetland Consultancy Services Pty Ltd (WCS) for study areas in the Free State (FS) and Mpumalanga (MP) provinces (Table 6.1, see also Appendix H). The comparison was done with a near-final draft of NWM5, version 5.4, which was available 30 November 2017. No edits to these areas were done between this version and the release of NWM5 for these areas.

The data sets were compared using ArcGIS 10.3 (ESRI, 1999-2014) and an overlay procedure with all the data in the Albers Equal Area coordinate system for South Africa which least distorts surface area. The statistics were summarised in two ways:

a) the **extent of the wetlands mapped** for each data set was listed in hectares (ha) as well as the percentage (%) of wetlands relative to the surface area of each study area. These statistics provides a general overview of the extent of wetlands mapped, although it doesn't indicate the agreement or disagreement between the data sets.

b) the percentage **agreement, omission and commission errors** of NWM5.4 relative to the reference data set and expressed as percentage of the surface area of each study area.

Table 6.1: Areas for which fine-scale wetlands maps were used in comparison to NWM5

Area or district	Extent (ha)	Description
Free State study area (FSSA), FS	109 831	Not provided
Olifants River study area (ORSA), MP	30 886	Located near the town Witbank, characterised by sandy soils derived from Karoo sandstones, resulting in very extensive seep wetlands.
Vaal River study area (VSRSA), MP	13 763	Located near the town Secunda, characterised by vertic clay soils derived from intrusive dolerites. Given the clay soils, seep wetlands are less prevalent in this area and valley bottom wetlands predominate.

Three wetlands data sets which were modelled at a country-wide extent were subsequently considered for supplementation of NWM5:

- Wetlands modelled for South Africa by Thompson et al. (2002);
- The Global Inundation Extent from Multi-Satellites (GIEMS) (Fluet-Chouinard et al., 2015); and
- the *wetland probability map* (see Chapter 5).

Although other probable wetland mapping data sets have been produced for the KwaZulu-Natal Province, these were not considered for inclusion in the NWM5 (Van Deventer et al., 2018). For example, time and budget constraints prohibited the typing of the extent of wetlands modelled for the province (Hiestermann and Rivers-Moore, 2015) from inclusion and comparison to fine-scale inland wetland data sets.

A comparison was done between the three data sets which had modelled inland wetlands at a national scale and eight fine-scale wetlands data across the country (Table 6.2). Inland wetlands from three study areas listed in Table 6.1 were compared to the *wetland probability map*. In addition, a baseline of NWM5.4, which was available by 30 November 2017 and included fine-scale data for the three metropolitan municipalities as well as the Cape Winelands District (CWD), was also used in a comparison to Thompson et al. (2002) and the GIEMS data (Fluet-Chouinard et al., 2015).

Table 6.2: Areas for which fine-scale wetlands maps were used in comparison to modelled wetlands data

Study area or district	Extent (ha)	Biome	Thompson et al., 2002	GIEMS	*Wetland probability map*
City of Cape Town Metropolitan Municipality of 2016 (CoCTMM 2016), WC*	244 048.9 ***	Fynbos	√	√	√
City of Johannesburg Metropolitan Municipality of 2016 (CoJMM 2016), GT**	164 493	Grassland	√	√	√
City of Tshwane Metropolitan Municipality of 2009 (CTMM 2009), GT**	217 456.5	Grassland	√	√	√
FSSA, FS	109 831	Grassland			√
ORSA, MP	30 886	Grassland			√
VRSA, MP	13 763	Grassland			√
Saldanha-Sandveld study area (SSSA), WC*	2 592 192	Fynbos			√
Cape Winelands District of 2016 (CWD 2016), WC**	2 147 328	Fynbos / Succulent Karoo	√	√	√

** Prior to inclusion into NWM5.4 ** Included in NWM5.4 by time of assessment *** The extent excluding islands was used*

The data sets in Table 6.2 vary in completeness and accuracy. Most were captured at a desktop scale without fieldwork verification and edits. In some instances, such as the City of Tshwane, the data capturing focused on what was attainable within a restricted timeframe and budget. Therefore, many of the reference data sets represent only a portion of wetlands that exists in these catchments, although with high confidence. For most of the municipalities, the latest boundaries from the Municipal Demarcation Board have been used, except for the City of Tshwane where the 2009 boundary was used, because the reference data was mapped to the 2009 boundary. The method of comparison and resulting statistics between the modelled wetlands data sets and the reference data sets, were similar to those used for the NWM5.

6.3 Results

6.3.1 NWM5 comparison to reference data sets

All three reference data sets showed that more than 10% of the surface area of the study areas in the Free State and Mpumalanga (grassland biomes), were mapped as wetlands (Table 6.3). For two of the three study areas, the NWM showed an underrepresentation of mapped wetland area by > 5% of the surface area of the study area, whereas in the Vaal River study area there was only a 3% difference in wetlands mapped.

Table 6.3: Comparison between the extent (ha and %) of wetlands mapped relative to the size of the study area and the reference data set

Study area	Data set	Extent of wetlands (ha)	Percentage (%) surface of study area mapped as wetlands
FSSA	Reference	11 027	10.0
	NWM 5.4	1 425	1.3
ORSA	Reference	7 663	24.8
	NWM 5.4	2 841	9.2
VRSA	Reference	2 227	16.2
	NWM 5.4	1 838	13.4

NWM5.4 showed a low percentage of agreement for the Free State study area (1.1%) compared to the Orange River and Vaal River study areas (8-10%), relative to the surface areas of the study areas (Figure 6.1). The omission errors of the Olifants River study area was the highest (17%) followed by the Free State study area (9%) and the Vaal River study area (6%). This means that between 30% of the Vaal River, 70% of the Olifants River and 90% of the Free State study areas' wetlands of the reference data set are not represented in NWM5.4. Commission errors, on the other hand, were generally low (<3%), ranging from the highest for the Vaal River (3%), followed by the Olifants River (1.3%) and the Free State (0.2%) study areas.

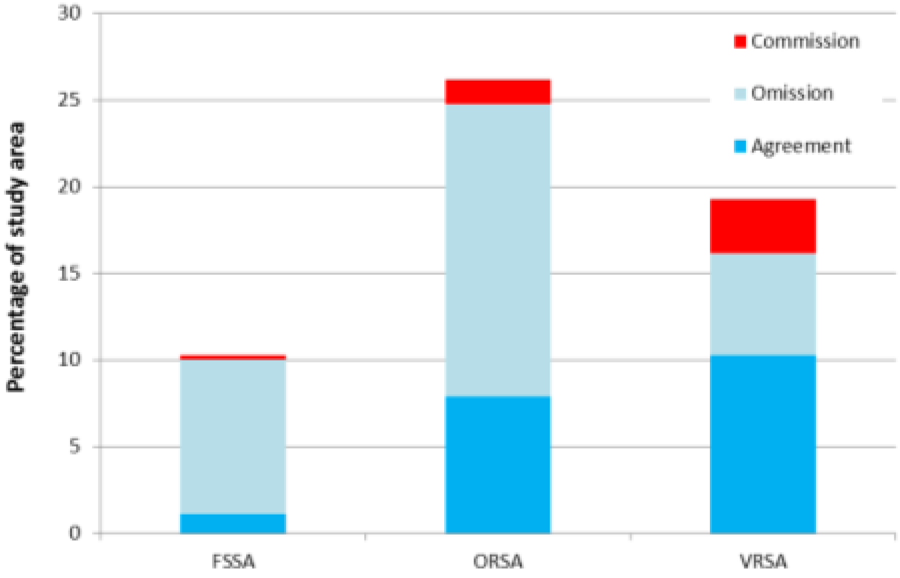

Figure 6.1: Comparison of NWM5.4 to the reference data set as percentage (%) of the surface area of each study area.

6.3.1 Comparisons between modelled wetlands data sets and reference data

The extent of wetlands relative to the surface area of the study areas varied from 2% in the arid biome to 25% in some parts of the grassland biome (Table 6.4). On average, 10% of the surface area of most study areas was wetland. The modelled wetland data from Thompson et al. (2002) and the *wetland probability map* (Chapter 5) predicted the surface areas of the study areas to be between 1% and 12% wetland, and on average 6%, whereas the DIEMS data, with an average spatial resolution of a pixel 450 m, ranging from 11 to 28% and on average predicting 11% of the study areas to be wetland.

Table 6.4: Comparison between the extent (ha and %) of wetlands mapped relative to the size of the study area and the reference data set

Study area	Data set	Extent of wetlands (ha)	Percentage (%) surface of study area mapped as wetlands
CoCTMM 2016	Reference	11 205.5	4.6
	Thompson et al., 2002	7 615.3	3.1
	GIEMS	68 372.4	28.0
	Wetland probability map	16 072.8	6.6
CoJMM 2016	NWM5.4 (reference)	18 992.5	11.5
	Thompson et al., 2002	7 236.3	4.4
	GIEMS	4 963.6	3.0
	Wetland probability map	9 208.1	5.6
CTMM 2009	NWM5.4 (reference)	11 507.1	5.3
	Thompson et al., 2002	1 977.1	0.9
	GIEMS	14 307.3	6.6
	Wetland probability map	11 430.5	5.3
FSSA	Reference	11 027	10.0
	Wetland probability map	13 198	12.0
ORSA	Reference	7 663	24.8
	Wetland probability map	3 007	9.7
VRSA	Reference	2 227	16.2
	Wetland probability map	1 684	12.2
SSSA	Reference	51 320.6	2
	Wetland probability map	136 906.4	5
CWD 2016	NWM5.4 (reference)	108 609.3	5.1
	Thompson et al., 2002	25 540.7	1.2
	GIEMS	102 871.6	4.8
	Wetland probability map	116 464.02	5.4

The comparison between the modelled data from Thompson et al. (2002) and the reference data showed a low % of agreement (<2.7%) relative to the surface area of the catchment (Figure 6.2). This accounts for less than 24% of the extent of wetlands mapped by the reference data set. Omission errors ranged from 3.7 to 8.8% of the study areas, or between 76% and 90% of the wetlands mapped in the reference data set. The amount of commission errors was generally low (< 2%).

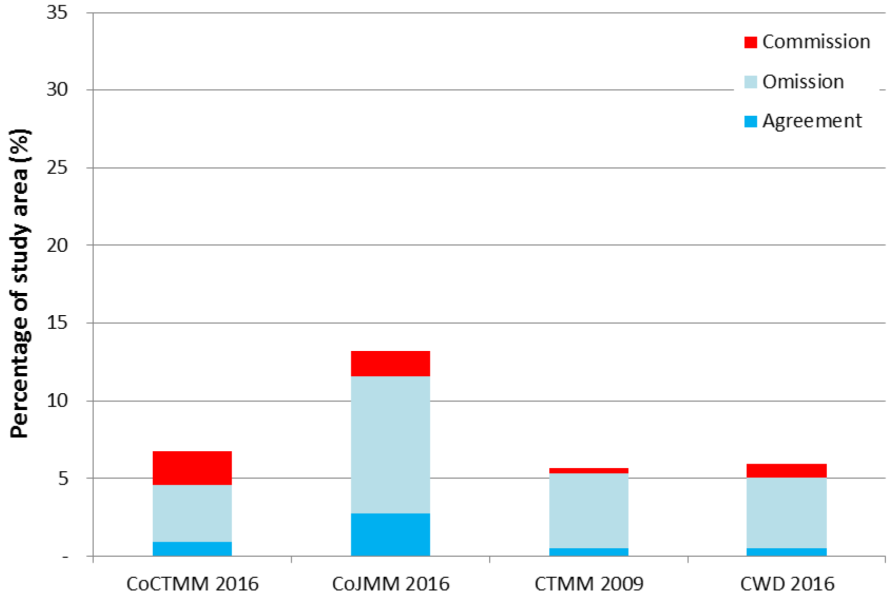

Figure 6.2: Comparison of the *Thompson et al. (2002)* to the reference data set relative to the surface area of the study area.

The GIEMS data showed a low agreement with the reference data sets (≤2%) relative to the surface area of the study areas when compared to the modelled wetlands data of Thompson et al. (2002) (Figure 6.3). Even though there is a low agreement, in the City of Cape Town Metropolitan Municipality, it accounts for 43% of the extent of the wetlands mapped by the reference data set. In the Gauteng municipalities, it accounts however only for <3.5% of the extent of wetlands mapped by the reference data, but increases to 33% for the Cape Winelands District. The omission errors ranged from 2.6% to 11% of the surface area of the study area, accounting for between 57% and 97% of the extent of wetlands mapped by the reference data. The amount of commission errors was generally low (<6.5%) except for the City of Cape Town Metropolitan Municipality where 25% of the surface area of the municipality was predicted as wetlands. After visually inspecting these areas it was concluded that they largely coincided with the coastline and the Cape Flats and are unlikely to be wetlands.

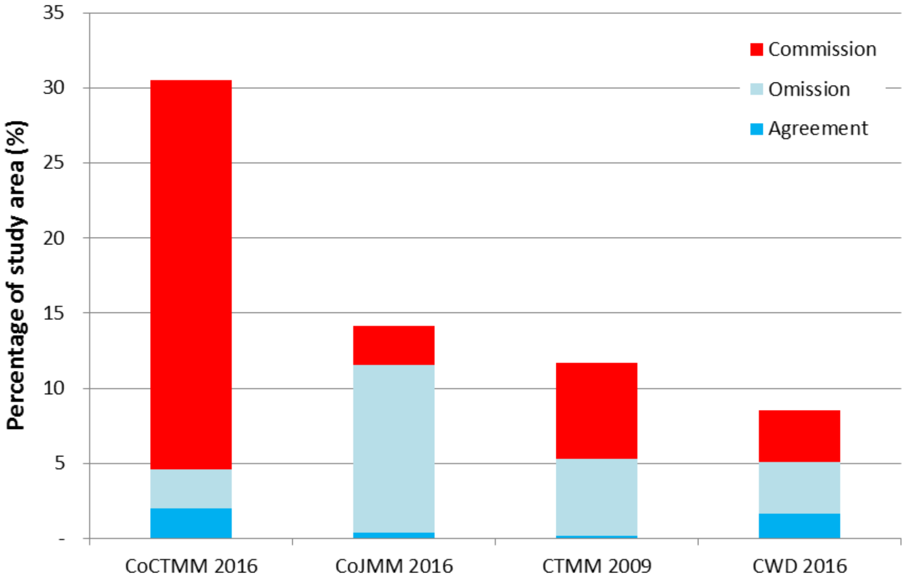

Figure 6.3: Comparison of the *GIEMS* data to the reference data set relative to the size of the study area.

When the *wetland probability map* was compared to the reference data, it showed a low agreement (<8.9%) with the reference data relative to the surface area of the study areas (Figure 6.4). This accounted for less than 58% of the extent of wetlands mapped by the reference data sets. Omission errors ranged from 1% to 18% of the surface area of the study areas, which accounts for between 42% and 74% of the extent of wetlands mapped by the study areas. The Olifants River catchment showed the highest omission error (18%), whereas the omission errors in the other study areas were lower (< 8%). Commission errors were mostly low (< 6.4%) for all study areas.

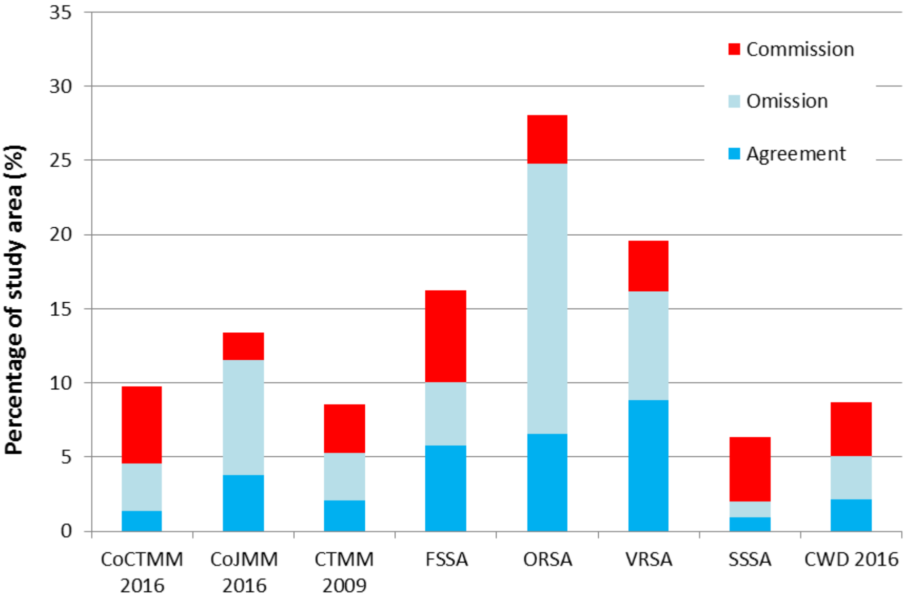

Figure 6.4: Comparison of the *wetland probability map* to the reference data set relative to the size of the study area.

6.4 Discussion and recommendations

The assessment of the representation of NWM5.4 relative to three reference data sets, showed agreement between 8% and 10% for the Orange and Vaal River study areas, relative to the surface area of the study areas, which accounts for only between 30% and 64% of the extent of wetlands mapped by the reference data sets. Wetlands in the Free State study area were poorly represented, since NWM5.4 mapped only 10% of the wetlands which were mapped by the reference data set. The omission errors ranged from 6% to 17% of the surface area of the study areas, which accounted for up to 89% of the extent of wetlands mapped in the reference data set. The amount of commission errors was generally low (≤ 1.3%) compared to the surface area of the study areas.

Of the three data sets that modelled wetlands for the country, the *wetland probability map* appeared to perform better: for three of the eight reference study areas, the agreement ranged from 6% to 9% while the maximum commission error was < 6.3% of the surface area of the study areas. All three modelled data sets showed, however, that a large percentage (average 70.4%) of the extent of wetlands mapped in the reference data sets have not been included in the prediction, raising a concern about the capability of the models to predict true presence of wetlands. The Thompson et al. (2002) model had the least commission errors (< 2.2% of the surface area of the study areas), compared to the GIEMS data and the watercourse probability map. Yet in section 4.1 of this report, we indicated the type of commission errors which were present in the NWM4, as a result of the inclusion of modelled data.

The watercourse probability would likely address shortcomings of the NWM5 and can be selectively used to supplement NWM5, however the limited number of reference data available for comparison, yielded a narrow view and understanding of where the data could be valuable without adding level of error that is unacceptably high. It is clear from the statistics of the reference data sets that the extent of wetland area varies across regions and that the reference data or accuracy assessment would be required to determine the completeness of representation of the NWM across the country. Visual inspection in some parts of Gauteng did indicate that the *wetland probability map* predicted valley-bottom systems which were omitted, however, the wetland probability map overestimated the extent of these systems. The results will be presented to the Wetland Ecosystems Classification Committee (WECC) at the end of January 2018, and the final decision to include the modelled data into NWM5 for the assessment of inland aquatic ecosystems in the National Biodiversity Assessment of 2018 (NBA 2018), will be documented in an update of this report, as well as the NBA 2018 technical reports. The intention is to recommend no modelled wetlands data to be included in NWM5. However, these modelled data can be used as a guide for the capturing of wetlands in NWM6. The data should be made widely available by the South African National Biodiversity Institute (SANBI) to interested parties, to use in combination with NWM5 for an improved inland wetlands data set.

6.5 References

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7. CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

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This chapter provides an overview of the motivation for a South African Inventory of Inland Aquatic Ecosystems (SAIIAE) and elaborates further details the appropriate scale and uses of the associated data. A summary of the recommendations of the SAIIAE data is provided, as well as those pertaining to the rivers and inland wetlands.

