IMPROVING THE SPATIAL INLAND WETLAND DATA FOR NATIONAL WETLAND MAP 5 IN SOUTH AFRICA TO INFORM POLICY AND DECISION-MAKING

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IMPROVING THE SPATIAL INLAND WETLAND DATA FOR NATIONAL WETLAND MAP 5 IN SOUTH AFRICA TO INFORM POLICY AND DECISION-MAKING

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

Background and rationale

It is widely agreed that it is a high priority to achieve an accurate map of South Africa's wetlands. Such a map will provide a critical baseline into the future, where, over time, the extent to which different forms of land use impinge into wetland extents can be mapped, and inferences can be drawn in terms of wetland condition and functioning.

Compiling inventories of wetlands in order to collect information on their location, size, type, condition and other important features is fundamental to a strategic approach to the protection, rehabilitation and sustainable management of wetlands. Such inventories underpin the ability to develop policies, strategies and plans that are responsive and relevant to the problems identified and focus on matters of priority. A strategic framework can guide fine-scale local efforts so that they contribute effectively to wetland management and conservation objectives at regional, national and even international scales.

Inventories provide information needed to prioritise the most important wetlands systematically and allocate limited resources accordingly. The National Wetland Inventory (NWI), housed within the South African National Biodiversity Institute (SANBI), is the current repository of national spatial information regarding wetlands in South Africa. The NWI generates the National Wetland Map (NWM), which is the primary wetland layer used in national planning projects such as the National Freshwater Ecosystem Priority Areas (NFEPA) and the 2011 National Biodiversity Assessment (NBA). The NFEPA project created a wetlands layer that was adopted by SANBI as NWM4. Based on the available data at the time of preparation of NWM4, the 2011 NBA published by SANBI identified wetlands as the most threatened ecosystem type in South Africa, with 48% of wetland ecosystem types classified as critically endangered, 12% as endangered and 5% as vulnerable.

Much funding and specialist time has already been invested by the Water Research Commission (WRC), the Council for Scientific and Industrial Research (CSIR), the Department of Water and Sanitation, the Department of Environmental Affairs and SANBI in the collaboration that generated the Atlas of Freshwater Ecosystem Priority Areas in South Africa and its supporting technical and implementation manuals. The NFEPA project was a tremendous step forward in consolidating existing knowledge and generating new knowledge on the distribution, type and condition of freshwater ecosystems. However, experience in using the maps has shown that there still room for considerable improvement in both the wetland map (the mapping accuracy was low in extensive areas) and assessing the ecological condition of South Africa's wetlands (which was conducted at a very low resolution). For example, the wetland area mapped in WRC Project TT614/14, completed in 2015, that focused on the Mpumalanga Highveld coalfields showed a 75% improvement compared with the NFEPA wetlands layer, also referred to as NWM4. As a consequence of this mapping work, 23 wetland types had their threat status moved to less threatened classes for the Mpumalanga Highveld. Another recent study showed that fine-scale mapping increased the area of wetlands within the municipal boundaries of the City of Cape Town by almost 50% compared with NWM4.

Report TT614/14 concluded that sufficient data has been collected to indicate that the weaknesses in NWM4 are severe and widespread, which warrant investment to improve the quality of the NWM as a matter of urgency. It also reiterated the consensus view within the community of practice that the magnitude of the task of improving the quality of wetland inventory data for the country as a whole is beyond the ability of any single organisation. The report further recommended that additional research and development are needed to improve techniques to determine the wetland type and condition accurately at desktop level. Given that the resources available to conduct this much-needed work are limited and that a variety of different approaches can be applied to carry out this work, there is a great need for research to identify the most effective and practical means of carrying out the required mapping and assessment.

Objectives and aims

Designed within the context described above, this project set out to achieve the following aims:

- **Aim 1**: Assess the accuracy of the current NWM and improve the quality of spatial data on wetland extent.
- **Aim 2:** Investigate the impacts of scale and regional environmental patterns on predictor variables informing probabilistic models of wetland occurrence, type and condition.

Methodology

The current NWM4 has been compiled from several sources, including land cover data sets, satellite imagery and fine-scale wetland maps. While this map is a good start, it underrepresents the true extent of wetlands, especially seasonal, linear, narrow and/or vegetated wetlands. The limitations of remote sensing therefore require an extensive contribution of fine-scale mapping of wetlands across the country. Recognising that fine-scale maps exist only for a limited extent of South Africa, many data-poor areas will benefit from desktop digitising.