7.1 Introduction

A wide range of strategic, regulatory and reporting processes require a comprehensive inventory of inland aquatic ecosystems; including the National Biodiversity Assessment (NBA), State of Environment Reporting, reporting on international conventions (e.g. the Ramsar Convention, the United Nations Convention on Biological Diversity (UNCBD) and the Sustainable Development Goals (SDGs)), systematic conservation planning, Environmental Impact Assessments (EIAs) and Strategic Environmental Assessments (SEAs). An inventory of inland aquatic ecosystems is therefore not only needed, but also supported by a number of legislative Acts, such as the South African National Water Act (NWA) and the National Environmental Management: Biodiversity Act (NEMBA) with ministries of the Department of Water and Sanitation (DWS), Department of Environmental Affairs (DEA) and the South African National Biodiversity Institute (SANBI) mandated with responsibilities related to these ecosystems.

To date, the South African inventory of inland aquatic ecosystems had a strong focus on the river ecosystems as well as the National Wetland Map (NWM). The capabilities of Geographical Information Systems (GISs) enabled the faster capturing, ease of updating, efficient storage and wide dissemination of these data sets to multiple stakeholders. Building on previous efforts, this document provides an overview of the creation of the first South African Inventory of Inland Aquatic Ecosystems (SAIIAE) which includes additional data on the condition and management of inland aquatic ecosystem types.

This SAIIAE version and document list key decisions made between 2015 – 2018 by the inland aquatic team, in agreement with the inland aquatic reference committee of the NBA 2018 as well as the River and Wetland Ecosystem Classification Committee (RECC; WECC), with regards to the mapping of the ecosystem types as well as proposed improvements for future updates and versions. It has become quite clear that the representation of both rivers and inland wetlands, which are small fine-scale objects, pose a challenge at a country-wide scale. The maps serve multiple purposes at various scales. Considering that the data sets will be used in a variety of applications, we have therefore attempted to detail its origins and shortcomings as best as possible. In conclusion, we therefore provide guidance on the appropriate use of the products as well as recommendations in this chapter.

7.2 Key highlights, findings and knowledge gaps

Key highlights

- A South African Inventory of Inland Aquatic Ecosystems (SAIIAE) have been established as a collection of data layers that represent the extent of river and inland wetland ecosystem types as well as pressures on these systems.
- The extent of inland wetland ecosystems have been increased by 123% compared to the NFEPA wetlands.
- Eight unique limnetic depressions (lakes) have been identified.
- A confidence map of inland wetlands guides users to appropriate use of the map.

Key findings

- Inland Aquatic ecosystems are represented by a river lines data set as well as polygons of river and inland wetland types in NWM5. Both data sets should be used to represent inland aquatic ecosystems.
- NWM5 represents nearly 4 million hectares (ha) of aquatic ecosystems which cover 3.3% of the surface area of South Africa. These include:
    - Inland wetlands which constitutes > 2.6 million ha or 2.2% of the surface area of South Africa;
    - > 1 million ha of river channels; and
    - 201 381 ha of estuarine ecosystems (<0.2% of the surface area of South Africa).
- The rivers data set represent 200 955 km of river length of which 164 018 km (82%) is situated within South Africa. The majority of the rivers in South Africa (90%) has a river ecosystem types assigned; 10% are ephemeral and episodic systems within the arid Northern Cape Province and <0.1% coincide within an estuary. Mainstem rivers constitute 76 830 km (47%) of the total length of the South African rivers, and tributaries 87 188 km (53%).
- Eight limnetic depressions (lakes) have been identified where the depth of the water-level at low tide is > 2 m. These system constitute 13 376 ha of which Lake Sibayi is the largest.
- Artificial wetlands have been mapped as a separate layer, totalling almost 600 000 ha.

List of Limnetic depressions (lakes) of South Africa:

Name	Extent (ha)	Percentage of the total extent of limnetic depressions
Barberspan	1 720.6	12.9
Chrissiesmeer	1 282.6	9.6
De Hoop	949.3	7.1
Groenvlei	357.3	2.7
Lake Banagher	184.5	1.4
Lake Fundzudzi	192.3	1.4
Lake Sibayi	8 360.1	62.5
Tevredenpan	329.2	2.5
Total extent	13 376.0	

Knowledge gaps

- Uncertainties pertaining to the conceptual ecosystem types represented for river and inland wetlands implemented in the SAIIAE should be addressed. Research is required to better understand whether these conceptual ecosystem types represent faunal and floral species biodiversity as well as function diversity well.
- Inland aquatic ecosystems in the arid region are poorly understood. In the rivers data layer these are typed as ephemeral and episodic rivers. In the NWM a high uncertainty of the hydrogeomorphic typing is associated with these systems. Further work should be done to better define and distinguish water courses, floodouts and washes in these regions.

Key Messages

- Baseline data related to inland aquatic ecosystems are crucial for planning, conservation and management of inland aquatic ecosystems. Currently the baseline data sets provide a poor representation of inland aquatic ecosystem types, as well as their pressures and impacts. The inland wetlands, for example, showed a 69% low confidence for representing the extent of ecosystems, with an estimated 50% omission error. Confidence and accuracies of other data layers, such as rivers and artificial wetlands, are deficient.

Priority actions

Institutional collaboration across all organisations and stakeholders for the improved understanding, mapping, conservation, monitoring and management of inland aquatic ecosystems should be established and sustained. Responsibilities related to ecosystem data sets should be listed by relevant data custodians under the South African Spatial Data Infrastructure (SASDI) Act.

- Research priorities:
    - Improve understanding of the relationship between the ecosystem types and species biodiversity.
    - Improve understanding and classification of watercourses, particularly in arid systems.
    - Broad regional representation of Level 2 of the Classification Systems should be informed by analysis of relevé data from the National Wetland Vegetation Database (Sieben, 2015).
    - Improved national modelling and monitoring of inland wetlands across long-term hydrological regime cycles. This will improve our understanding of ecosystem types and their functions. Currently GIS is used for once-off prediction of extent, types and condition. Time-series should be considered in such modelling. The improvement of freely available remote sensing images at finer scale
    - Methods of accuracy assessment of the extent and types of inland aquatic ecosystems at various scales.
- Improvement of the extent of river and inland wetland ecosystem types.
- Collation of species data, particularly macro-invertebrate data (Nel and Driver, 2012).
- Improved understanding between the association of ecosystem services and ecological infrastructure with ecosystem types (adapted from Nel and Driver, 2012).

7.3 Appropriate use of the ecosystem data sets

Disclaimer of the data and report:

This report was compiled and reviewed by at least 14 experts within the field of inland aquatic ecosystems prior to the approval for publication. Approval does not signify that the contents necessarily reflect the views and policies of the respective organisations, nor does it mention of trade names or commercial products constitute endorsement or recommendation of use.

All data sets were amalgamated from previously created data sets done for a variety of purposes at multiple scales. Regardless of the attempt made to explicitly state known errors, the complete understanding of representation and accuracy cannot be provided in full. Therefore we acknowledge that this nationally compiled data set is not free from errors, be it spatial or attribute accuracy, errors of omission or commission, names, ecosystem types or any other error. Therefore, the authors and designers hold no responsibility in the use of the data and content of the report. The data is intended for country-wide assessment and planning and no other uses at a regional to local scale. The data and reports can provide context, guidance and support to inform the improved mapping of inland aquatic ecosystems at a regional to local scale.

The appropriate use of the data is therefore recommended in short as set out in Table 7.1.

Table 7.1: Guidelines on the appropriate use of the data sets compiled in the SAIIAE

Scale	Appropriate use
Country-wide 1:250 000 – 1:1 000 000 1 km spatial resolution	National biodiversity assessments and conservation planning
Regional 1:50 000 – 1:250 000 Approximately 30 – 50 m spatial resolution	To inform provincial biodiversity assessment and conservation planning
Local (1:1 000 – 1:50 000) < 30 m spatial resolution	Providing context and guidance to support the improved mapping of inland aquatic ecosystems

7.4 Recommendations

Table 7.2 provides a summary of the recommendations made in the Technical Report of the Freshwater component of the NBA 2011 (Nel and Driver, 2012), and extended to the recommendations made in this report. The table summarises information discussed in Section 7.2 of this chapter and elaborates on a number of aspects. Recommendations made include those by members of the reference committee members of the inland aquatic ecosystems component of the NBA 2018, the Ecosystem Classification Committees (ECCs) and the National Ecosystem Classification Committee (NECC).

Table 7.2: Recommendations for the improvement of SAIIAE and related data sets

Component of SAIIAE	Recommendation
SAIIAE	• Collaboration across mandated ministries for inland aquatic ecosystems, and listing of data custodians under the South African Spatial Data Infrastructure (SASDI) Act. • Address uncertainties and knowledge gaps through concerted research funding. Funders should be approached to discuss the advancement of these research priorities listed. • Improve species representation in the SAIIAE.
River network	• Maintain and update the 1:500 000 rivers data set. Improved spatial accuracy should be obtained using best available data (e.g. hydrologically corrected digital elevation data at a high resolution), techniques and software. Human capacity and knowledge transfer in this regard is essential at Resource Quality Information Services (RQIS), DWS. • Produce a country-wide polygon coverage for the 1:500 000 rivers. The Department of Rural Development and Land Reform – Chief Directorate: National Geospatial Information (DRDLR:NGI) already mapped some river channels and their associated geomorphological features (e.g. flood benches). The Department of Water and Sanitation (DWS) has done a hydrological and topological correction of the DRDLR:NGI data and should be considered. • Obtain higher confidence in the 1:50 000 river coverages. Their utility continues to be constrained by several inconsistencies (e.g. river coverage densities differ) and inaccuracies (e.g. isolated and incomplete river arcs), imparted by compilation from aerial photographs (Weepener et al., 2015). Future improvements should also include applying the 1:500 000 verification and reach allocation procedures (DWAF, 2006) as well as transferring its attributes (e.g. river ecosystem types) to the 1:50 000 rivers. • Update the flow variability attributes attached to the 1:500 000 rivers data set. This includes a revision and adding more river flow categories. Flow types for quinary catchments are important. There may also need to be a stronger focus on the water requirements of non-perennial rivers. These rivers cover a large area of South Africa. An update is needed for improving the description of river ecosystem types in the country (Nel, et al., 2011).
Catchment boundaries	• Develop an endorsed quaternary and sub-quaternary or quinary catchment boundary GIS layers using the latest information and methods. Updates of these data layers were done for example by Schulze and Horan (2010), Weepener et al. (2012) and Maherry et al. (2013). • Develop sub-catchment planning units that take into account altitudes and where possible change in functional hydrology may occur.
River ecosystem types	• Improve and validate the landscape classification map with data. Consider different approaches such as the Level 1 ecoregions (Kleynhans et al., 2005) and the geomorphic provinces (Partridge et al., 2010). • Validate the river ecosystem types with species data. These subtypes are components of rivers with similar physical features and are an essential coarse-filter biodiversity surrogate. However, knowledge on whether the river types identified are associated with species representing biodiversity for persistence and evolution, remains lacking (Nel et al., 2011). • Consideration of new approaches to the classification of geomorphological or longitudinal zones developed for both perennial and non-perennial river systems (e.g. Jaeger et al., 2017). This will influence the extent of the river ecosystem types. In addition, explore ecological meaningful lumping of the geomorphological zone categories by extending the Dallas and Day (2007) macroinvertebrate analysis to include fish and vegetation data. • Map and identify riparian zones and their vegetation along rivers (both mainstems and tributaries) on a national scale. Riparian zones are not represented in the river ecosystem type layer. This data layer should be incorporated in river typing procedures. Buffers of vegetation surrounding all freshwater ecosystems, even heavily used ones, go a long way to reducing the effects of harmful land-use practices (Nel and Driver, 2012).

	• Publish a river ecosystem type map. This product should resemble the Mucina and Rutherford (2006) vegetation map, with descriptions and characteristic species attached.
River condition	• Improve skills and monitoring capacity for river ecosystem condition updates. This process is also linked to strengthening collaboration of DWS and Department of Environmental Affairs (DEA) around managing and conserving inland aquatic ecosystems. • Strengthen river inventorying and monitoring programmes. Strategic field sampling sites and metrics should be chosen and an implementation plan (including a financing plan) for monitoring these over time should be developed (Nel and Driver, 2012). The River Health Programme (RHP) (now the River EcoStatus Monitoring Programme (REMP)) offers an ideal platform from which to begin. These REMP sites should be reassessed, refined and supplemented according to an explicit set of criteria that also includes consideration of wetlands and other new information, e.g. SWSA. • Explore all data sets (e.g. Reserve and Classification data) that could be used for a national assessment. Collation of these data sets should be a medium term goal. • The desktop Present Ecological State (PES) database must be updated with higher confidence data (i.e. provincial to local level PES data) as it becomes available. It is based on expert opinion. A confidence rating (e.g. mean rating per ecosystem type) could be applied to improve the accuracy of the data. • Develop biodiversity indices that speak directly to biodiversity (i.e. of which macroinvertebrates would be one, and fish, riparian vegetation, diatoms, etc.). This is related to developing a comprehensive fish atlas and a solid database of macroinvertebrates for use in assessments and planning.
NWM5 (extent of inland wetlands)	• Improvement the representation and hydrogeomorphic wetland types to at least a Low to Medium confidence level for 75% of the country within the next 5 years. These can be achieved through continuous desktop improvement of NWM5, supplemented with the cleaning and typing of the *wetlands probability map*. The NWM5 confidence map should be used to identify areas where the *wetlands probability map* should be used. • Prioritise certain areas where the NWM needs higher levels of confidence. Set a minimum target for the minimum confidence, omission and commission errors as well as minimum requirements for the mapping and in-field visits for these priority areas. Consideration should be given to the Strategic Water Source Areas (SWSA), areas identified in the Assessment report of Inland Aquatic ecosystems as threatened and poorly protected, Ramsar sites and other areas where development pressure is high. • Continue to develop and compare the capabilities of remote sensing and GIS probability modelling to map the extent of inland aquatic ecosystems. The results should be evaluated against fine-scale data sets. Modelled data should be considered to supplement NWM5 only in data-poor areas. • Improve the extent of artificial systems and consolidate categories in the polygon data layer. Ensure that systems represented in point files (e.g. Aquaculture and the WWTW) are fully represented in the polygon data layer.
Inland wetland ecosystem types	• Continue to develop and compare the capabilities of remote sensing and probability modelling to map the ecosystem types of inland aquatic ecosystems. The results should be evaluated against fine-scale data sets. Modelled data should be used only in data-poor areas.
Condition of inland wetlands	• Condition modelling of wetlands should be attended to with urgency, particularly identifying data sets which can best be used to represent existing pressures on inland aquatic ecosystems.

7.5 References

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APPENDIX A: LIST OF MEETINGS HELD FOR DEVELOPMENT OF THIS REPORT

The following meetings were held for the development of this technical report. Meeting reports are available on request.

Meeting date	Venue	Nature of meeting	Participants	Key decisions
2015/07/27	SANBI Pretoria	Wetland Ecosystem Classification Committee (WECC)	Andrew Skowno; Boyd Escott; Bonani Madikizela; Denise Schael; Dirk Roux; Elija Mogakabe; Farai Tererai; Genevieve Pence; Hannes Marais; Heidi van Deventer; Hermien Roux; John Dini; Kate Snaddon; Kennedy Nemutamvuni; Mervyn Lotter; Mike Silberbauer; Nacelle Collin; Namhla Mbona; Nancy Job; Naomi Fourie; Nick Rivers-Moore; Nicolene Fourie; Peter Ramsilo	• Inaugural meeting of WECC • Need for guidelines and standards were highlighted, as well as registration as data custodian under SASDI Act
2016/01/28	CSIR VCs: Pretoria, Stellenbosch	WECC	Namhla Mbona , Nancy Job , Heidi van Deventer, Nacelle Collin , Mervyn Lotter, Nicolene Fourie, John Dini, Hannes Marais, Nick Rivers-Moore, Mike Silberbauer, Andrew Skowno, Kate Snaddon; Skhumbuzo Kubheka	• TOR of WECC; frq of meetings • Availability of EIA data • Preliminary results of the data audit • Priorities for NWM5 • Dr Collins presented watercourse probability map • Errors in threat status of wetlands in NBA 2011 resulted from assessment done at L4A
2016/05/23	SANBI Cape Town	River Ecosystem Classification Committee (RECC)	Mike Silberbauer (DWS), Dean Impson (CapeNature), Mmaphefo Thwala (standing in for Lebogang Matlala, DWS), Michael Granfell	• Inaugural meeting of RECC • Agreement to use the 1:500 000 rivers data used for the NBA 2011

			(UWC), Jeanne Nel (CSIR), Chantel Petersen (CSIR), Ashton Maherry (CSIR), Heidi van Deventer (CSIR), Lindie Smith-Adao (CSIR), Namhla Mbona (SANBI), Helen Dallas (FRC), Karl Reinecke (Southern Waters), Andrew Gordon (DWS) and Andrew Skowno (SANBI) [3 DWS staff members, 1 CapeNature staff member, 1 UWC staff member, 5 CSIR staff members, 2 expert consultants and 2 SANBI staff members. Representing 14 participants from 7 organisations.]	• Keep river ecosystem type categories as is • Use PES PES/EIS 2011 data to update the river condition data for NBA 2018
2016/08/12	SANBI VC Pretoria, Cape Town	National Ecosystem Classification Committee (NECC)	NECC members from SANBI and CSIR	• Inaugural meeting, TOR • Coastal ecosystems introduced • Connectedness between aquatic ecosystems • Mapping of islands
2016/10/27	NWI2016	Inland Aquatic reference committee	1 CSIR, 1 SANBI, 4 Inland aquatic reference committee members, 6 interns, 1 collaborator (ICLEI) and Douglas McFarlane	• Accuracy assessment discussion. Should be taken up in future meetings • see CSIR report no CSIR/NRE/ECOS/IR/2016/0161/A • Alignment with WRC prj of Dean Ollis on condition*
2017/01/26	CSIR VCs: Pretoria, Durban, Cape Town	WECC	Namhla Mbona , Heidi van Deventer, Nacelle Collin, Mervyn Lotter , John Dini , Hannes Marais , Mike Silberbauer , Tebogo Kgongwana, Andrew Skowno, Kate Snaddon, Nancy Job , Nick Rivers-Moore Skhumbuzo Kubheka , Erwin Sieben	• NBA 2018 progress on the Freshwater Component
2017/05/19	CSIR VCs: Pretoria, Stellenbosch	RECC	Andrew Gordon (DWS), Chantel Petersen (CSIR), Christa Thirion (DWS), Heidi van Deventer (CSIR),	• Nomination of 2 RECC members for Inland Aquatic reference committee

			Helen Dallas (FRC), Lindie Smith-Adao (CSIR), Michael Grenfell (UWC), Mike Silberbauer (DWS), Namhla Mbona (SANBI), Nick Rivers-Moore (Private Consultant, presented in absentia) and Patsy Scherman (SC&A) [3 DWS staff members, 1 UWC staff member, 3 CSIR staff members, 3 expert consultants and 1 SANBI staff member. Representing 11 participants from 7 organisations.]	• Update of the PES data for the NBA 2018 • Fish species atlas • Nick Rivers-Moore's presentation on WRC prj modelling in-stream flow requirements • Keep all detailed condition categories and do not lump. • Addition of 22 rivers approved • Agreement that a change analysis can be done, not trends • Priorities after NBA 2018: ○ Revisit the river flow categories ○ Macroinvertebrates ○ Riparian vegetation mapping on a national scale ○ Sub-quaternary catchments and altitude zones (NFEPA) ACTION: LS discuss with Jeanne Nel as to the motivation for getting this done ○ If new data is generated then it should be used ○ PES (habitat template) is the totality and features characteristics of a river and its riparian areas that can support an appropriate natural fauna and flora. Not a biodiversity assessment but an indication of the ecological condition of the resource. ○ Need biodiversity indices that speak directly to biodiversity (of which macroinvertebrates would be one, and fish, riparian vegetation, diatoms, etc.) (DEA mandate)