Desktop digitising from available imagery combined with field verification, which is under the supervision of regional wetland specialists, has substantially improved the accuracy of the national map. Fine-scale mapping and field verification are, however, an exhaustive task for a country as large as South Africa. It requires a phased approach starting with an initial prioritisation process. Generating an improved picture of the extent of wetlands in South Africa is only one component of this project. Fulfilling the objectives of NWI and the needs of many of the primary users of wetland inventory data requires that a range of attribute data be generated for each mapped wetland. The other components of this project focus on how to generate data on the type and condition of individual wetlands better.

In giving effect to the aims outlined in the previous section and operationalising the broad approach described above, the project proceeded according to the steps outlined below:

Aim 1: Accuracy assessment and improvement of quality of NWM

- Situation analysis

  To understand the availability, gaps and limitation regarding the existing wetland data, a survey based primarily on an electronic questionnaire and a workshop at the National Wetlands Indaba 2015 was compiled, which formed the basis of the situation assessment. The survey initially took place between October 2015 and December 2015 but was extended until end of February 2016. During the National Wetlands Indaba of 2015, the draft wetland data gathering questionnaire/survey form was discussed and improvements were made to improve its approach.

- Assemble and train teams for wetland mapping

  Once areas were prioritised, the core project team identified experts with knowledge of wetlands in these areas for inclusion in fine-scale mapping. Provision was made for regional wetland experts to be procured by SANBI in order to create decentralised teams with specialist knowledge of the areas they would be involved in mapping. Including such experts and other stakeholders in mapping at local scale is crucial. The experts calibrated the mapping approach to local conditions, undertook ground-truthing, trained and supervised junior professionals/ interns, and drew on their regional networks for relevant data and capacity.

- Undertake wetland mapping in priority areas where existing data is poor

  The project conducted its mapping and ground-truthing work using the methods and instruments developed through a WRC-funded project led by SANBI 2015; further developed into wetland mapping guidelines and a wetland digitising guideline prepared by Van Deventer. Various data sets were provided to the mapping team for guiding data capturing.

- Incorporate existing data sets into the NWM

  In parallel to the above steps, work proceeded on improving the NWM in those areas where existing fine-scale wetland data sets of good quality had been identified. In these areas, the work done focused on incorporating these data sets into the NWM thereby averting the need for immediate new mapping. The process involved collating the existing data, examining metadata for the merging of attributes, assigning confidence levels to the data based on source and scale of mapping, comparing the new polygons and attributes with NWM4, and replacing or merging the new data into the NWM.

- Produce version 5 of the NWM

  All the wetland data collected during the situation assessment period was integrated into a single national layer that contributes to version 5 of the NWM (NWM5). The minimum data to be included for each wetland polygon was the mapped wetland boundary and wetland type classification to Level 4A [hydro-geomorphic (HGM) unit] of the classification system for wetlands and other aquatic ecosystems of South Africa.

  Using procedures and standards developed as part of wetland mapping guidelines, data was collated and incorporated into the existing architecture of the NWI within SANBI together with the relevant metadata. The data will be curated by SANBI, as the home of the NWI, and existing links to the wetland vegetation database, developed by the University of the Free State with WRC funding, will be reinforced. As is the case with the current version 4 of the NWM, version 5 and any subsequent updates are freely available on the SANBI Biodiversity Geographic Information System (GIS) website in a variety of formats.

Aim 2: Improving predictive modelling of wetlands

Available fine-scale, wetland data for selected regions [Western Cape and KwaZulu-Natal (KZN) provinces] was used in the development of predictive models for wetland occurrence, HGM units, and ecological condition. For the wetland occurrence models, we developed multiple logistic regression models for the Western Cape study region. Wetland presence/absence data was used as the response variable against 17 predictor variables for climatic, hydrological and topographical parameters. Model output was converted to a probability surface for the Cape Winelands study area using model coefficients and relevant predictor raster images. Prediction accuracy for training and test data was assessed using receiver operating curves (ROC) and the area under ROC curves (AUC).