2017/09/27	SANBI Pretoria and Cape Town	NECC	NECC members from SANBI and CSIR	• Update and integration efforts • Vegetation map • Coastal ecosystems • Ecosystem map
2017/10/2-4	SANBI Kirstenbosch	Inland Aquatic reference committee	3 SANBI, 3 CSIR, 1 WCS, 8 reference committee members (complete)	• Inventory: ○ Hydrological features which are not rivers or wetlands should be kept in the inventory geodatabase as a separate feature class and may include for example streams from the *wetland probability map* as well as washes ○ Correction on terminology was done to align with the Classification System ○ 8 unique limnetic depressions identified; set target as 100% for threat status. ○ agreement that the NWA definition of wetlands should be used ○ add information on groundwater dependent ecosystems ○ EIA polygons are considered less suitable compared to large, catchment funded projects for mapping wetlands and updating the NWMs ○ Citizen science may contribute, however inconsistent collection and verification not ideal. • Landforms was previously used to inform modelling of wetland types and not required when HGM wetland types have been captured at desktop-level.
2017/11/24	CSIR VCs: Pretoria, Durban, Cape Town	Inland Aquatic reference committee	3 SANBI, 3 CSIR, 1 WCS, 8 refcom members (full representation)	• Assessment: only Levels 2 and 4A should be used for assessing biodiversity pattern • The improvements of L2 is essential using

				the NWVD • A target threshold of 20% will be retained for assessing ecosystem threat status until further research has been done on species responses and other outcomes which would inform other target thresholds for wetlands. • Grouping of HGM wetland types: 4 to 3 groups can be considered, but first present the results of the assessment, before the refcom will decide. • Landforms: ○ Landforms in the Classification System are to guide classification and doesn't reflect biodiversity of wetland ecosystem types ○ Landforms automated at desktop level is not essential for now, since NWM5 was typed at desktop level to L3 and 4A
2018/01/23	CSIR VCs: Pretoria, Durban, Cape Town	WECC	Namhla Mbona, Heidi van Deventer, Nacelle Collin, Mervyn Lotter, Hannes Marais, Mike Silberbauer, Millicent Dinala, Happy Khumalo Andrew Skowno, Kate Snaddon, Nancy Job, Mogakabe Elijah, Skhumbuzo Kubheka, Erwin Sieben	• National Wetland Map 5 progress • SAIIAE • Layout of NBA 2018 Assessment report • Future planning for the SAIIAE and NWM • Wetland modelling inclusion
2018/05/23	CSIR VCs: Pretoria, Stellenbosch	RECC	Andrew Skowno (SANBI), Chantel Petersen (CSIR), Dean Impson (CapeNature), David le Maitre (CSIR), Heidi van Deventer (CSIR), Helen Dallas (FRC), Michael Grenfell (UWC Mike Silberbauer (DWS), Namhla Mbona (SANBI), Nancy Job (SANBI) and Patsy Scherman (SC&A) [1 DWS staff member, 1 UWC staff member, 3 CSIR staff members, 1 CapeNature staff member, 2 expert consultants and 3 SANBI staff	• Agreement not to update the NFEPA rivers GIS layer with additional 1:50 000 rivers associated with estuaries • Do not include rivers which have no PES scores, since modelling has a number of complications • Most of the rivers are episodic / ephemeral and should be left as "Data Deficient". Not necessary to model the condition of the PES scores for the DD systems. Don't assess, display as DD on the final map. • Erosion can be natural and not induced and

			members. Representing 11 participants from 7 organisations.]	the current maps cannot distinguish between these, therefore do not use it to model river condition • Do not use invasive species (e.g. *Prosopis*) to model river condition, experts are needed • Intersect the rivers with the dam layer and type the section of a river within any of the large 92 dams as artificial and PES = F.
2018/05/28	SANBI Kirstenbosch	Inland Aquatic workshop	Team members, reference committee members and co-authors to the Assessment Report. Please refer to the attendance register for more information.	Wetland flats in most of the provinces would be depressions, since they may receive surface contribution from adjacent seep wetlands. These are not purely groundwater driven systems. Wetland flats from the C.A.P.E. project was also desktop-typed and have a low confidence. These should however be kept as wetland flats in the NWM5.

* WRC project K5/2549, Project lead Mr D Ollis; ‘Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems.’

APPENDIX B: PROCESSING STEPS TAKEN TO CREATE A SOUTH AFRICAN INVENTORY OF INLAND AQUATIC ECOSYSTEMS (SAIIAE) AND UPDATE THE NATIONAL WETLAND MAP 5

Chapter Citation: Van Deventer, H. 2016. Appendix B: Creation of a National Freshwater Inventory and update of the National Wetland Map 5 in preparation for the National Biodiversity Assessment for 2018. *CSIR: Pretoria, South Africa.* South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

Introduction and purpose

The National Wetland Map 4 (NWM4) resulted from the modelling of wetland types from the extent of wetlands in the NWM3 for the National Biodiversity Assessment of 2011 (NBA2011) and National Freshwater Priority Areas Atlas (NFEPA) (Nel *et al.*, 2011; Nel and Driver, 2012; Driver *et al.*, 2012). The South African National Biodiversity Institute (SANBI) compiled NWM3 from various sources, including the National Land Cover of 2000 (Van den Berg *et al.*, 2008), hydrological polygon data from the former Department of Land Affairs (DLA): Directorate Surveys and Mapping, as well as wetlands predicted for the country in 2002 (Thompson *et al.*, 2002). A flow diagram of the integration of the data sets up to NWM3 is available on SANBI's Biodiversity Advisor site (Figure B1).

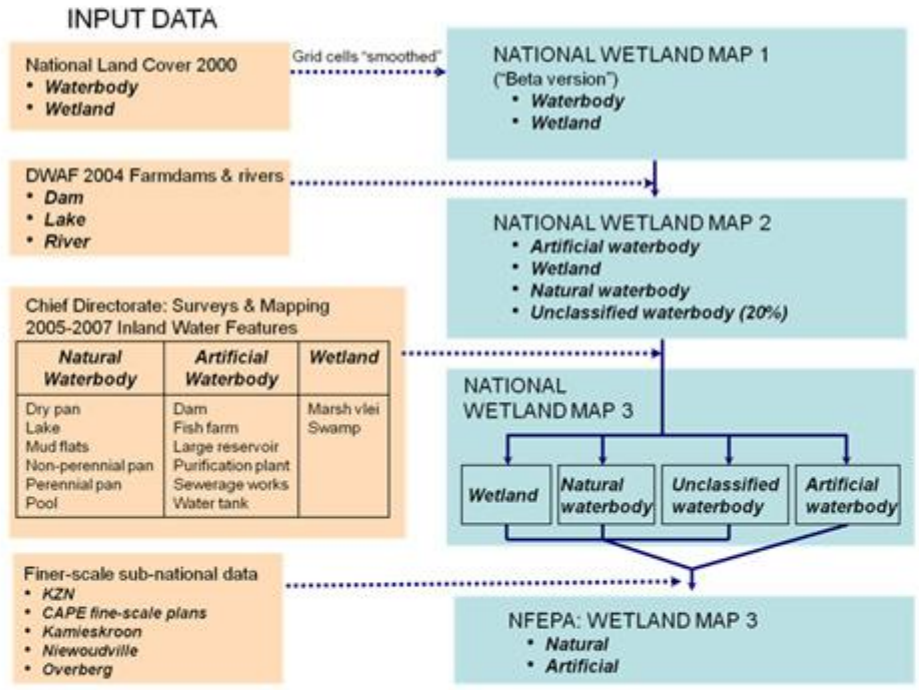

Figure B.1: Flow-diagram showing the development of the National Wetland Map 3, used in the modelling of wetland types for the NBA2011. Image from http://bgis.sanbi.org/NFEPA.

A number of errors in the NWM4 became evident subsequent to the publishing of the data and user's working with the data. These included some key errors:

- The inclusion of the predicted wetlands introduced a large number of commission errors (although not indicated in Figure B1, this data set was included);
- Artificial wetlands such as tailing impoundments were classified as natural; and
- Polygons around dams were initially thought to be natural palustrine type of wetlands however later considered to rather be dams and should be merged with the polygon of the dam.

In addition a number of projects indicated that the NWM4 represented < 54% of the wetlands found at fine-scale level (Mbona *et al.*, 2015; Schael *et al.*, 2015; Van Deventer *et al.*, 2016).

To address the errors and shortcomings of the NBA 2018, Heidi van Deventer and Jeanne Nel (CSIR) decided that it is better to start from scratch and create two separate products for the NBA 2018:

i. A Fine-scale data set which will include the NGI data and any fine-scale data that was mapped through heads-up digitising from orthophotos.
ii. A data set of predicted wetland extent and possibly types.

The typing of the Freshwater Ecosystems will be done according to the 7 hydrogeomorphic types of the Classification System (Ollis *et al.*, 2013).

In addition to the extent and types of the wetlands, the landscape unit (landforms) will be updated to improve on previous limitations (Van Deventer *et al.*, 2014).

Sub-versions of the National Wetland Map 5 (NWM5) as well as associated data in the National Freshwater Inventory (NFI) will be made available during the course of the project on the Freshwater ecosystems page, to allow all users to provide feedback and suggestions to Heidi (HvDeventer@csir.co.za) for improvement. The freshwater page can be accessed via

http://gsdi.geoportal.csir.co.za/projects/national-biodiversity-assessment-of-2018

The aim of involving stakeholders during the progress of the work allows the best quality is delivered for the NBA 2018. The planned update is listed in Table B1 with the planned work flow of the project in Figure B2.

Table B.1: Existing and planned sub-versions of the NWM5

National Wetland Map 5 Sub-version no.	Description
5.1	The topologically corrected national extent of the NGI data issued in March 2016 as provincial data sets. **Called feature class National_Wetland_Map_5_1**
5.2.	NGI2006 and 2016 data unioned into a single feature class (NGI_2006_2016, D and D2 – section 1 below), as well as union with the Estuaries Functional Zone, Working for Wetlands data, peatlands data, and the 1 m buffers of the NGI spring points (referred to as the **ADD1 feature class** – see section 2 below). Called feature class **National_Wetland_Map_5_2** The data will from here on be split into provincial data sets for attending to slivers,

	checking names and assigning HGM units to a polygon. The fine-scale data sets will be unioned as per section 3 below.
5.3.	This will include the following data sets: • NGI 2006 & 2016* • Working for wetlands* • Selected peatlands data* • Estuaries functional zones* • Springs and thermal springs* At provincial level the data will be first cleaned as a separate data set. The fine-scale data obtained from other sources will be cleaned as a separate data sets. The two data sets will be unioned and the Level 1 and Level 4A fields of the National_Wetland_Map_5 updated.
5.4.	Cleaned NWM5 for desktop and fieldwork validation. The predicted wetlands and landscape features (L3) will be issued as a separate feature data sets to be validated with NWM5.4.
5.5.	Cleaned NWM5 including desktop and fieldwork validation. To be completed 31 March 2017
5.6.	A possible integration between the fine-scale wetlands of NWM5.5 and the wetland extent and modelled data

**The CSIR and SANBI's data audit reports will document the full details and references of these data sets.*

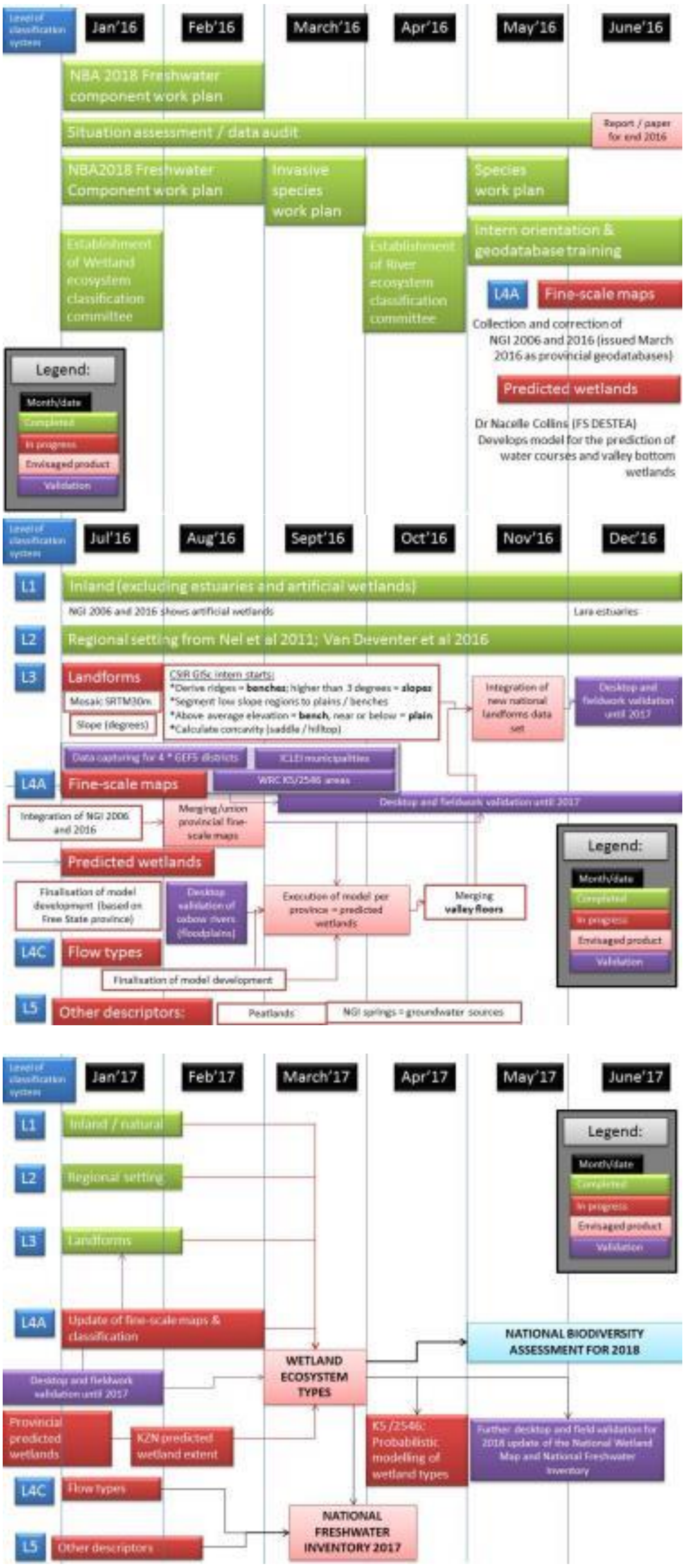

Figure B.2: Workflow for the update of the National Wetland Inventory in preparation for the NBA 2018.

B1. Step 1: Pre-processing and preparation of the NGI 2006 and 2016 data as a base layer.

a. Both NGI 2006 and NGI 2016 data were imported to a geodatabase file as feature classes in the projection Albers Equal Area for South Africa and topologically cleaned of overlapping polygons. Table B2 indicate field names used in the feature class.

b. The two feature data sets were unioned into **NGI_2006_2016_AEA** which had four fields (Table B2). The records were exploded to ensure that no multi-part polygons were present, however the records remained at 613 296 polygons (which includes slivers).

c. The hectares were calculated and a frequency done on the NGI2006_FT and NGI2016_FT fields to assess how many contradictions exists between NGI2006 and NGI2016. The results are tabled in Tables B7-9 with matrices indicating similarities between the two data sets (grey cells) as well as differences. Differences were addressed in the steps below.

d. Two new fields were added NGI0616_FT and NGI0616_NAME (Table B1) and the feature types (FT) from various fields consolidated to these fields. Similarly, names were consolidated to the NGI0616_NAME field. The following steps were taken to integrate the feature type classes through a sequential process of elimination to NGI0616_FT while names were integrated to NGI0616_NAME through each selection step:

    i. First, all feature types classes which were similar between 2006 and 2016 (grey cells in Table B9 of) were kept in NGI0616_FT. The remaining polygons in NGI0616_FT were called “Not classified”. Where no names were presented for similar classes, the records were classified in NGI0616_NAME as “No name” and remaining records “Not classified”. Care was taken not to override records which were already classified, through starting each selection query with the records which were not yet classified, for example, create a new selection where [NGI0616_FT = 'Not classified' AND (NGI2006_FT = 'DRY PAN' AND NGI2016_FT = 'Dry Pan')]. The 8 427 “Marsh Vlei” records from 2006 were all given the 2016 classes in NGI0616_FT.

    ii. Secondly, a number of classes which were in NGI2006_FT and not in NGI2016_FT, were kept to the feature type class given in 2006. These include the Fish farm, Large reservoir, Pool, Purification plant, Sand Bank, Sewerage Works, Slimes dam, Swamp, Tailing Impoundment and Water tank.

    iii. The feature type of 2006 or 2016 was kept where no overlaps were present.

    iv. For remaining overlaps, the 2016 class was used.

e. A dissolve was done on feature class **NGI_2006_2016_AEA** using the two fields NGI0616_FT and NGI0616_NAME to feature class **NGI_2006_2016_AEA_D** with the option to keep multipart polygons (this allows minimisation of polygons with names to be edited). The names were checked throughout by Heidi van Deventer from 2 – 5 August2016, to ensure all names were consistently spelt between years 2006 and 2016. The feature class **NGI_2006_2016_AEA_D** was again dissolved on the two fields to **NGI_2006_2016_AEA_D2**, keeping multipart polygons and resulting in 5666 records. The feature class was then exploded to result in 437 308 single-part records.

f. **Take note:** the dissolve unfortunately assigned 'pan' categories to a large number of dams without names. These were corrected through extracting the dams from the 2006 and 2016 NGI data as points, and selecting by location the polygons which intersect the points, and classifying them as dams again. Some errors may still occur though. These should be corrected during the desktop screening per province (when typing NWM5.3 to NWM5.4.

Table B.2: Description of field names in NGI_2006_2016d

Field name	Description	Origin
NGI_FT_2006	Feature types issued by the NGI in 2006	NGI 2006
NGI_2006_NAME	Feature types issued by the NGI in 2006	NGI 2006
NGI_FT_2016	Feature types issued by the NGI in 2006	NGI 2016
NGI_2006_NAME	Feature types issued by the NGI in 2006	NGI 2016
NGI_FT_0616	Feature types integrated by Heidi van Deventer of the CSIR in 2016	NGI 2016
NGI_0616_NAME	Feature names integrated by Heidi van Deventer of the CSIR in 2016.	CSIR 2016

B3. Step 2: Inclusion of other national data sets

A first level integration was done between the **NGI_2006_2016_AEA_D2** feature class and a number of national data sets. A union was run with the NGI data and the following polygon feature classes:

- The working for wetlands data captured as polygon data between 2004 – 2007 and available from SANBI's Biodiversity Advisor website (BGIS), was also included.
- The NGI springs data were buffered with 1 m to indicate possible seep wetlands.
- Dr Althea Grundling and Joseph Mulders (Prime Africa) provided Heidi with an intermediate peat point and some polygon *.kml files dated to end July 2016 as part of the National Peatland Database (WRC project K5/2346). The polygons were unioned into the other polygons, while the points will be used to guide potential locations of wetlands where C >2 (organic soils).

The output feature class was called **NWM52**. The estuaries were then erased from this file (**NWM52_erase_estuaries**) and then the estuaries were unioned with **NWM52_erase_estuaries** to create **NWM52_with_estuaries.**

- The Estuarine Functional Zone polygons were received from Lara van Niekerk (CSIR) on 26 July 2016. These were cleaned topologically. The file is still being updated for the

NBA 2018, and the capturing of micro-estuaries may have to be included in future updates of the NWM5.

The **NWM52_with_estuaries** was renamed the **National Wetland Map 5.2** feature class in the geodatabase. All records were selected and exploded to ensure no multipart polygons exist.

A number of fields and associated subtypes were added for the purpose of standardising the National Wetland Map 5.2 to the levels of the Classification System (Ollis *et al.*, 2013) and to allow recording of ancillary data (Table B3).