We used a Bayesian network model to calculate the most probable HGM type based on topographical variables. Stepwise multiple logistic regression models were also used to predict wetland ecological condition. This study expanded on research previously undertaken to predict the condition of HGM units (WRC K8/928), which determined the environmental factors that significantly predict the condition per wetland type at a quaternary catchment resolution for the KZN Province. Improvements to the previous study included a larger data set with outputs being a continuous probability surface rather than a probability value per quaternary catchment.

Results and discussion

Aim 1: Accuracy assessment and improvement of quality of NWM

Compared with the NWM4, the team noticed an increase in the extent (hectares) of inland wetlands that were mapped in some of the focus district municipalities during this exercise. The Ehlanzeni District Municipality showed an increase of nearly 13 000 ha in inland wetlands. Most inland wetlands were typed as channelled valley bottom within this focus area. In the Vhembe District Municipality, the extent increased by 15 000 ha with channelled valley bottom wetland being the dominant type. For the uMgungundlovu District Municipality, the wetland extent increased by 22 000 ha compared with NWM4. The commission error (areas previously incorrectly mapped as wetlands) was also reduced for all wetlands within the focus area. In the Frances Baard District, a reduction in the extent of wetlands was observed when NWM5 was compared with NWM4. Most inland wetlands were typed as depression within this focus area.

The NFEPA wetlands (NWM4) and the final NWM5 were compared to assess differences NWM5 mapped. An additional 1.3 million ha of inland wetlands was mapped, which had not been represented in the NFEPA wetlands. Nearly 700 000 ha of the inland wetlands mapped in the NFEPA wetlands, however, were not included in the NWM5 because they were considered to be terrestrial (commission errors).

Aim 2: Improving predictive modelling of wetlands

Wetland occurrence was modelled using data sets for the City of Cape Town and Drakenstein municipalities. A principal component analysis indicated little clear evidence to split data sets by HGM type for model development, and with good correlations between wetland occurrence and candidate predictor variables. The optimal model for predicting wetland extent was based on five of the 17 original variables (elevation, run-off, depth-to-groundwater level, slope, and mean annual precipitation). Model performance was good, with the AUC from the ROC curves being 0.67. Morphometric variables were useful in distinguishing HGM type with a subset of five (elevation, depth-to-groundwater level, relief ratio, slope, and shape) providing clear qualitative distinctions between HGM group. When median HGM type characteristics for morphometric variables that offered a degree of distinguishing power were plotted on a radar diagram, each HGM signature was unique. The relationship between the most easily mapped topographic variables was linked by probabilities in a Bayesian network. This model indicated that HGM type was most sensitive to elevation, and that prediction accuracy was good with an error rate of 32.5%.

Ecological condition models for valley bottom (channelled and unchannelled), floodplain and seep were all statistically significant ($p < 0.05$ for all coefficients, and $p < 0.001$ for most variables). Both seep and floodplain degradation probabilities were best predicted using elevation, with both HGM types more likely to be degraded at lower elevations. In both instances, elevation may be functioning as surrogate variables for other factors such as population density and catchment transformation. The condition of both valley bottom types required multivariate models, with only elevation and percentage plantation common to both. Channelled valley bottom wetlands had a more heterogeneous spatial degradation pattern than unchannelled valley bottom wetlands. The potential degradation surface for seeps and floodplains in the Cape Winelands District study area indicates highest probabilities of degradation in the Cape Peninsula region.

The logistic regression approach could be applied at a national scale using national data sets. While models for the three regions in South Africa currently completed (Eastern Cape, KZN and Cape Winelands District) showed regional differences in variable requirements, common variables suggest that a generic variable list could be adequate to model wetland occurrence at a national scale. Most critical of all the variables is elevation, since this was common to all models, and was also the basis for a number of digital elevation model (DEM)-derived variables. Further motivation for a generic approach to model wetland occurrence, type and condition at a national scale is that all three model suites developed in this study also shared a common core variable list (elevation and groundwater depth), or used DEM-derived variables. Elevation was a suitable surrogate for predicting condition of seep and floodplain wetlands. While prediction of valley bottom wetland condition required multiple landscape variables, percentage plantation was an important predictor of channelled valley bottom wetland condition in KZN, while percentage natural vegetation was important for predicting unchannelled valley bottom wetland condition.

Conclusion

This project has made a major contribution to the improvement of the NWM, a foundational data set of national strategic importance. The improved spatial data gathered as part of this project and feeding into the NWM will improve the NBA 2018, support better environmental decision-making, and improve conservation planning efforts. The implementation of the project included training, capacity-building and vital work experience for 13 young scientists and GIS technicians. As a result of the experience gained in this project, some technicians have embarked on further studies pertaining to wetlands. Despite the improvements to the wetland spatial data (in the focus areas in particular), it is clear that further work is required to increase the quality (i.e. confidence level) of the map. These future efforts should maintain the momentum of this project and focus the improvement of the NWM in areas of high development pressure, areas of strategic importance for catchment management, and in conservation priority areas.

The models predicting wetland occurrence and HGM type, developed as part of this project, performed well. The modelling process included the novel approach of using Bayesian networks to predict HGM type. The condition models are an improvement on the initial models developed for KZN as they are able to predict the probability of degradation of individual HGM type using a raster image, rather than a general probability per quaternary catchment. These models are now being used in conjunction with more traditional desktop mapping methods to improve wetland mapping and classification in independent studies, and future projects focused on the improvement of the NWM should adopt this combined approach of desktop mapping and modelling.

Recommendations for future research

There remains a great deal of scope to improve the NWM, both in terms of spatial accuracy and confidence, and in terms of HGM typing. To be feasible from a cost perspective and time perspective, these future efforts should be focused specifically on regions where high development pressure (human settlements, mining and agriculture) and/or in areas of strategic importance (e.g. Ramsar sites, critical biodiversity areas, and strategic water source areas). The sheer number and variety of wetlands scattered across South Africa make it obvious that any efforts going forward will need to be highly collaborative. But as this project has discovered, highly capacitated central coordination of mapping efforts and GIS data management is crucial to the iterative improvement of the NWM. Moving the confidence from medium to high levels generally requires infield verification, which is a mammoth task and one that will require a sector-wide collaborative effort. Again, central coordination and data management is crucial if any of these collaborations are to succeed.

The situation assessment results were useful for mapping the areas that are data-poor; but the process also illustrated that many ad hoc projects capture wetland data, and this data rarely gets absorbed into national data sets. An important step for improving the inclusion of local wetland mapping efforts into the national inventory would be to design/develop a protocol linked to environmental impact assessments, environmental management plans, strategic environmental assessments, bioregional plans and water use licence applications that extract and centrally collate wetland mapping and typing information. A map showing areas that have received fine-scale wetland mapping should be served and updated annually, and the data should be made easily accessible. Areas that need further attention should be identified and highlighted in the map to encourage participation.

Ongoing training and capacity-building is necessary for stakeholders to fully understand and become familiar with wetland delineation methodology, and appreciate the scope of the efforts still required. The project involved 13 junior data capturers who were trained for wetland mapping. This capacity built should be nourished in the sector going forward.

This project used a combination of desktop mapping and data contributions from other projects. Several lessons have been learnt in respect to training the team; review of data or quality control; etc. From these lessons, an emerging recommendation is to investigate the use of citizen science for mapping and monitoring of wetlands. To this end, wetland inventory implementation and practice would benefit from standardised methodology and procedures at a national and provincial scale. The recently published Guidelines for Mapping Wetland in South Africa (Job et al., 2018) represent a good start to these efforts.

From a more technical perspective, we recommend the following research and model refinement:

- Regeneration of the flow accumulation image with actual rainfall data included rather than the default 1 mm applied.
- Translation of the HGM type model to a spatial product and initial verification of this using Cape Winelands District wetland data, as wetland polygons have been accurately attributed by HGM type in this region.
- Generation of HGM degradation probability maps by district municipality, which can act as degradation hypotheses through systematic field assessments.
- Testing of the methods for fusing the desktop wetland mapping approach with a probabilistic modelling approach; develop workflows that use the models of wetland occurrence and HGM typing to streamline and direct desktop mapping efforts to improve efficiency and reduce costs.