Table B.3: Field names and descriptions for the National Wetland Map 5.2

Field (column name)	Description
NGI0616_FT	Final feature type class based on the NGI 2006 and NGI 2016 data
NGI0616_NAME	Name given to the wetland in the NGI 2006 and NGI 2016 data
Peatlands	Where attributes are present, it indicates peatlands
NGIsprings	NGI springs buffered by 1 m, possibly indicating seeps
WETLAND_NO	Wetland number assigned by the Working for Wetlands team
W4W	HGM type assigned by the Working for Wetlands team
Estuaries_name	Name of the estuary
ESTUARIES	Field indicating the class estuaries
CS_L1*	Level 1 of the classification system was given the following subtypes: • ES : Estuarine • CS : Coastal • IA : Inland – artificial • IN : Inland – natural • UNKNOWN • UNSPECIFIED
CS_L2	No subtypes were given here. This field should be populated later with the regional setting used in the NBA 2011.
CS_L3	The field should be populated based on the landform which fills the majority of the surface area of the polygon. The polygons should not be split. Subtypes include: • BENCH : Bench • BHILL : Bench – hilltop • BSAD : Bench – saddle • BSHE : Bench – shelf • PLAIN : Plain • SLOPE : Slope • VF :Valley floor • UNKNOWN • UNSPECIFIED
CS_L4A	The following subtypes were specified, which include the 7 hydrogeomorphic types of the Classification System • ART : Artificial • CVB : Channelled valley-bottom** • DEPR : Depression (the old pan categories of NGI)** • EST : Estuary • FLAT : Wetland flat** • FLOOD : Floodplain** • RIVER : River (riverine wetland)** • SEEP : Seep** • UVB : Unchannelled valley-bottom**

	• UNKNOWN • UNSPECIFIED • DELETE – the data capturer recommends to the validator that this polygon should be deleted Additional categories are added here for alignment to the estuarine and coastal groups. These would be refined and finalised by March 2017 (red = estuarine and blue = coastal): ESTCHANNEL Estuary that is now channelized POE Permanently open TOCE Temporarily closed ESTRIV River mouth ESTLAKE Estuarine lake ESTBAY Estuarine bay ESTMICRO Micro estuary LAGOON Lagoon COASTLAKE Coastal lake COASTWF Waterfall OUTLET Ephemeral outlet TRANS Transitional waters (fans and plumes) COASTGW Groundwater Dependent Coastal Ecosystem
CS_L4C	Drainage flow subtypes: • INFLOW : Inflow • OUTFLOW : Outflow • THROUGH : Throughput • UNKNOWN • UNSPECIFIED
CS_L5_source	Subtypes (predominant): • GWD : Groundwater dependent • MIX: Ground and rainfall dependent • RAIN : Rainfall dependent • UNKNOWN • UNSPECIFIED
CS_L5_hydroperiod	Hydroperiod (only level 5A was used) with subtypes: • PERM : Permanently inundated • SEASON: Seasonally inundated • INTER : Intermittently inundated • NEVER : Never inundated • UNKNOWN • UNSPECIFIED
CS_L5_satperiod	Saturation period: • PERM : Permanently saturated • SEASON : Seasonally saturated • INTERMIT : Intermittently saturated • UNKNOWN • UNSPECIFIED
CS_L6_artificial	Artificial subtypes descriptors: • CAN : Canal • DC : Dam (in-channel) • DO : Dam (off-channel)

	• OR : Open reservoir • CR : Closed reservoir • R : Reservoir • EXC : Excavation • SALT : Salt works • WTW : Water Treatment Works • WWTW : Wastewater treatment works • AQUA : Aquaculture pond • STORM : Stormwater pond • IRR : Irrigated land • UNKNOWN • UNSPECIFIED
CS_L6_salinity	(Salinity levels)
CS_L6_pH	(pH levels)
CS_L6_substratum	Subtypes: • BR : Bedrock • BD : Boulders • COB : Cobbles • PEB : Pebbles/gravel • SS : Sandy soil • CS : Clayey soil • LS : Loamy soil • SILT Silt (mud) • OS: Organic soil • SC : Salt crust • UNKNOWN • UNSPECIFIED
CS_L6_vegetation	Subtypes: • VAQ : Vegetated – aquatic • VH : Vegetated – herbaceous • VFS : Vegetated – forest (swamp) • VFR : Vegetated – forest (riparian) • VST : Vegetated – shrubs/thicket • VCROP : Vegetated – crops • VALIEN: Vegetated – alien / invasive • UNVEG : Unvegetated • UNKNOWN • UNSPECIFIED
CS_NAME	Name of the wetland
Image_date	The date of the image used (always record the maximum extent of a wetland, even if not a recent date of image)
Image_type	The image (sensor) used: e.g. the NGI 50 cm colour orthophotography, SPOT 5/6, IKONOS, Quickbird, greyscale orhophotography etc. No subtypes were specified for this group.
Data_editor	Person's full name who edited the polygon
Edit_date	Day-month-year of the date on which the polygon was edited
Val_type	The type of validation done for the polygon. Code options: • NONE : Not validated • DESK_EXTENT : Desktop validation was done of the extent of the wetland. • DESK_TYPE : Desktop validation was done of the HGM type of the wetland. • DESK_COND: Desktop validation was done of the condition of the wetland.

	• DESK_ET: Desktop extent and HGM type • DESK_ALL : Desktop extent, HGM type and condition • FIELD_EXTENT : Fieldwork validation was done of the extent of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_TYPE : Fieldwork validation was done of the HGM type of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_COND : Fieldwork validation was done of the condition of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_ET : Field validation of extent and HGM type. *In this case no further edits are allowed on this wetland!* • FIELD_ALL : Field validation of extent, HGM type and condition. *In this case no further edits are allowed on this wetland!*
Val_person	Person's full name who validated the polygon
Val_date	Day-month-year of the date on which the polygon was validated

**CS refer to classification system (Ollis et al., 2013)*

***Hydrogeomorphic (HGM) wetland type*

After adding the fields, domains and subtypes, the following steps were taken to crosswalk NGI categories to L1 and L4A of the classification system:

- Where the field ESTUARIES = "Estuaries", CS_L1 were calculated as "Estuarine" and CS_L4A as "Estuary" and the CS_NAME as {[Estuaries_name] & " estuary"}. This totalled 304 records.
- Where NGI0616_NAME <> empty, the CS_NAME was calculated as the NGI0616_NAME.
- Twelve of the 29 feature types from the NGI data were calculated as artificial wetlands, under CS_L1 as code "IA" and CS_L4A as code "ART":
    - Select where *NGI0616_FT = 'Closed reservoir' OR NGI0616_FT = 'Dam' OR NGI0616_FT = 'Fish farm' OR NGI0616_FT = 'Large reservoir' OR NGI0616_FT = 'Open reservoir' OR NGI0616_FT = 'Purification plant' OR NGI0616_FT = 'Reservoir' OR NGI0616_FT = 'Sewerage works' OR NGI0616_FT = 'Slimes dam' OR NGI0616_FT = 'Tailings impoundment' OR NGI0616_FT = 'Water tank' OR NGI0616_FT = 'Waterworks'* and calculate L1 and L4A accordingly.
- Sixteen of the 29 feature types from the NGI data were calculated as inland natural wetlands under CS_L1 code "IN":
    - Select where *NGI0616_FT = 'Dry pan' OR NGI0616_FT = 'Dry water course' OR NGI0616_FT = 'Flood bank' OR NGI0616_FT = 'Lake' OR NGI0616_FT = 'Marsh' OR NGI0616_FT = 'Marsh / vlei' OR NGI0616_FT = 'Mudflats' OR NGI0616_FT = 'Non-perennial pan' OR NGI0616_FT = 'Non-perennial river' OR NGI0616_FT = 'Perennial pan' OR NGI0616_FT = 'Perennial river' OR NGI0616_FT = 'River_area_2006' OR NGI0616_FT = 'Salt pan' OR NGI0616_FT = 'Sand bank' OR NGI0616_FT = 'Swamp' OR NGI0616_FT = 'Vlei'* and calculate L1 accordingly.
- Pools will have to be individually assessed, since it includes the MacMac waterfall's pools as well as swimming pools.
- The four pan feature types were selected (NGI0616_FT = 'Dry pan' OR NGI0616_FT = 'Non-perennial pan' OR NGI0616_FT = 'Perennial pan' OR NGI0616_FT = 'Salt pan') and calculated under CS_L4A as "Depression"
- Feature types relating to river systems (NGI0616_FT = 'Dry water course' OR NGI0616_FT = 'Flood bank' OR NGI0616_FT = 'Non-perennial river' OR NGI0616_FT = 'Perennial river' OR

NGI0616_FT = 'River_area_2006' OR NGI0616_FT = 'Sand bank') were calculated as "River" under CS_L4A.

- 19 polygons which were recorded as "Swamp" and classified under CS_L6_vegetation as "Vegetated – forest (swamp)".
- Next the Working for wetlands data was used to identify CS_L1 as "Inland – natural" and specific hydrogeomorphic types to CS_L4A, and some to Level 6 (Table 4).
    - Where the NGI already indicated the wetland as artificial, the CS_L1 was kept at "Artificial".
    - Existing categories of NGI were not overwritten by the W4W categories, particularly the artificial wetlands, and river and depression wetlands. For example, where the extent of a river channel was mapped in the NGI as a river HGM type, but classified as an HGM type other than "River" in the Working for Wetlands data, the CS_L4A was kept as "River". The adjacent wetlands surrounding the river channel extent should be captured as a "Channelled valley-bottom" under CS_L4A.
    - 8 records were classified under W4W as "Valley Bottom / Flood Plain" and should be investigated closer before an HGM class is selected
    - 119 "Valley Bottom" records should also be investigated to assess whether they are channelled or unchanelled.
    - The CS_L4A classes of the swamp wetlands should be identified using the NGI 50 cm colour orthophotos.

Table B.4: Cross-walking the Working for Wetlands classes to the level 4 and 6 classes of the Classification System

W4W HGM type:	No. of records	CS_L4A	CS_L6_ substratum	CS_L6_ vegetation
Channelled Valley Bottom	974	Channelled valley-bottom	N.A.	N.A.
Depression	130	Depression	N.A.	N.A.
Estuary	6	Estuary	N.A.	N.A.
Flood Plain	278	Floodplain	N.A.	N.A.
Flood Plain/ lake	4	Floodplain	N.A.	N.A.
Floodplain	241	Floodplain	N.A.	N.A.
Hill side seep	68	Seep	N.A.	N.A.
Hillslope seepage	7	Seep	N.A.	N.A.
Hillslope seepage feeding	2	Seep		
Pan	2	Depression		
Riparian	19	River	N.A.	Vegetated – forest (riparian)
Seep slope	39	Seep	N.A.	
Swamp forest/ Peatland	2	Floodplain	Organic soil	Vegetated – forest (swamp)
Unchannelled Valley Bottom	397	Unchannelled valley-bottom	N.A.	N.A.
Valley Bottom	119	(Should be investigated)	N.A.	N.A.
Valley Bottom/ Flood Plain	8	(Should be investigated)	N.A.	N.A.

B3. Step 3: Integration of the provincial data sets

Following the compilation of the National Wetland Map 5.2, the data will be clipped to each province and allocated to a number of people to refine and validate (Table B5). Rules and principles for wetland data capturing and integration are documented here:

Van Deventer, H. 2016. Principles or rules in capturing wetlands for the update of the National Freshwater Inventory and National Wetland Map 5 in preparation for the National Biodiversity Assessment for 2018. CSIR: Pretoria, South Africa.

Table B.5: Provinces allocated to people for integrating, editing and validating the wetlands and other data

Province	Person integrating provincial fine-scale data and editing layer	Person validating the layer
EC - Eastern Cape	Leolin Qegu (NRF intern based at CSIR Pretoria)	Mr Brian Colloty (Scherman, Colloty & Associates)
FS - Free State	Ridhwannah Ganget (GISc intern at CSIR Pretoria)	Dr Nacelle Collins (FS DESTEA)
GT - Gauteng	Ridhwannah Ganget (GISc intern at CSIR Pretoria)	Mr Retief Grobler (Imperata Pty Ltd) and Dr Althea Grundling (ARC-ISCW)
KZN – KwaZulu-Natal	Phumlani Zwane (CSIR GISc intern)	Mr Vince Egan or Mr Meshak Misindi, (LDEDET)
LP – Limpopo	Namhla Mbona (SANBI)	Mr Skhumbuzo Khubeka (EKZNW)
MP - Mpumalanga	Namhla Mbona (SANBI)	Mr Hannes Marais and Mr Mervyn Lötter, (MTPA)
NC - Northern Cape	To be determined, depending on progress of CSIR / SANBI	Mr Enrico Oosthuysen (NC DENC)
NW - North-West	Ridhwannah Ganget (CSIR GISc intern)	Ms Hermien Roux (UNIVEN)
WC - Western Cape	Kedibone Lamula and Heather Terrapon (SANBI) (also research assistant)	Genevieve Pence (Cape Nature), Kate Snaddon (FCG), Nancy Job (UFS), Jeanne Gouws (Cape Nature), Dean Impson (Cape Nature)
Coastal ecosystems	*Phumlani Zwane (CSIR GISc intern)*	*Lara van Niekerk (CSIR) and Dr Kerry Sink (SANBI)*

A number of people are also involved in the validation of the oxbow points and waterfall points in August 2016 (Table B6).

Table B.6: Provinces allocated to verify the location of oxbows and waterfalls

Province	Capturing and verification of oxbow and waterfall points	Completed?	Person validating the layers	Validation received?
EC - Eastern Cape	Phumlani Zwane (CSIR GISc intern)	Yes	Mr Brian Colloty (Scherman, Colloty and Associates)	First set received. Updates of oxbows to be sent by Heidi.
FS - Free State	Ridhwannah Ganget (CSIR GISc intern)	Yes	Dr Nacelle Collins, (FSDESTEA)	Updates of oxbows to be sent by Heidi.
GT - Gauteng	Ridhwannah Ganget (CSIR GISc intern)	Yes	Retief Grobler (Imperata Pty Ltd, Dr Althea Grundling (ARC-ISCW) and Dr Piet-Louis Grundling (DEA)	Updates of oxbows to be sent by Heidi.
KZN – KwaZulu-Natal	Phumlani Zwane (CSIR GISc intern)	Yes	Skhumbuzo Khubeka (EKZNW)	Updates of oxbows to be sent by Heidi.
LP – Limpopo	Phumlani Zwane (CSIR GISc intern)	Yes	Vince Egan (LDEDET)	Updates of oxbows to be sent by Heidi.
MP - Mpumalanga	Phumlani Zwane (CSIR GISc intern)	Yes	Mervyn Lotter and Hannes Marais (MTPA)	Updates of oxbows to be sent by Heidi.
NC - Northern Cape	Ridhwannah Ganget (CSIR GISc intern)	Yes	Enrico Oosthuizen (NC DENC)	Review received, awaiting additional coordinates of one or two waterfalls.

				Updates of oxbows to be sent by Heidi.
NW - North-West	Ridhwannah Ganget (CSIR GISc intern)	Yes	Hermien Roux (UNIVEN)	Updates of oxbows to be sent by Heidi.
WC - Western Cape	Ridhwannah Ganget (CSIR GISc intern)	Yes	Genevieve Pence (Cape Nature), Kate Snaddon (FCG), Nancy Job (UFS), Jeanne Gouws (Cape Nature), Dean Impson (Cape Nature)	Updates of oxbows to be sent by Heidi.

Fine-scale data received from institutions is listed in the situation assessment and data audit reports (Van Deventer et al., 2018) being compiled by the CSIR (Heidi van Deventer) and SANBI (Namhla Mbona). These reports should be available by end of August 2016 from the respective institutions. Fine-scale data received will be topologically cleaned, cross-walked and then unioned with National Wetland Map 5.2 to create National Wetland Map 5.3 version. SANBI has secured funding to appoint a number of freshwater ecologists to undertake desktop and/or fieldwork validation of the data. Figure B2 shows how a number of processes will run parallel in the project and the approximate deadlines for the project.

Table B.7: Number of polygons per feature type shared between the NGI 2006 and 2016 feature class

	Feature class of 2016 (columns)																
Feature class 2006 (rows)	Closed Reservoir	Dam	Dry Pan	Dry water course	Flood Bank Area	Lake	Marsh	Mudflat	Non-Perennial Pan	Non-Perennial River	Open Reservoir	Perennial Pan	Perennial River	Salt Pan	Vlei	Water Tank	(blank)	Grand Total
DAM	26	106 396	221	3 348	177	75	11	3	625	243	4 645	111	129	2	1 476		122 233	239 721
DRY PAN		362	7 518	221	4	4		2	146	9	9	7	4	16	2		4 690	12 994
DRY WATER COURSE EXTENT		320	71	1 453	67	2			18	106	7		2				1 023	3 069
FISH FARM		20			1						41						44	106
FLOOD BANK		72	2	119	5 745	14	1	15	2	224			4 531		99		4 850	15 674
LAKE		46		1	17	877		8	22		7	21	31		170		1 059	2 259
LARGE RESERVOIR	51	39		3	1				4		2 164	1			5	4	1 967	4 239
MARSH VLEI		809	7	29	29	160	4	29	192	20	33	62	153		3 981		2 919	8 427
MUD FLATS		3	1		5	14		78	16			12	57		32		53	271
NON-PERENNIAL CENTER LINE										1							1	2
NON-PERENNIAL EXTENT		395	23	1 301	845	5	1	7	10	4 066	1	1	265		71		3 386	10 377
NON-PERENNIAL PAN		492	1 034	153	32	387	1	16	37 254	21	36	211	16		244		31 430	71 327
PERENNIAL																		

CENTER LINE																	1	1
PERENNIAL EXTENT		284	1	45	3 927	116	16	116	13	130	6	17	4 333		561		4 705	14 270
PERENNIAL PAN		153	27	10	4	1 088	1	15	279	7	21	1 392	29		554		3 486	7 066
POOL		6			1	1			2		1	1			3		127	142
PURIFICATION PLANT		15							1		50						60	126
River_area_2006		137	29	430	677	20	2	23	38	346	8	2	1 916		36		3 271	6 935
SAND BANK		34	5	160	163	48	6	21	14	77		4	307		7		732	1 578
SEWERAGE WORKS		33				1					317						252	603
SLIMES DAM																	1	1
SWAMP						3	18			2			4		10		9	46
TAILINGS IMPOUNDMENT		1																1
WATER TANK	5										31					59	329	424
(blank)	223	119 437	11 378	6 882	5 568	3 246	98	126	39 274	2 516	12 353	1 659	2 708	10	8 083	76		213 637
Grand Total	305	229 054	20 317	14 155	17 263	6 061	159	459	77 910	7 768	19 730	3 501	14 485	28	15 334	139	186 628	**613 296**

Table B.8: Feature class results of the DRDLR:NGI 2016 data

	Feature class of 2016 (columns)																	
Feature class 2006 (rows)	Closed Reservoir	Dam	Dry Pan	Dry water course	Flood Bank Area	Lake	Marsh	Mudflat	Non-Perennial Pan	Non-Perennial River	Open Reservoir	Perennial Pan	Perennial River	Salt Pan	Vlei	Water Tank	(blank)	Grand Total
DAM	31	394 341	275	3 187	264	259	29	3	816	232	3 940	929	3 924	1	1 562		58 615	468 408
DRY PAN		183	287 233	91 112	24	320		1	2 850	186	2	5	6	64	27		20 687	402 699
DRY WATER COURSE EXTENT		387	6 862	229 392	408	1			24	1 778	1		16				27 221	266 089
FISH FARM		34			0						11						94	139
FLOOD BANK		327	1	1 227	53 148	32	2	198	1	3 710			5 712		995		18 295	83 649
LAKE		653		1	16	48 495		121	50		4	805	411		1 892		1 308	53 756
LARGE RESERVOIR	24	33		1	0				0		631	1			4	1	230	925
MARSH VLEI		1 365	20	1 096	319	453	120	51	702	158	44	329	433		129 481		39 601	174 172
MUD FLATS		3	0		2	3		4 732	6			1	44		28		232	5 052
NON-PERENNIAL CENTER LINE										1							0	1
NON-PERENNIAL EXTENT		243	300	19 677	5 215	3	1	17	104	57 560	1	0	950		293		24 094	108 458
NON-PERENNIAL PAN		592	9 383	1 672	153	419	0	8	193 891	31	15	2 636	39		609		24 945	234 393

PERENNIAL CENTER LINE																	0	0
PERENNIAL EXTENT		1 672	2	762	7 928	58	19	416	37	1 045	2	8	126 799		805		38 123	177 677
PERENNIAL PAN		697	39	3	10	1 911	0	12	2 032	10	19	16 408	27		526		2 546	24 240
POOL		16			1	1			4		0	12			2		30	67
PURIFICATION PLANT		25							0		30						88	145
River_area_2006		131	678	1 416	1 132	312	3	51	136	258	1	3	997		185		22 382	27 685
SAND BANK		92	4 483	19 442	1 645	32	8	125	15	187		4	923		40		9 679	36 676
SEWERAGE WORKS		35				0					141						262	438
SLIMES DAM																	5	5
SWAMP						0	972			0			0		297		43	1 313
TAILINGS IMPOUNDMENT		2																2
WATER TANK	0										4					4	33	41
(blank)	62	119 233	79 373	1 452 943	57 204	4 525	1 098	1 203	54 227	14 009	5 882	3 361	25 874	15	118 829	3		1 937 840
Grand Total	117	520 063	388 648	1 821 931	127 469	56 824	2 253	6 940	254 897	79 166	10 730	24 500	166 156	80	255 575	8	288 516	4 003 871

Table B.9: Decision matrix showing preferences in integrating NGI2006 and NGI2016 feature types. Green cells show a match between the NGI 2006 and 2016 feature types; Green cells in the last column indicated where the 2006 feature types were kept whereas the remaining cells with 0.00 show where the 2016 feature types were kept

	Feature class of 2016 (columns)																Classification based on the 2006 feature type class
Feature class 2006 (rows)	**Closed Reservoir**	**Dam**	**Dry Pan**	**Dry water course**	**Flood Bank Area**	**Lake**	**Marsh**	**Mud flats**	**Non-Perennial Pan**	**Non-Perennial River**	**Open Reservoir**	**Perennial Pan**	**Perennial River**	**Salt Pan**	**Vlei**	**Water Tank**	
DAM	0.00	Dam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Dam**
DRY PAN	0.00	0.00	Dry Pan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Dry pan**
DRY WATER COURSE EXTENT	0.00	0.00	0.00	Dry water course	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Dry water course**
FISH FARM																	**Fish farm**
FLOOD BANK	0.00	0.00	0.00	0.00	Flood bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Flood bank**
LAKE	0.00	0.00	0.00	0.00	0.00	Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Lake**
LARGE RESERVOIR																	**Large reservoir**
MARSH VLEI	Closed Reservoir	Dam	Dry Pan	Dry water course	Flood Bank Area	Lake	Marsh	Mud flats	Non-Perennial Pan	Non-Perennial River	Open Reservoir	Perennial Pan	Perennial River	Salt Pan	Vlei	Water Tank	**Marsh / vlei**
MUD FLATS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Mud flat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Mudflats**
NON-PERENNIAL CENTER LINE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Non-perennial River	0.00	0.00	0.00	0.00	0.00	0.00	**Non-perennial river**
NON-PERENNIAL EXTENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Non-perennial River	0.00	0.00	0.00	0.00	0.00	0.00	**Non-perennial river**
NON-PERENNIAL PAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Non-perennial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Non-perennial pan**

									Pan								
PERENNIAL CENTER LINE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Perennial River	0.00	0.00	0.00	**Perennial river**
PERENNIAL EXTENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Perennial River	0.00	0.00	0.00	**Perennial river**
PERENNIAL PAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Perennial Pan	0.00	0.00	0.00	0.00	**Perennial pan**
POOL																	**Pool**
PURIFICATION PLANT																	**Purification plant**
River_area_2006	Closed Reservoir	Dam	Dry Pan	Dry watercourse	Flood Bank Area	Lake	Marsh	Mud flats	Non-Perennial Pan	Non-Perennial River	Open Reservoir	Perennial Pan	Perennial River	Salt Pan	Vlei	Water Tank	
SAND BANK																	**Sand bank**
SEWERAGE WORKS																	**Sewerage works**
SLIMES DAM																	**Slimes dam**
SWAMP																	**Swamp**
TAILINGS IMPOUNDMENT																	**Tailings impoundment**
WATER TANK																	**Water tank**

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APPENDIX C: REPORT BACK TO DATA CUSTODIAN DRDLR:NGI ON TOPOLOGICAL ERRORS FOUND IN HYDROLOGICAL POLYGON DATA OF 2016

Chapter Citation: Van Deventer, H. 2016. Appendix C. Report back to data custodian DRDLR:NGI on topological errors found in hydrological polygon data of 2016. South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

Report compiled by Heidi van Deventer, 2016-06-23, CSIR senior researcher. E-mailed to NGI in 2016.

Addressed to the data custodian Department of Rural Development and Land Reform (DRDLR), Directorate National GeoInformation (NGI).

I have collected the provincial geodatabase files issued by NGI as version March 2016 on 30 May 2016. These files were exported from Geomedia as geodatabases.

The files were imported into ArcGIS 10.3 as provincial feature classes in a feature data set. The provinces were then merged into three feature data classes (Table C1). The intention was to union the three feature classes into a single national hydrological data set, however owing to topological problems, the data errors had to be fixed first. The issues are therefore reported to the data custodian for improvement as per the SASDI Act.

(A) Overlapping polygons

A total amount of 3 961 overlapping polygons have been detected in the data (3rd column of Table C1; Figure C1). A large percentage of the polygons were overlaps of polygons with identical geometry and the duplicates were therefore removed, leaving 831 polygons which overlapped (last column of Table C1). These have been subsequently cleaned and edited by the CSIR and a clean version of this data set will be sent to NGI in Pretoria.

Table C.1: Number of overlapping polygons listed per feature data class

Layer	Provinces included	No. of polygon overlaps	After removing identical polygons which are on top of one another
Hydrological merge 1	EC, NW and MP	1379	182 (13 %)
Hydrological merge 2	WC, FS and LP	1526	372 (24 %)
Hydrological merge 3	NC, GT and KZN	1056	277 (26 %)

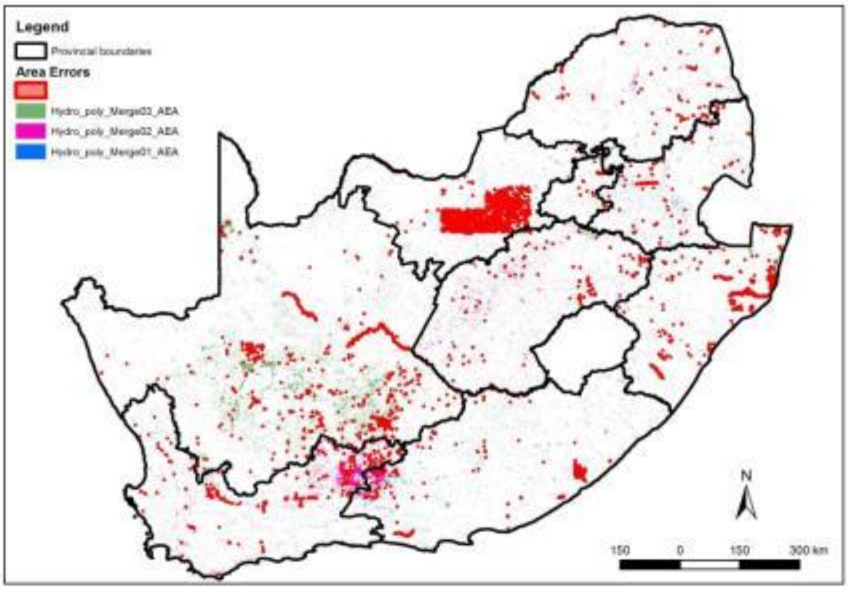

Figure C.1: Overlapping polygons in the hydrological data issued by NGI in March 2016.

(B) the updates of 2016 doesn't following logical hydrological boundaries of features (Figure C2).

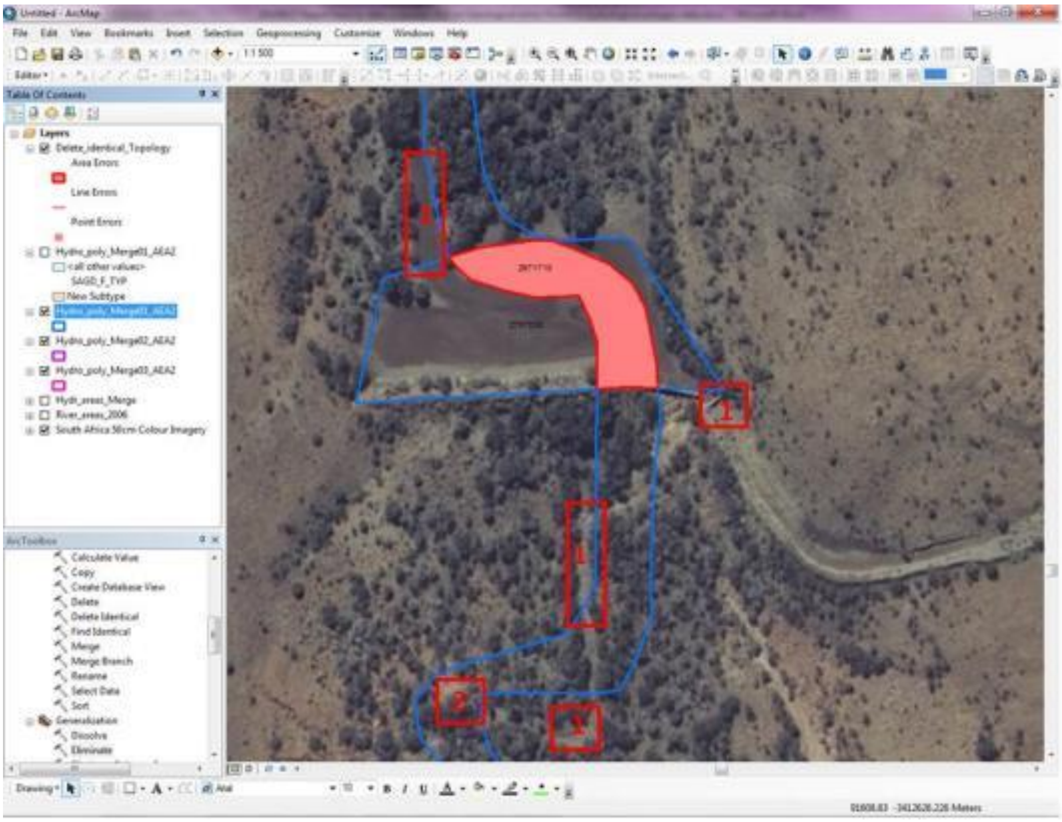

Figure C.2: Omission errors (1) and commission errors (2) in digitising hydrological features. The overlapping polygon between the dam and river is filled with red. The polygons are labelled with the "GID" code. The coordinate system is Albers Equal Area for South Africa, Datum = WGS84.

(C) the updates of 2016 differs from the shapefiles that were issued in 2006 (Figure C3)

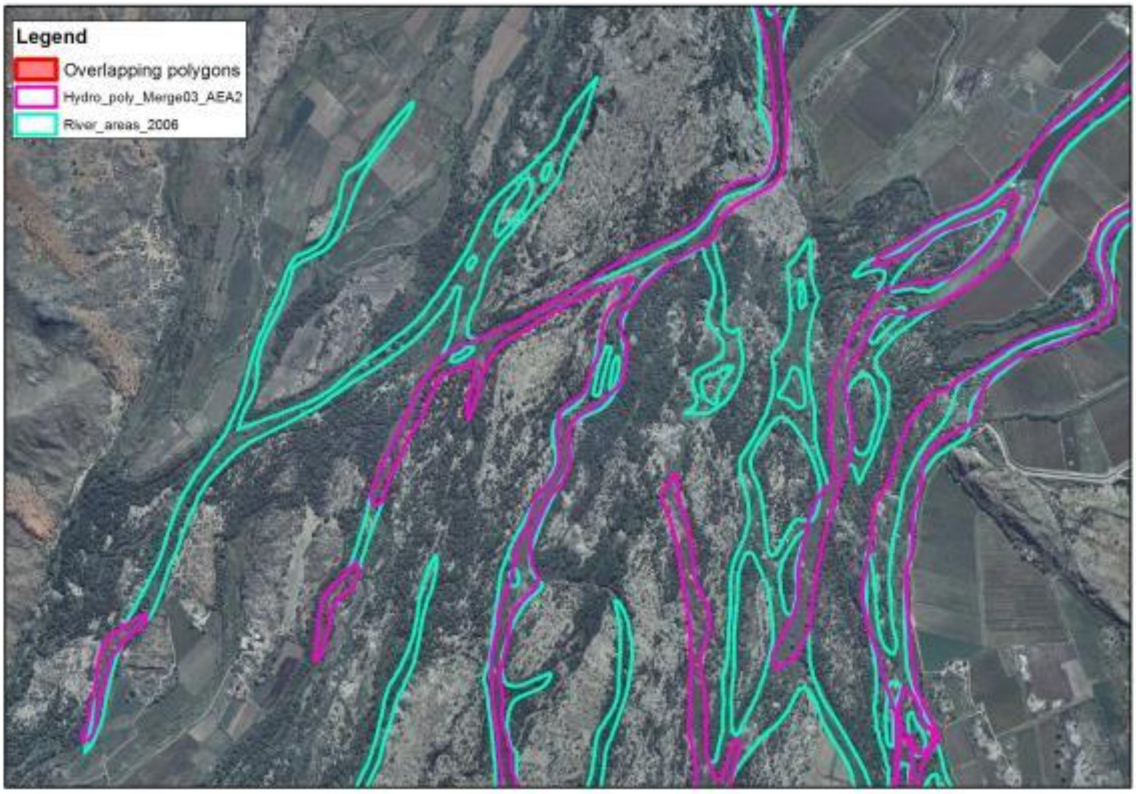

Figure C.3: Difference between the river areas captured in 2006 and 2016 for the Orange River.

Figure C3 shows that more areas were captured in 2006 than in 2016, but the areas in 2016 also differ and the amount of hydrological features is also incomplete for the floodplain north-west of the Orange River. The full extent of a hydrological feature would not change, regardless if the visible amount of water changes. The features should therefore be rather kept consistent over time, but only boundaries refined or extended.

Please let me know if you have any other questions.

Heidi

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APPENDIX D: DATA CAPTURING RULES USED FOR FOCUS AREAS IN THE UPDATE OF THE NATIONAL WETLAND MAP 5 (NWM5)

Citation: Van Deventer, H. 2016. Appendix D: Principles or rules in capturing wetlands for the update of the National Freshwater Inventory and National Wetland Map 5 in preparation for the National Biodiversity Assessment for 2018. South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

D1. Introduction and background

This document was compiled for the purpose of creating the first National Freshwater Inventory of South Africa, as well as updating the National Wetland Map to version 5 (NWM5) in preparation for the National Biodiversity Assessment for 2018 (NBA 2018). Sub-versions of the NWM5 were used during the update to indicate various improvements.

A number of guidelines already exists which can also be consulted. I have drawn some key recommendations and concepts from the following references to guide the wetland mapping and classification for the NBA 2018:

- Ollis et al. (2013) Classification document for more information about the classes (Ollis *et al.*, 2013), see *www.sanbi.org/documents/sanbi-biodiversity-series-22-wetlands-classification*
- The WRC Implementation guideline by Job et al. (2018) which was not available publicly at the time when this manuscript was compiled.
- Guidelines for data capturing from Ezemvelo KwaZulu-Natal Wildlife (EKZNW)
- Department of Water and Sanitation (DWS)

D2. Principles to follow during the editing and mapping of wetlands

- **Always capture the maximum extent of a wetland.** If you have received data from elsewhere, such as the NGI data, it may have captured the extent of a wetland from images which showed a different extent. This extent should be kept but extended where the current imagery shows the wetland to be wider. The full extent of a wetland may also not have been recognised whereas the current imagery offers better visual interpretation.
- **Do not capture wetlands inside the estuarine functional zone**
- **Never delete a wetland polygon!** If you think a polygon is not a wetland and should be deleted, please classify this as "Unknown (freshwater ecologist to help). For other polygons, extend or correct the boundary, HGM type (Level 4A of the classification system) or condition, or merge the sliver with the adjacent polygon but do not delete it.
- **Fill up the gaps in a polygon.** In some instances islands in a wetland were excluded or deleted, however it is part of the functional wetland unit, and must be included and merged to the HGM type. Should an inner polygon be a dam inside a river, capture the polygon and classify it accordingly.

- **Wetlands should be captured at a scale between 1:500 and 1:2 000**. You can browse through an area and attempt to detect wetlands at a scale between 1:2 000 and 1:5 000, depending on the region and size of the wetlands. The wetland can be captured roughly at these scales, however you should zoom in to the wetland to reshape, cut and edit the wetland at a scale below 1:2 000.
- **Always complete the following classes:**
    - **Identify Level 1** of the Classification System for Inland wetlands (CS_L1) of the polygon as any of the three types listed below. Codes are available from the dropdown option in the attribute table as per Table D1.
    - Level 2 of the Classification System for Inland wetlands (CS_L2) will be unioned / integrated at a later stage and should not be completed by the data editor.
    - Level 3 of the Classification System for Inland wetlands (CS_L3) will be guided by the slope categories. The L3 class will be assigned based on the majority overlap of the wetland with a slope, plain, bench or valley floor.
    - Most importantly, **ALWAYS capture the wetland type of the Level 4A** or Hydreomorphic (HGM) type as one of 7 types. In this field, artificial wetlands and estuaries are included to avoid these wetlands being classified as one of the 7 HGM types. Should you not be able to identify the wetland type, list it as “Unknown”. The codes and descriptions of the HGM types are as per Table D1.
- Always add the **date of the image** used for capturing or desktop validation of the extent or type of the wetland. Where multi-season images are available, a comparison should be made between the images, the maximum extent of the wetland map, and the respective date of the images recorded. In this regard, the most recent imagery doesn’t necessarily indicate the widest extent of the wetland.
- Always add details on the editing and/or validation in the following fields:
    - Data_editor : Person’s full name who edited the polygon
    - Edit_date : Day-month-year of the date on which the polygon was edited
    - Val_type: the type of validation done for the polygon. Code options are listed in Table D1.
    - Val_person : Person’s full name who validated the polygon
    - Val_date : Day-month-year of the date on which the polygon was validated
- Use the topographical maps to confirm the name of the wetland and correct spelling where necessary to the field [CS_NAME]. All names have been checked by Heidi van Deventer on 3 – 5 August 2016, however a second check is always valuable! Somme errors crept in where Augrabies were assigned to a multipart polygon. All such errors should all be corrected. Do not edit any of the previous fields with names at all. It is also important to attend to the following naming conventions and other issues:
    - The name of the wetland should be consistently spelt in Sentence case.
    - English names are usually spelt as two separate words with both starting with a capital letter, e.g. Aston Dam, Orange River, Jackson Reservoir, Heywood Dam, Albert’s Falls Dam or Zoo Lake.
    - Afrikaans names are usually spelt as one word. Where more than one word, only the first letter of the first word is capitalised and not the others, except where it is a name of a person. Examples of the correct spelling are Blesbokspruit, Stormsrivier, Oranjerivier, Bokdam, Seekoevlei, Hans se leegte, Gert Josop se vlei, Geelpan.

  - Rivers change names at confluences or along the longitudinal extent. Be careful not to merge polygons of rivers with different names.
- All data for the NBA 2018 project will be in Albers Equal Area WGS84, do not change this coordinate system. Please work in this coordinate system. Data will also be made available in Geographic WGS84 for external people to validate the data and ease the compatibility with QGIS and other open source software systems.
- Unknown and Unspecified is used in each field to identify the option:
  - Unspecified – the polygon has not been attended to yet by anyone
  - Unknown – the data capturer needs guidance and confirmation from the freshwater ecologist whether the polygon should be deleted or identification of the HGM type.

Table D.1: Field names and descriptions for the National Wetland Map 5.2

Field (column name)	Description
NGI0616_FT	Final feature type class based on the NGI 2006 and NGI 2016 data
NGI0616_NAME	Name given to the wetland in the NGI 2006 and NGI 2016 data
Peatlands	Where attributes are present, it indicates peatlands
NGIsprings	NGI springs buffered by 1 m, possibly indicating seeps
WETLAND_NO	Wetland number assigned by the Working for Wetlands team
W4W	HGM type assigned by the Working for Wetlands team
Estuaries_name	Name of the estuary
ESTUARIES	Field indicating the class estuaries
CS_L1*	Level 1 of the classification system was given the following subtypes: • ES : Estuarine • CS : Coastal • IA : Inland – artificial • IN : Inland – natural • UNKNOWN • UNSPECIFIED
CS_L2	No subtypes were given here. This field should be populated later with the regional setting used in the NBA2011.
CS_L3	The field should be populated based on the landform which fills the majority of the surface area of the polygon. The polygons should not be split. Subtypes include: • BENCH : Bench • BHILL : Bench – hilltop • BSAD : Bench – saddle • BSHE : Bench – shelf • PLAIN : Plain • SLOPE : Slope • VF :Valley floor • UNKNOWN • UNSPECIFIED
CS_L4A	The following subtypes were specified, which include the 7 hydrogeomorphic types of the Classification System • ART : Artificial • CVB : Channelled valley-bottom** • DEPR : Depression (the old pan categories of NGI)** • EST : Estuary • FLAT : Wetland flat** • FLOOD : Floodplain**

	• RIVER : River (riverine wetland)** • SEEP : Seep** • UVB : Unchannelled valley-bottom** • UNKNOWN • UNSPECIFIED • DELETE – the data capturer recommends to the validator that this polygon should be deleted Additional categories are added here for alignment to the estuarine and coastal groups. These would be refined and finalised by March 2017 (red = estuarine and blue = coastal): ESTCHANNEL Estuary that is now channelized POE Permanently open TOCE Temporarily closed ESTRIV River mouth ESTLAKE Estuarine lake ESTBAY Estuarine bay ESTMICRO Micro estuary LAGOON Lagoon COASTLAKE Coastal lake COASTWF Waterfall OUTLET Ephemeral outlet TRANS Transitional waters (fans and plumes) COASTGW Groundwater Dependent Coastal Ecosystem
CS_L4C	Drainage flow subtypes: • INFLOW : Inflow • OUTFLOW : Outflow • THROUGH : Throughput • UNKNOWN • UNSPECIFIED
CS_L5_source	Subtypes (predominant): • GWD : Groundwater dependent • MIX: Ground and rainfall dependent • RAIN : Rainfall dependent • UNKNOWN • UNSPECIFIED
CS_L5_hydroperiod	Hydroperiod (only level 5A was used) with subtypes: • PERM : Permanently inundated • SEASON: Seasonally inundated • INTER : Intermittently inundated • NEVER : Never inundated • UNKNOWN • UNSPECIFIED
CS_L5_satperiod	Saturation period: • PERM : Permanently saturated • SEASON : Seasonally saturated • INTERMIT : Intermittently saturated • UNKNOWN • UNSPECIFIED

CS_L6_artificial	Artificial subtypes descriptors: • CAN : Canal • DC : Dam (in-channel) • DO : Dam (off-channel) • OR : Open reservoir • CR : Closed reservoir • R : Reservoir • EXC : Excavation • SALT : Salt works • WTW : Water Treatment Works • WWTW : Wastewater treatment works • AQUA : Aquaculture pond • STORM : Stormwater pond • IRR : Irrigated land • UNKNOWN • UNSPECIFIED
CS_L6_salinity	(Salinity levels)
CS_L6_pH	(pH levels)
CS_L6_substratum	Subtypes: • BR : Bedrock • BD : Boulders • COB : Cobbles • PEB : Pebbles/gravel • SS : Sandy soil • CS : Clayey soil • LS : Loamy soil • SILT Silt (mud) • OS: Organic soil • SC : Salt crust • UNKNOWN • UNSPECIFIED
CS_L6_vegetation	Subtypes: • VAQ : Vegetated – aquatic • VH : Vegetated – herbaceous • VFS : Vegetated – forest (swamp) • VFR : Vegetated – forest (riparian) • VST : Vegetated – shrubs/thicket • VCROP : Vegetated – crops • VALIEN: Vegetated – alien / invasive • UNVEG : Unvegetated • UNKNOWN • UNSPECIFIED
CS_NAME	Name of the wetland
Image_date	The date of the image used (always record the maximum extent of a wetland, even if not a recent date of image)
Image_type	The image (sensor) used: e.g. the NGI 50 cm colour orthophotography, SPOT 5/6, IKONOS, Quickbird, greyscale orhophotography etc. No subtypes were specified for this group.
Data_editor	Person’s full name who edited the polygon
Edit_date	Day-month-year of the date on which the polygon was edited
Val_type	The type of validation done for the polygon. Code options:

	• NONE : Not validated • DESK_EXTENT : Desktop validation was done of the extent of the wetland. • DESK_TYPE : Desktop validation was done of the HGM type of the wetland. • DESK_COND: Desktop validation was done of the condition of the wetland. • DESK_ET: Desktop extent and HGM type • DESK_ALL : Desktop extent, HGM type and condition • FIELD_EXTENT : Fieldwork validation was done of the extent of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_TYPE : Fieldwork validation was done of the HGM type of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_COND : Fieldwork validation was done of the condition of the wetland. *In this case no further edits are allowed on this wetland!* • FIELD_ET : Field validation of extent and HGM type. *In this case no further edits are allowed on this wetland!* • FIELD_ALL : Field validation of extent, HGM type and condition. *In this case no further edits are allowed on this wetland!*
Val_person	Person's full name who validated the polygon
Val_date	Day-month-year of the date on which the polygon was validated

**CS refer to classification system (Ollis et al., 2013)*

***Hydrogeomorphic (HGM) type*

D3. Steps to take in editing provincial data sets

The following steps should be taken sequentially in the editing of the provincial data sets extracted from the National Wetland Map 5_2 feature class.

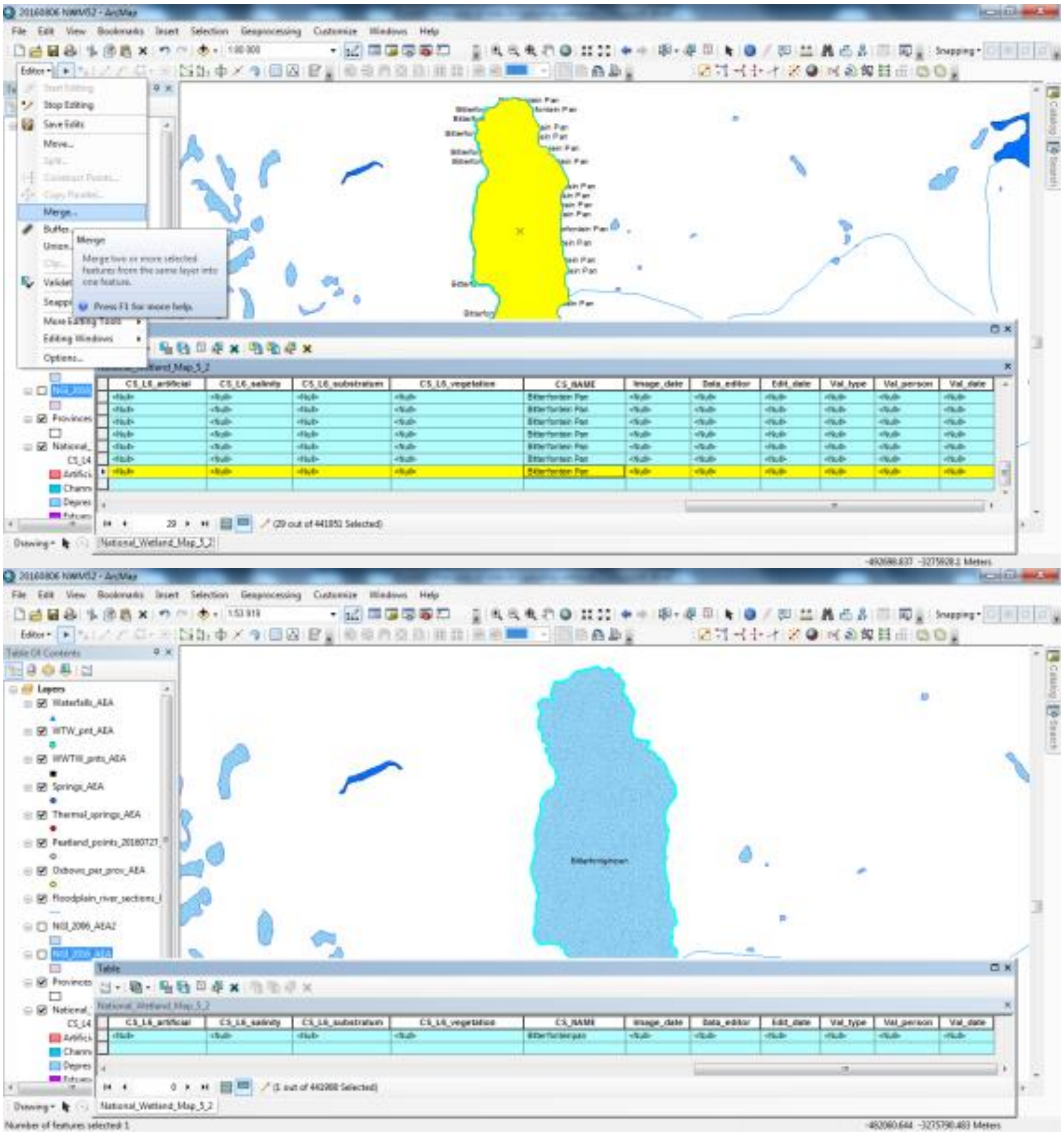
1. The data for COASTAL PROVINCES SHOULD NOT BE CLIPPED, since the coastal features are not confirmed yet. Rather select all the polygons that intersect with the province, and export these as a new feature class.
2. **CSIR INTERNS: Verify the oxbow points for your province.** Use the feature class: C:\Projects\NBA2018\National Freshwater Inventory 5.2.gdb\Data_AEA_WGS84\Oxbows_per_prov_AEA. Zoom to each point and display it on the NGI's 50 cm colour orthophoto. If the point is indeed an oxbow, then classify it as "Confirmed oxbow" in the field [Validate]. If it is not an oxbow, then classify it as "No"; if you are unsure, then classify it as "Unsure". Do not delete any points. Add points if you know of any. It would be good to browse through the images to ensure all oxbows are captured to identify floodplains. Process completed, duration 1 - 24 August 2016 for Ms Ridhwannah Ganget and Mr Phumlani Zwane.
3. The SRTM 30 m data was mosaicked by Leolin Qegu and slope calculated in degrees. Mask the data for your province. Make sure the tiles extend beyond your province. Then calculate the slope in degrees and display this as one of the background layers. The slope should be visually displayed as three categories: 0 – 1 °, 1 – 3 ° and > 3 °. This can be used to inform the HGM type. The specific threshold for the cut-off between slope and bench/plain has not been tested thoroughly and is therefore merely a given as a range to guide you.

4. When Merging polygons, first select the polygons, then zoom to the selected and make sure it is not a multi-part polygon, and then press merge. If it is a **multi-part polygon, then explode the data first**, before restarting the selection and merging process.
    a. Do not merge polygons where other Levels of the classification system separate the polygon based on substratum or vegetation.
5. If you are allocated a province with estuaries, attend to the estuaries first. **Where small polygons occur adjacent to the estuaries polygons, merge them into the estuary**. Field [ESTUARIES_Name] show the estuary name and field [ESTUARIES] which polygons are Estuary Functional Zones. Zoom to the estuary, start editing, select all the polygons that are classified as "estuary" as well as small adjacent polygons, and merge the polygons into one.
6. Visit each peatland point and see if you can recognise the full extent of the wetland, capture the necessary and associated fields.
7. Edit the remaining polygons by going consistently through the provinces. Use the 1:10 000 gridlines of the NGI to guide you. Browse for example from top left to right first, and then down and then right to left again till the tile is completed.
8. Look for slivers and inconsistent naming and merge these polygons. Figure D1, for example, shows slivers on the edge of a pan. In 2006 it was called Bitterput se pan, while in 2016 it was called "Bitterfonteinpan". All the polygons were selected and merged into a single polygon called "Bitterfonteinpan".
9. The location of floodplain wetlands can be indicated by 3 features: the presence of floodbanks in river areas from the NGI field, or the location of oxbow rivers and highly sinuous river lines. Oxbow rivers were captured as points and should be displayed in your screen. Sections of the 1:500 000 river lines which are highly sinuous were also extracted and should also be viewed.
10. River channels should be captured as separate polygons from the adjacent wetland. Only a selection of the highest river stream order numbers (Figure D2) for each province (orders 7 – 4, maybe 3) should be mapped, not orders 1 and 2. The data is available in the geodatabase, see field ORDER.
11. Wetlands adjacent to river channels, could be either floodplain areas, CVB wetlands or seeps. If there is no evidence of a floodplain or seep, it could likely be CVB wetlands, for example, polygons adjacent to the Mathwaring River (Figure D3) should be classified as CVB wetlands.
12. Small polygons adjacent to a dam should be merged with the dam.
13. Polygons on top of other polygons should be cleaned with the Clip option.
14. Many errors crept in during the dissolve operation and now a large majority of polygons in across the country appears to be Depressions but are in fact artificial wetlands. The images should be used to see whether they are not in fact ART wetlands and all of these correctly classified.
15. A number of ancillary data sets should be used to guide the mapping and classification:
    a. The 50 cm colour orthos of the NGI is available from the ArcGIS online service. Display this in the background.
    b. Waste water treatment works (WWTW) and water treatment works (WTW) data is available to see where artificial wetlands are. Capture these as polygons and classify L1 as Inland – Artificial, and L4A as ART.

c. The slope classes: depressions, flats and floodplain wetlands would usually form on low slope. Valley-bottom and seep classes on slopes (>1 or 3 ° of slope). Rivers could occur on both.
d. The 1:500 000 rivers can be used to identify river channels. These should be captured as separate river wetland types. If a channel is visible between wetland polygons, it could either be a floodplain wetland or a channelled valley-bottom wetland. Use the oxbows and slope < 1 ° for floodplain wetlands and the slope > 1 or 3 ° for channelled valley-bottom wetlands.
e. The **springs** data should be used to identify seep wetlands in the landscape. The springs data was buffered with 1 m and included as polygons in the National_Wetland_Map_5_2 feature class under field [NGI_springs] to guide you to confirm the location of this wetland. If you can't recognise the wetland, leave it as the default "UNKNOWN". If you have mapped it, though can't identify the wetland type, classify it as "UNSPECIFIED".
f. Also look at the **thermal springs** point data, visit each point in the province, and if you can detect or recognise the thermal spring feature, capture it as a polygon, and classify it as a SEEP under L4A.
g. The working for wetlands data was also integrated in the National_Wetland_Map_5_2 feature class showing the extent and HGM types of the wetland. The field [WETLAND_NO] shows the code of the wetland rehabilitated, with [W4W indicating the HGM type that was identified during fieldwork. The wetland should be modified to include the adjacent polygons and the L4A category kept as indicated in the Working for Wetlands field.
h. We are still expecting the Aquaculture farms too, and this will have to be captured and classified as artificial wetlands and Aquaculture ponds at Level 6.

Please sign below to indicate that you understood the principles and rules and agree to follow these during your work on the NBA 2018.

______________________________	____________________________________	__________
PERSON'S NAME	SIGNATURE	DATE



Merge two or more selected features from the same layer into one feature.

Press F1 for more help.

National_Wetland_Map_5_2

	CS_L6_artificial	CS_L6_salinity	CS_L6_substratum	CS_L6_vegetation	CS_NAME	Image_date	Data_editor	Edit_date	Val_type	Val_person	Val_date
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
▸	<Null>	<Null>	<Null>	<Null>	Bitterfontein Pan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>

(29 out of 441851 Selected)

-492686.837 -3275928.1 Meters

National_Wetland_Map_5_2

	CS_L6_artificial	CS_L6_salinity	CS_L6_substratum	CS_L6_vegetation	CS_NAME	Image_date	Data_editor	Edit_date	Val_type	Val_person	Val_date
	<Null>	<Null>	<Null>	<Null>	Bitterfonteinpan	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>

(1 out of 442988 Selected)

Number of features selected: 1

-492080.644 -3275790.483 Meters

Figure D.1: Example of sliver polygons which should be merged into one polygon.

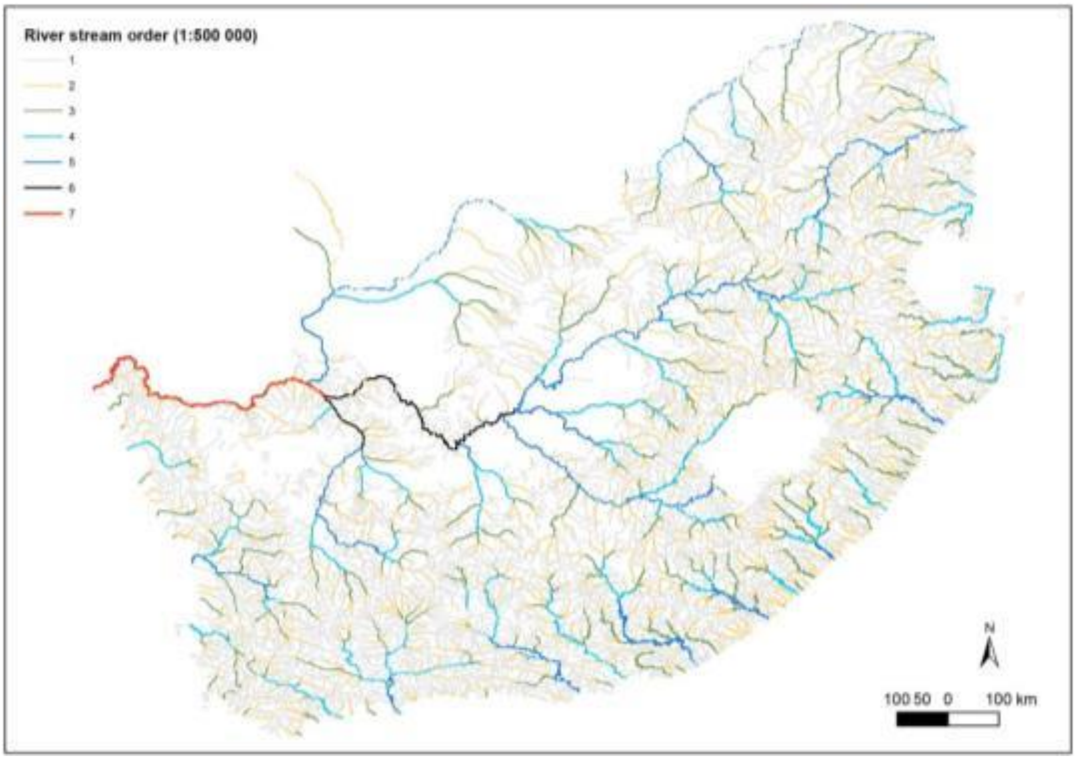
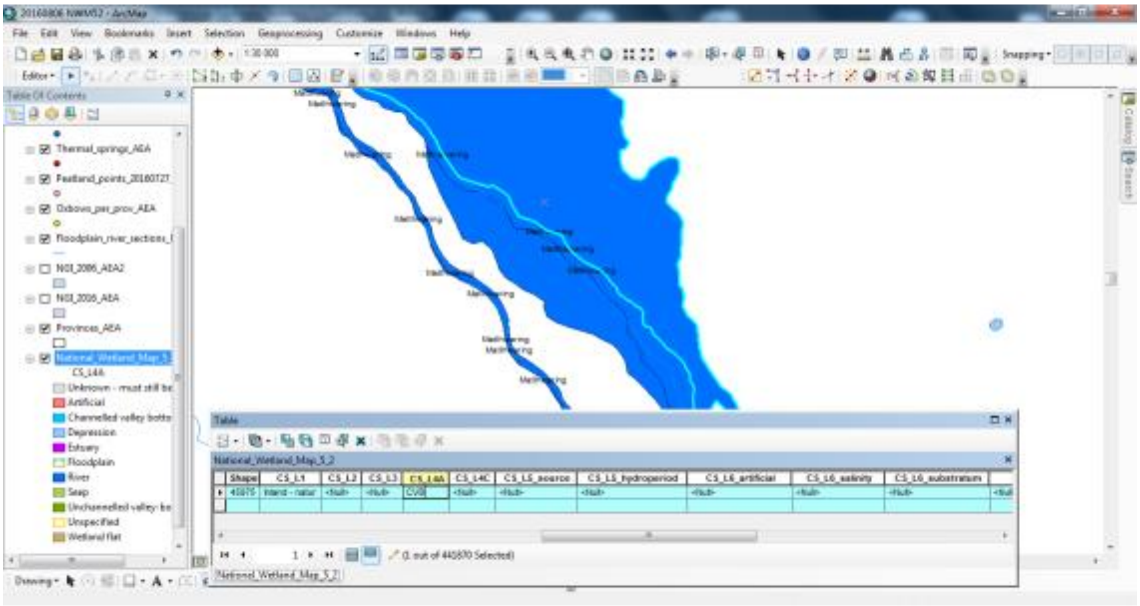


Figure D.2: River stream orders for the 1:500 000 quaternary mainstem rivers.



Shape	CS_L1	CS_L2	CS_L3	CS_L4A	CS_L4C	CS_L5_source	CS_L5_hydroperiod	CS_L6_artificial	CS_L6_salinity	CS_L6_substratum
[illegible]	Inland - natur	<Null>	<Null>	CVB	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>

(1 out of 440870 Selected)

Figure D.3: Areas on either side of a river channel should be classified as CVB wetlands.

Literature Cited

Ollis, D.J.; Snaddon, C.D.; Job, N.M.; Mbona, N. 2013. *Classification System for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems.* SANBI Biodiversity Series 22, South African National Biodiversity Institute: Pretoria, RSA.

APPENDIX E: DATA SETS USED FOR THE COMPILATION OF NATIONAL WETLAND MAP 5 (NWM5)

Chapter Citation: Van Deventer, H. 2018. Appendix E: Data sets used for the compilation of National Wetland Map 5 (NWM5). South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

This table was derived from the Supplementary material published in Van Deventer et al., 2018. In some instances only a selected number of the polygons had been used. Details of the data sets can be obtained from the Van Deventer et al., 2018 Supplementary material. Additional data sets used have been added in the list below.

Extent	Data description	Citation
National	Chief Directorate National Geo-Information (NGI) update to the topographical maps data from aerial photography. Hydrological polygon data (wetlands).	DEPARTMENT OF LAND AFFAIRS: CHIEF DIRECTORATE OF SURVEYS AND MAPPING (DLA:CDSM) (2006) Hydrological polygon and river line shapefiles mapped from the 1:50 000 topographical maps. DLA:CDSM, Cape Town, South Africa. DEPARTMENT OF RURAL DEVELOPMENT AND LAND REFORM: NATIONAL GEO-INFORMATION (DRDLR:NGI) (2016) Provincial geodatabases of hydrological databases exported from GeoMedia in March 2016. DRDLR:NGI, Cape Town, South Africa.
National	DEA Working for Wetlands and Working for water programmes	DEA, unknown
National	Geology data at 1:250 000 (alluvial related categories)	CGS, unknown
National	Vegetation map of South Africa ~ azonal vegetation	MUCINA L and RUTHERFORD MC (2006) The Vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute (SANBI) Strelizia, Pretoria, South Africa.
National	WRC Project K5/2346 Eco-region model of peatlands; upgrade existing peatland database	GRUNDLING P, GRUNDLING AT, PRETORIUS L, MULDERS J and MITCHELL S (2017) South African peatlands: ecohydrological characteristics and socio-economic value. Water Research Commission (WRC) report no. 2346/1/17. WRC, Pretoria, South Africa.
National	Estuaries	VAN NIEKERK L, ADAMS JB, BATE G, CYRUS D, DEMETRIADES N, FORBES A, HUIZINGA P, LAMBERTH SJ, MACKAY F, PETERSEN C, TALJAARD S, WEERTS S, WHITFIELD AK and WOOLDRIDGE TH (2011) In: Van Niekerk L and Turpie JK (eds). *South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. Pretoria: South African National Biodiversity Institute. CSIR Report CSIR/NRE/ECOS/ER/2011/0045/B.* Stellenbosch: Council for Scientific and Industrial Research.

National	Wetlands data from NSS	Not cited
National	NFEPA and other fine-scale data sets used for a number of Strategic Environmental Assessments at sub-national scale by the Freshwater Consultancy Group, including the Electricity Grid SEA, the Shale Gas SEA and the Wind and Solar SEA.	SNADDON K, TODD S, KIRKWOOD D and EWART-SMITH J (2015) *National Electricity Grid Infrastructure SEA Specialist Report: Terrestrial and Aquatic Biodiversity. Report submitted to CSIR, July 2015.* FCG, Cape Town, South Africa. SKOWNO A, TODD S, SNADDON K, EWART-SMITH J (2014) *National Wind and Solar PV SEA Specialist Report - Terrestrial and Aquatic Biodiversity. Report submitted to the CSIR, July 2014.* FCG, Cape Town, South Africa.
Eastern Cape	Data mapped by Greer Hawley and Annamarie Fish for selected catchments in the Eastern Cape	Not cited
Eastern Cape	Nelson Mandela Bay wetlands, WRC project 2182	MELLY BL, SCHAEL DM, RIVERS-MOORE N and GAMA PT (2016) Mapping ephemeral wetlands: manual digitisation and logistic regression modelling in Nelson Mandela Bay Municipality, South Africa. Wetlands Ecol Manage, doi:10.1007/s11273-016-9518-7. SCHAEL DM, GAMA PT and MELLY BL (2015) Ephemeral Wetlands of the Nelson Mandela Bay Metropolitan Area: Classification, Biodiversity and Management Implications. Water Research Commission (WRC) Report No. 2181/1/15. WRC, Pretoria, South Africa.
Eastern Cape	Inland wetlands mapped and verified by Nancy Job and Heidi van Deventer for Hogsback	The work was done for both the Water Research Commission (WRC) under the project K5/2545 "Establishing remote sensing toolkits for monitoring freshwater ecosystems under global change" as well as the Council for Scientific and Industrial Research (CSIR), project titled "Common Multi-Domain Development Platform (CMDP) to Realise National Value of the Sentinel Sensors
Eastern Cape	SANParks Mountain Zebra National Park	JOB N, ROUX DR, RAMABULANA L, BAARD J, AHRENDS B, BEZUIDENHOUT H, COLE N, SITHOLE H, DU TOIT L and CRUYWAGEN K (2016) Wetland inventory of Mountain Zebra National Park. South African National Parks (SANParks) Scientific Report 05/2016. SANParks, Cape Town, South Africa.
Gauteng	Wetlands mapped for the City of Tshwane Metropolitan Municipality	GRUNDLING AT (2005a) Development of a preliminary inventory and status assessment of wetlands in the Northern Tshwane study area. Report GW/A/2005/43 compiled by the Agricultural Research Council: Institute for Soil, Climate and Water (ARC:ISCW) for the City of Tshwane. ARC:ISCW, Pretoria, South Africa. GRUNDLING AT (2005b) Development of a preliminary inventory and status assessment of wetlands in the Southern Tshwane study area. Report compiled by the Agricultural Research Council: Institute for Soil, Climate and Water (ARC:ISCW) for the City of Tshwane. ARC-ISCW, Pretoria, South Africa.

Gauteng	Wetlands mapped for the City of Johannesburg Parks	BATCHELOR A (2009) Wetland and riparian protection and management plan for the City of Johannesburg. Report from Wetland Consulting Services (Pty) Ltd to the City of Johannesburg, Jane Eagle. Wetland Consultancy Services (WCS), Pretoria, South Africa.
Gauteng	Ekurhuleni Metropolitan Municipality	ENVIRONOMICS (2007) Environmental Management Framework for Ekurhuleni. Environomics, Pretoria, South Africa.
Gauteng	Site delineations for some wetland areas within GP from Limosella Pty Ltd	Not cited
Gauteng	Wetlands data from Andre Grobler	Not cited
Gauteng	Inland wetlands for the West Rand District Municipality	USAID, 2018
KZN	KwaZulu-Natal (KZN) freshwater wetlands captured (in vegetation types)	SCOTT-SHAW R and ESCOTT BJ (Eds) (2011) KwaZulu-Natal Provincial PreTransformation Vegetation Type Map – 2011. Unpublished GIS Coverage [kznveg05v2_011_wll.zip], Biodiversity Conservation Planning Division, Ezemvelo KZN Wildlife, P. O. Box 13053, Cascades, Pietermaritzburg, 3202.
KZN	Wetland extent mapped for Key Focus Areas in KZN	uMgungundlovu District Municipality (uMDM) (2017) *Environmental Management Framework for the uMgungundlovu District Municipality.* Unpublished GIS Coverage (wetland spatial layer). Prepared by the Institute of Natural Resources, Pietermaritzburg, KZN.
KZN	Wetlands (river reaches and riparian areas) mapped and verified in field for the GEF5 project in the uMDM (Quaternary catchments U20G and U20F)	Lechmere-Oertel, R.G. 2017. *Desktop predictive delineation of water resource areas (wetlands, riparian habitats, river areas and dams) within the quaternary catchments of the uMgungundlovu District Municipality.* Unpublished GIS data, funded by the SANBI-GEF5 project.
KZN and part in MP	Wetlands data for WWF areas of interest	JOB N, WALTERS D, KOTZE D (2015) *A desktop assessment of wetland condition in the Upper Mooi, Upper Mgeni and Upper Mvoti catchments*. Report for the World Wildlife Fund (WWF), South Africa.
KZN	Ethekwini municipality Desktop wetland mapping	Not cited
Limpopo	DWS Limpopo Province wetland data	Not cited
Mpumalanga	Mpumalanga Highveld WET project data	MBONA M, JOB N, SMITH J, NEL J, HOLNESS S, MEMANI S and DINI J (2015) Supporting better decision-making around coal mining in the Mpumalanga Highveld through the development of mapping tools and refinement of spatial data on wetlands. Water Research Commission (WRC) Report No. TT614/14. WRC, Pretoria, South Africa.
Mpumalanga	Anton Linström's data	Not cited

Mpumalanga	Inland wetlands mapped and verified by Anton Linström and Heidi van Deventer for Tevredenpan	The work was done for both the Water Research Commission (WRC) under the project K5/2545 "Establishing remote sensing toolkits for monitoring freshwater ecosystems under global change" as well as the Council for Scientific and Industrial Research (CSIR), project titled "Common Multi-Domain Development Platform (CMDP) to Realise National Value of the Sentinel Sensors
Northern Cape	Wetlands data captured for the Kamiesberg municipality	JOB NM (2008) *Wetlands of Kamiesberg Municipality.* Prepared for the Critical Ecosystems Partnership Fund and Conservation International.
Northern Cape	Wetlands data captured of Nieuwoudtville for the Botanical Society and NC DENC	JOB NM (2009) *Nieuwoudtville wetland layer.* Prepared for the Botanical Society of South Africa: Conservation Unit and Northern Cape Department of Environment and Nature Conservation as part of the Bokkeveld Plateau Catchment Action Plan.
Northern Cape	Kamiesberg (was already in NWM4) updates; also a WfWetlands project and a Vegetation survey by Helme and Desmet, 2006.	HELME N and DESMET P (2006) *A Description Of The Endemic Flora And Vegetation Of The Kamiesberg Uplands, Namaqualand, South Africa.* Report for CEPF/SKEP.
Northern Cape	Nieuwhoutville vegetation types	DESMET PG, TURNER RC, HELME NA and KOOPMAN R (2009) *Namaqualand Sand Fynbos: Vegetation Description and Conservation Status. Report for the Namakwa District Products Prject, the Botanical Society of South Africa / Critical Ecosystems Partnership Fund.* Claremont, South Africa.
Northern Cape	Bushmanland Conservation Initiative (BCI) Report; mapped vegetation types associated with wetland and dryland ecosystems. Kloofs (seeps) modelled from 90 m SRTM DEM.	DESMET PG, YATES M, and BOTHA M (2005) *Bushmanland Conservation Initiative Spatial Data Report.* Botanical Society of South Africa, Kistenbosch, South Africa
Northern Cape	SKA - Square Kilometre Array spiral core area	COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH (CSIR) (2016a) Integrated Environmental Management Plan for the South African mid-frequency array of SKA Phase 1 - Aquatic Ecosystems Assessment of the SKA Phase 1 in South Africa. CSIR Report Number: CSIR/02100/EMS/ER/2016/15241/B. CSIR, Pretoria, South Africa.
Northern Cape	SANParks Bontebok National Park	FISHER RC, ADAMS TA and EBRAHIM Z (2017a) NFEPA Wetland Groundtruthing in Bontebok National Park. Wetlands data set compiled by the South African National Parks: Scientific Services, Cape Research Centre. SANParks, Cape Town, South Africa.
North West	North West Province predictive modelled wetland extent and classes. Also include peatlands	Not cited

Western Cape	CoCT Wetland extent and classes of the City of Cape Town Metropolitan Municipality (CTMM)	SNADDON K and DAY A (2009) Prioritisation of City Wetlands. Report and shapefiles submitted to the City of Cape Town: Department of Environmental Resource Management. The Freshwater Consultancy Group (FCG), Cape Town, South Africa. SNADDON K, TURNER R, JOB N, OLLIS D and JONES L (2009) City Wetlands Map: Phase 5 - Ground-truthing and map update. Submitted by the Freshwater Consultancy Group to the City of Cape Town, Department of Environmental Resources Management. The Freshwater Consultancy Group (FCG), Cape Town, South Africa.
Western Cape	SANBI C.A.P.E. programme wetlands data on http://bgis.sanbi.org/fsp/additional.asp	SNADDON K, JOB N, DAY L, NEL J and SMITH-ADAO L (2008) C.A.P.E. Fine-Scale Planning Project: Surface Freshwater Ecosystems. Methodology Report. The Freshwater Consulting Group (FCG) and Council for Scientific and Industrial Research (CSIR), Cape Town, South Africa.
Western Cape	Knysna Protected Environment's Development Control Area	HAYES JS, KRUGER N, DE KLERK J and MAPHANGA B (2016) A wetland survey in selected areas of the Knysna Protected Environment. Report from the South African National Parks (SANParks), Scientific Services, Knysna. SANParks, Knysna, South Africa.
Western Cape	Alanna Rebelo PhD thesis work	REBELO AJ (2017) Ecosystem Services of Palmiet Wetlands: The Role of Ecosystem Composition & Function. PhD thesis, University of Antwerp, Belgium.
Western Cape	SANParks data for Overberg and Ratel River, Hagelkraal and around Agulhas National Park	FISHER RC, GOUWS J, ADAMS TA and EBRAHIM Z (2017b) NFEPA Wetland Groundtruthing for catchment SQ4 ID 9434 on the Agulhas Plain. Wetlands data set compiled by the South African National Parks: Scientific Services, Cape Research Centre. SANParks, Cape Town, South Africa. FISHER RC, GOUWS J, JOB N, NIEWOUDT H, EBRAHIM Z and ADAMS TA (2017c) NFEPA Wetland Groundtruthing for the Ratel River catchment (SQ4 ID 9428) on the Agulhas Plain. Wetlands data set compiled by the South African National Parks: Scientific Services, Cape Research Centre. SANParks, Cape Town, South Africa. FISHER RC, GOUWS J, NIEWOUDT H, ADAMS TA and EBRAHIM Z (2017d) Wetland Groundtruthing for catchment SQ4 ID 9433 on the Agulhas Plain. Wetlands data set compiled by the South African National Parks: Scientific Services, Cape Research Centre. SANParks, Cape Town, South Africa.

APPENDIX F: REVIEW PROTOCOL AND TEMPLATE USED FOR THE DESKTOP REVIEW OF THE DRAFT NATIONAL WETLAND MAP 5.

Chapter Citation: Mbona, N.; Van Deventer, H. 2017. Appendix F: Review protocol and template used for the desktop review of the draft National Wetland Map 5. South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A.

Project purpose: This document was compiled for the purpose of reviewing desktop mapping of wetland data sets. The National Wetland Map (NWM) 5 is currently under improvements as part of data sets to feed in the freshwater component of the National Biodiversity Assessment (NBA) 2018. The NBA is due to be published in 2018/9. The data capturing and integration of fine-scale wetlands data is currently taking place aiming to be finalised 1 August 2017. Thereafter CSIR (Heidi van Deventer) will integrate Levels 2 and 3 of the Classification System to complete the NWM 5 for inclusion into the National Freshwater Inventory and assessment in the NBA 2018.

Looking at the timeframe and resources available, we have prioritised certain areas to be mapped in this revision of the NWM. The selected district municipalities were mapped on desktop by junior data captures. The wetland data sets will be reviewed by SANBI according to the criteria listed in Table F3. Following that it will be passed to the wetland specialist appointed for the area to be further reviewed according to the same criteria listed in Table F3 with additions of any other comments. Consultants can add important systems that have been obviously missed and also correct the typing if time is available.

Table F.1: Prioritised areas for desktop fine-scale mapping of wetlands and data capturer responsible

District Municipality	Region	Data Capturer
Enhlanzeni (MP)	Mesic	Millicent Dinala
Umgungundlovu (KZN)	Mesic	Phumlani Zwane
Vhembe (LP)	Mesic and Arid	Tebogo Kgongwana
Francis Baard (NC)	Arid	Gcobani Nzonda
Lejweleputswa (FS)	Arid	Ridhwannah Gangat
Cape Winelands (WC)	Winter rainfall	John April, Sinekhaya Maliwa and Bongiwe Simka
Amathole (EC)	Winter rainfall	Leolin Qegu

The wetland data sets captured by the various data capturers for priority districts in South Africa, will be reviewed according to a number of criteria (Table F2). Historical and current imagery in Google Earth, the National Geospatial Information's 50 cm colour orthophotos available online and SPOT imagery from (January 2012) will be used to assess the extent and hydrogeomorphic types of wetlands in a systematic manner. Hydrogeomorphic types will be reviewed visually against existing fine scale and with also the use of ancillary data (e.g. contours, DEM) as specified in Van Deventer, 2016.

The data will later be integrated into fine-scale provincial wetland data sets and this will form NWM 5.4 to be used in the NBA 2018.

Note: The National Wetland Map is defining wetlands as on the Ramsar definition of wetland. This is the definition that has been used for all the National Wetland Map products. It also uses the wetland classification system (Ollis et al., 2013) definition of wetlands. The map can be further subdivided into other layers per feature in order to follow the South African Water Act definition of wetland.

Table F.2: Proposed timeframe for data iterations

District Municipality	Region	Data Capturer	Date received by Namhla from data capturer	Date received by wetland specialist	Date received by data capture (Namhla to pass)	Date received by Namhla Final layer
Enhlanzeni (MP)	Mesic	Millicent	28 February 2017	2 March 2017	16 March 2017	
Umgungundlovu (KZN)	Mesic	Phumlani	13 Feb 2017	14 Feb 2017	27 Feb 2017	
Vhembe (LP)	Mesic and Arid	Tebogo	07 Feb. 2017	08 Feb 2017	21 Feb 2017	
Francis Baard (NC)	Arid	Gcobani	13 Feb 2017	14 Feb 2017	27 Feb 2017	
Lejweleputswa (FS)	Arid	Ridhwannah	09 Feb 17	10 Feb 2017	21 Feb 2017	
Cape Winelands (WC)	Winter rainfall	John, Sinekhaya, Bongiwe	15 Feb 2017	16 Feb 2017	28 Feb 2017	
Amathole (EC)	Winter rainfall (sent to WCS)	Leolin	13 Jan 2017	18 January 2017	17 Feb 2017	

F1. Review of wetland data extent, types and other criteria by Namhla Mbona (SANBI)

Priority district:

Name of intern / data capture:

Filename of geodatabase and feature class to review (2):

Dates	Signature
Date received by Namhla	
Date reviewed by Namhla	
Date sent to the Wetland specialist	
Date received from Wetland specialist	
Revision submitted by Intern / data capturer	
Date of final sign-off	

Table F.3: Review table for data check prior passing to the wetland specialist

Criterion evaluated	**Aspect / standard**	**Namhla review**	**Intern response**
Topology	Polygons must not overlap, multipart, etc. The file must be topologically correct		
Check if all attributes have been captured Attributes must be checked up to Level 4 A	Report total amount of polygons per each row below that are *not* completed and put % in brackets to indicate severity of the issue NULL		
	Level 1, field CS L1		
	Level 3, field CS_L3		
	Level 4A, field CS_L4A		
	Date of the image		
	Data editor		
	Edit date		
Metadata and criteria document: detailing river order mapped, slope threshold used, source of imagery in more detail, criteria for floodplains etc., issues experienced and map showing areas complete	1. What method has been followed for mapping? 2. How was the HGM typing applied?		
HGM typing	*Specify errors as GPS coordinates with suggested HGM type*		
Omission and commission errors	*Specify GPS coordinates per class type (e.g. omission, commission)*		
Condition rating added	*Is there any condition ratings?*		

Attached is a shapefile containing points of areas with spatial errors to be fixed (**filename**) areas with over mapping, areas with under mapping and areas to be verified in field. Also please attach a shapefile for wetland typing errors.

F2. REVIEW BY WETLAND SPECIALIST

This section is for the data review by wetland specialist. The data sets will be submitted for each area to the specialist assigned. The project has tight timeframes and not many days within each contract. Specialist should strike a balance between comments to be sent back to data captures and the quick issues that can be fixed.

Table F.4: Review table for data check by wetland specialist

Criterion evaluated	Aspect / standard	Wetland specialist	Intern response
Topology	Polygons must not overlap, multipart, etc. The file must be topologically correct		
Check if all attributes have been captured Attributes must be checked up to Level 4 A	Report total amount of polygons per each row below that are *not* completed and put % in brackets to indicate severity of the issue NULL		
	Level 1, field CS L1		
	Level 3, field CS_L3		
	Level 4A, field CS_L4A		
	Date of the image		
	Data editor		
	Edit date		
Metadata and criteria document: detailing river order mapped, slope threshold used, source of imagery in more detail, criteria for floodplains etc., issues experienced and map showing areas complete	1. What method has been followed for mapping? 2. How was the HGM typing applied?		
HGM typing	*Specify errors as GPS coordinates with suggested HGM type*		
Omission and commission errors	*Specify GPS coordinates per class type (e.g. omission, commission)*		
Condition rating added	*Is there any condition ratings?*		

CHECK PRESENCE/ABSENCE

Check wetland areas that have been omitted and areas incorrectly identified as wetlands;

- Check for any NWM5.2 polygons that were mistakenly deleted by the new mapping, verify if they are wetlands and, if so, include into the new mapping.
- Delete polygons marked delete (Column NWM5.2_L4A) by the data capturers if you agree with them. Areas of deletion should be captured as points shapefile, so that in future iterations of the wetland map they are not to be captured again

- Use fine-scale wetlands data available for the District Municipality to check for any polygons that were missed by the new mapping, verify if they are wetlands and, if so, include into the new mapping.
- Use all available fine-scale wetlands data, specifically the artificial wetlands, a) to check if any new mapping inadvertently mapped a known dam as natural wetland and b) to verify mapped dams – allocate these as high confidence (Table 4).
- The NGI (certain years) data has been used to build the NWM 5.2 as documented on Van Deventer 2018. This geodatabase has been used as the base layer in the desktop mapping process. In the NGI data it seems some years are more accurate than the other for specific areas; therefore it can still be used in some reviews. Use NGI data set, specifically the perennial and non-perennial pans, a) to check if any known depressions were inadvertently deleted in the new mapping and b) to verify any corresponding mapped polygons to be depression HGM type – allocate these as high confidence to the x category of confidence.
- Make use of the available site-specific delineation of what? mapped by wetland specialists to a) align boundary of new mapping and b) adjust any corresponding mapped polygons to be the same HGM types as the Working for Wetlands (included in the NWM5.2) mapping – allocate these as high confidence of the x category of confidence.

Table F.5: Confidence ratings for Commission/omission and for attribute details

Confidence level	Description
High	Wetland delineation reviewed by at least one wetland specialist and either ground-truthed or verified using existing high confidence data sets.
Moderate	Mapping outputs reviewed by at least one wetland specialist.
Low	Mapping outputs not reviewed by an expert.

F3. List of References

Ollis, D.J., Snaddon, C.D., Job, N.M. & Mbona, N. (2013) Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

Van Deventer, H, 2016. CSIR; Principles or rules in capturing wetlands for the update of the National Freshwater Inventory and National Wetland Map 5 in preparation for the National Biodiversity Assessment for 2018.

Van Deventer, H. 2016. Creation of a National Freshwater Inventory and update of the National Wetland Map 5 in preparation for the National Biodiversity Assessment for 2018. CSIR: Pretoria, South Africa.

APPENDIX G: ARTIFICIAL WATER BODIES MAP FOR SOUTH AFRICA

Chapter Citation: Skowno, A. & Van Deventer, H. 2018. Appendix G: Artificial water bodies map for South Africa. South African Inventory of Inland Aquatic Ecosystems (SAIIAE): Technical Report. SANBI report.

Artificial water bodies map for South Africa

Draft: 1.0

Date: January 2018

Author(s): Andrew Skowno[1]

Contributor(s): Heidi van Deventer[2]

1. South African National Biodiversity Institute (SANBI), 2. Council for Scientific and Industrial Research (CSIR)

Purpose

A national scale map of artificial water bodies was built to compliment the national wetland map and national habitat modification layer developed as part of the National Biodiversity Assessment (NBA) 2018. The objective was to improve on the existing maps of artificial water bodies such as the artificial water bodies class in the national water features splits dataset (GEOTERRAIMAGE, 2016), using national 1:50 000 topographic map features and a range of remote sensing products.

Description

Artificial water bodies layer, including features such as dams, sewage works and reservoirs was built from wide range of data sources. The process of development included basic desktop validation of features over 25 ha in extent, and the identification of dams built after 1990, to facilitate the use of the data set in the land cover change analyses.

Key limitations

The accuracy of the underlying Chief Directorate: National Geospatial Information (CD:NGI) 1: 50 000 hydrological features data dictates the accuracy of this layer to a large degree. Although efforts have been made to eliminate "gross errors" (such as misclassified features), the large number of features makes a comprehensive, feature by feature, validation process impossible, and many classification and mapping errors are likely to be encountered in the dataset. The aim is to iteratively improve this dataset through the release of an updated version annually or biennially.

Data sets used

Input

- Hydrological features from the provincial geodatabases of 1:50 000 topographic data. (Chief Directorate: National Geospatial Information, 2016)
- Dam and reservoirs (1:50 000 scale dataset) (Department of Water and Sanitation, 2015a)
- National dams register – a spread sheet with details of all registered dams with build data and dimensions (Department of Water and Sanitation, 2015b)

Verification data

- Global surface water explorer (Pekel et al., 2016)
- South African Land Cover Water Feature Splits (1990 – 2013/14) (GEOTERRAIMAGE, 2016)
- Artificial features in the wetland data from NBA 2011 (Nel et al., 2012)

Technical specifications

Type & Projection: ESRI polygon feature class, file geodatabase

South African national projection: Albers Equal Area, WGS84, Central Meridian = 25˚E, Standard parallels = 24˚S & 33˚S

Scale / resolution: 1:50 000

Extent: South Africa

Methods

Summary:

As part of the development of NWM 5.2 a draft artificial water bodies data set was built using the Chief Directorate: National Geospatial Information (CD:NGI) hydrological features 2016. All non-natural feature types were included in this feature class and were checked for consistency and then integrated with the national 1:50 000 dams map (Department of Water and Sanitation, 2015). This formed the foundational layer for the development of the artificial water bodies dataset. Due to the large number of features in the dataset, we focussed on identifying and correcting “gross errors”; including large features that were incorrectly included in the artificial water bodies dataset, features that were incorrectly mapped or were features that were missing from the data set. The correction of errors continued throughout the development of the data set, using a wide range of data sources and personal communication with regional experts.

Foundational data

As part of the process of updating the National Wetland Map 5.2, the following topographical features, identified as being man made / artificial, in the CD:NGI 2016 hydrological features, were selected and exported to a new feature class: water treatment plant, sewage works, fish farms, reservoirs, dams. The DWS 1:50 000 dams data were added to the new feature class for artificial water bodies (all features and attributes were retained).

Error checking

a. Very large features in the foundational data set (the top 100 in terms of extent) were manually inspected, and a number of natural wetland / dry river channel areas in the Northern Cape were found to be incorrectly classified as dams. These features were removed.
b. Zonal statistics tables were then calculated for all artificial water bodies features using percentage water occurrence (Pekel et al., 2016) and percentage 1990 water and percentage 2014 water (GEOTERRAIMAGE, 2016). The premise was that if a feature had a low percentage of surface water occurrence it was likely to be a miss-classified wetland

rather than an artificial water body. All features with low water occurrence (less than 10%) and extent of over 25 ha were visually inspected - using 50 cm colour orthophotography (ARCGIS online, CD:NGI, circa 2013) and satellite imagery (SPOT5 and SPOT6 country mosaics in false colour circa 2006, 2009, 2016). In total of 350 individual artificial water body features were inspected and corrected where required. The artificial wetlands class from the national wetlands database used in the NBA 2011 (Nel and Driver, 2012) was then compared to the dataset (using the ARCGIS Erase command large NBA 2011 wetlands that did not overlap with the artificial wetland dataset were identified and inspected visually) and a number of large features (greater than 25 ha in extent) were added.

Adding dam build dates

The make the dataset useful in land cover change analyses the build date of the dam or facility was added where ever this could be determined. The main source of information for this was the DWS national dams register that includes information such as build date, latitude and longitude, dimensions etc. The dataset was converted to a point shapefile (event theme) using the latitude and longitude in the spread sheet (no indication of datum was provided so for older features there is a risk of a datum shift of up to 300m due to use of Cape datum in the original data set). The points were then linked to the artificial water bodies database using the Nearest command in ArcGIS. The dam extent from the DWS database was compared to the GIS extent and where these were different the dam was visually inspected and corrected where necessary. All dams with very low water occurrence percentages were inspected and corrected were necessary. To align with the habitat modification time series data, dams were assigned pre 1990 or post 1990 build dates based on the available information. Dams for which no build date was noted in the register were visually inspected, and using a combination of the global surface water data set, the national water features split data, and topographic maps dams likely to have been built post 1990 were identified. This process also exposed numerous errors in the dataset (spatial errors and classification errors) which were corrected as part of the process.

A simple vector geo-database resulted, with the attribute Type [dam, sewage works, fish farm, reservoir, water treatment] and BuildDate [pre 1990, and post 1990, unknown]. This polygon feature was re-projected to the Universal Transeverse Mercator (UTM) 35N coordinate system and converted to a 30m raster (snapped to the habitat modification raster) and then combined with the habitat modification map. Artificial water bodies of unknown build date were assumed to be built pre 1990, and were reclassified as such.

Final product

The final map contains just over 200 000 features, covering an area of 597 324 ha, with dams making up the bulk of the artificial water bodies in South Africa (Table G.1). The final list of attributes can be found in Table G.2.

Table G.1: Total extent and number of artificial water bodies and related features captured in the January 2018 version of the dataset

Type	Count	Total extent (Ha)
Dam	190 573	585 807.0
Reservoir	15 001	10 868.5
Fish farm	47	103.1
Purification plant	98	141.3
Sewerage works	293	404.2
Total	**206012**	**597 324.1**

Table G.2: Attribute fields contained in the artificial water bodies map

Field Name	Description	Values
Type	Type of artificial water body	Dam; Fish farm; Reservoir; Sewerage works, Purification plant
BuildDate	Date of construction	pre 1990; post 1990; unknown
UniqueID	unique identification number	Long integer
NGI0616_FT	Original feature type from the CD:NGI geodatabase	Large reservoir, Small reservoir, Reservoir; Closed reservoir; Water treatment; Water purification; Slime Dam; Dam; Tank; Fish Farm
NGI0616_NAME	Original feature name from CD:NGI geodatabase	
ALS_NOTE2	Notes by Andrew Skowno on feature additions and edits	
ShapeArea	Extent of feature	Square meters
ShapeLength	Perimeter of feature	

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APPENDIX H: COMPARISONS BETWEEN NWM5.4 AND MODELLED WETLAND DATA SETS TO REFERENCE WETLAND DATA SETS.

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H1. Assessment done by Wetland Consultancy Services Pty Ltd (WCS)

FREE STATE Comparison

Free State Fine Scale Mapping Sample (study area = 109831ha)			
	ha	% of land surface	% of actual wetland extent
Actual extent of wetlands	11 027	10.04%	100.00%
NWM 5_4 30112017	1425	1.30%	12.92%
VB probability data	13198	12.02%	119.69%

FREE STATE	Hectares of wetlands	% of actual wetland extent	% of VB probability data
Wetland mapped by VB probability data	6372	57.79%	48.28%
Wetlands not mapped by VB probability data	4655	42.21%	
Terrestrial areas mapped by VB probability data	6841		51.83%

FREE STATE	Hectares of wetlands	% of actual wetland extent	% of NWM 5_4
Wetland mapped by NWM 5_4	1202	10.90%	84.35%
Wetlands not mapped by NWM 5_4	9825	89.10%	
Terrestrial areas mapped by NWM 5_4	226		15.86%

- NWM 5.4 coverage very poor, capturing only 11% of actual wetland extent
- VB probability data overestimates wetland extent by 20%, however:
    - Spatial accuracy is poor as 52% of VB probability data maps areas not actually wetland
    - 42% of fine-scale wetland areas not mapped by VB probability data
- Both data sets flawed
    - NWM 5.4 a significant underestimate
    - VB probability data a slight overestimate but poor spatial accuracy
- VB probability data potentially the better option

MPUMALANGA 1 Comparison

Mpumalanga Fine Scale Mapping Sample (study area = 30 886ha)			
	ha	% of land surface	% of actual wetland extent
Actual extent of wetlands	7 663	24.81%	100.00%
NWM 5_4 30112017	2841	9.20%	37.07%
VB probability data	3007	9.74%	39.24%

MPUMALANGA 1	Hectares of wetlands	% of actual wetland extent	% of VB probability data
Wetland mapped by VB probability data	2013	26.27%	66.94%
Wetlands not mapped by VB probability data	5649	73.72%	
Terrestrial areas mapped by VB probability	995		33.09%

MPUMALANGA 1	Hectares of wetlands	% of actual wetland extent	% of NWM 5_4
Wetland mapped by NWM 5_4	2427	31.67%	85.43%
Wetlands not mapped by NWM 5_4	5234	68.30%	
Terrestrial areas mapped by NWM 5_4	415		14.61%

- Both NWM 5.4 and the VB probability data significantly underestimate actual wetland extent, capturing only 37-39% of actual wetland extent
    - Largely as a result of Seep wetlands not being captured
- NWM 5.4 captures more wetlands and has less commission errors than the VB probability data
- NWM5.4 more accurate for this area

MPUMALANGA 2 Comparison

Mpumalanga Fine Scale Mapping Sample (study area = 13763ha)			
	ha	% of land surface	% of actual wetland extent
Actual extent of wetlands	2 227	16.18%	100.00%
NWM 5_4 30112017	1838	13.35%	82.53%
VB probability data	1684	12.24%	75.62%

MPUMALANGA 2	Hectares of wetlands	% of actual wetland extent	% of VB probability data
Wetland mapped by VB probability data	1218	54.69%	72.33%
Wetlands not mapped by VB probability data	1009	45.31%	
Terrestrial areas mapped by VB probability data	466		27.67%

MPUMALANGA 2	Hectares of wetlands	% of actual wetland extent	% of NWM 5_4
Wetland mapped by NWM 5_4	1413	63.45%	76.88%
Wetlands not mapped by NWM 5_4	813	44.23%	
Terrestrial areas mapped by NWM 5_4	424		23.07%

- Differs from Mpumalanga 1 site by having clayey soils and therefore much lower extent of Seep wetlands
- Both NWM 5.4 and VB probability data therefore capture a much higher proportion of actual wetland extent (75 – 83%)
- Commission errors are 28% for the VB probability data and 23 % for NWM 5.4
- NWM5.4 more accurate for this area

H2. Comparison done by Freshwater Consultancy Group (FCG)

WESTERN CAPE Comparison

1. Saldanha-Sandveld

Western Cape Fine Scale Mapping Sample = Saldanha-Sandveld CAPE FSP mapping domain (study area = 2 592 191.5ha)			
	ha	% of land surface	% of FSP wetland extent
FSP extent of wetlands	51 320.6	2%	100%
NWM 5_4	n/a	n/a	n/a
VB probability data	136 906.4	5%	267%

NOTE: the NWM5.4 was not available for the Western Cape in order to do a comparison at the time of this summary.

NOTE 2: the FSP data does not include any artificial wetlands, whereas the VB probability data does. The comparison should probably rather be done after an erase of all artificial wetlands, in this instance.

Saldanha-Sandveld FSP mapping domain (Western Cape)	**Hectares of wetlands**	**% of FSP wetland**	**% of VB probability**
Wetland mapped by VB probability data	23 413.95 = overlap between CAPE FSP and VB prob	45.62%	17.10%
Wetlands not mapped by VB probability data	27 906.6 = CAPE FSP only	54.38%	n/a
Terrestrial areas (most likely) mapped by VB probability data	113 492.4 = VB prob only	n/a	82.90%

- VB probability data overestimates wetland extent (in comparison with fine-scale data) by 167%.
- The VB probability map has poor spatial accuracy in this area, with only 17.1% of the VB probability map coinciding with the fine-scale data, and roughly 82.9% of wetland area being potentially non-wetland.

- 54.4% of fine-scale wetland area is not mapped by VB probability data.
- The VB probability map is flawed in terms of wetland extent and spatial accuracy and should not be used for this particular area.

2. Cape Winelands District

Western Cape Fine Scale Mapping Sample = Cape Winelands District (study area = 2 147 567.15ha)			
	ha	% of land surface	% of FSP wetland extent
NWM5.4 extent of wetlands	105432.5	4.91%	100.00%
VB probability data	116464.02	5.42%	110.46%

NOTE: In this instance, artificial wetlands were included in the comparison.

Cape Winelands District (Western Cape)	**Hectares of wetlands**	**% of FSP wetland**	**% of VB probability**
Wetland mapped by VB probability data	43 467.02 = overlap between NWM5.4 and VB prob	41.23%	37.32%%
Wetlands not mapped by VB probability data	61 965.49 = NWM5.4 only	58.77%	n/a
Terrestrial areas (most likely) mapped by VB probability data	73 028.69 = VB prob only	n/a	62.70%

- VB probability data overestimates wetland extent (in comparison with the digitised NWM 5.4) by only 10.5%.
- However, the VB probability map has poor spatial accuracy in this area, with only 37.3% of the VB probability map coinciding with the digitised data, and roughly 62.7% of wetland area being potentially non-wetland.
- 58.8% of fine-scale wetland area is not mapped by VB probability data.
- The VB probability map is relatively accurate in terms of wetland extent, however spatial accuracy is flawed.
- The VB probability map should not be used for this particular area.