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The Reference Group consisted of the following members:

- Mr Bonani Madikizela (WRC)
- Dr Wietsche Roets (Department of Water and Sanitation)
- Mr Ian Bredin (Institute of Natural Resources)
- Ms Nancy Job (South African National Biodiversity Institute)
- Mr Dean Ollis (Freshwater Consulting Group)

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GLOSSARY

Term	Definition
Bayesian network	A probabilistic graphical model representing system variables, states and their ecological conditional dependencies.
Ecological condition	A–F health score of a wetland HGM type, based on vegetation, hydrology and geomorphology (MacFarlane et al., 2009).
Degraded	A binary breakpoint of HGM types based on condition into degraded (PES of D–F) or non-degraded (PES of A–C) categories.
Hydro-geomorphic unit/ type	Functional wetland units based on hydrology and geomorphology; corresponds with Level IV classification of Ollis et al. (2013)
Morphometry	Quantitative indices describing the shape and form of a unit of analysis. Metrics include shape, relief ratio, fractal dimension, etc.
Principal component analysis	A statistical procedure that translates a number of (potentially correlated) variables into a smaller number of variables.

ABBREVIATIONS

Abbreviation	Full term
AUC	Area Under Curves
CoCT	City of Cape Town
CSIR	Council for Scientific and Industrial Research
DEM	Digital Elevation Model
DRDLR:NGI	Department of Rural Development and Land Reform: Directorate National Geo-spatial Information
DWS	Department of Water and Sanitation
FCG	Freshwater Consulting Group
GIS	Geographical Information System
HGM	Hydro-geomorphic Unit or Type
KZN	KwaZulu-Natal
NBA	National Biodiversity Assessment
NFEPA	National Freshwater Ecosystem Priority Areas
NWI	National Wetland Inventory
NWM	National Wetland Map
PCA	Principal Component Analysis
PES	Present Ecological State
ROC	Receiver Operating Curves
SAIIAE	South African Inventory of Inland Aquatic Ecosystems
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SPOT	Satellite Pour l'Observation de la Terre
SQ4	Subquaternary Catchment
T/F	True/ False
USA	United States of America
WCS	Wetland Consultancy Services (Pty) Ltd
WRC	Water Research Commission

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1 INTRODUCTION

1.1 Preamble

South Africa's first National Wetland Map (NWM) was derived from the National Land Cover 2000 geographic information system (GIS) layer (Van den Berg et al., 2008), in which wetland polygons were described as 'wetlands' or 'waterbodies'. The 'waterbody' category did not distinguish between natural or artificial waterbodies. To overcome this problem, National Wetlands Map 1 (NWM1) was combined with the 1:50 000 Department of Water Affairs farm dams layer to produce NWM2, which was divided into three GIS layers: *wetland*, *natural waterbody* and *artificial waterbody*. NWM3a was produced by combining NWM2 with inland water features from the 1:50 000 topographical map series (DLA:CDSM, 2006). Existing fine-scale regional wetland maps from other biodiversity planning initiatives[1] were added to produce the final NWM3b. The National Wetland Classification System (Ollis et al., 2013) was then applied to NWM3b to produce a national wetland type map. The wetland type map was generated by the Council for Scientific and Industrial Research (CSIR) for the National Freshwater Ecosystem Priority Areas (NFEPA) (Nel, Driver et al., 2011; Nel, Murray et al., 2011) and the National Biodiversity Assessment 2011 (Driver et al., 2011; Nel et al., 2011. Based on this state of knowledge of the extent, type and condition of our wetlands, the NBA 2011 identified wetlands as the most threatened ecosystem type in South Africa, with 48% of wetland ecosystem types classified as critically endangered, 12% as endangered and 5% as vulnerable (Nel & Driver 2012).

However, experience gained when using wetland data in the NFEPA wetland map (adopted by SANBI as NWM4) showed that there was considerable scope for improving the underlying data that under-represented wetlands by 30–50% in certain areas (Mbona et al., 2015; Van Deventer et al., 2016). This poses a risk in wetlands management and development, hence the urgent need to improve the inventory.

1.2 Overall Aims and Anticipated Outcomes of the Project

The ongoing improvement of South Africa's wetland map is a high priority. The information is crucial for NBA 2018 and for various conservation planning documents, such as NFEPA and national strategic water source areas. The information provided by this project and the NBA 2018 will improve the ability of a range of assessment, planning and decision-making processes to consider wetlands adequately. This includes improving NFEPA aspects before this strategic document is entirely reviewed in the near future. The anticipated output of the project is primarily to contribute to an improved NWM5.

This project set out to achieve the following aims:

1. Assess the accuracy of the current NWM4 and improve the quality of spatial data on wetland extent including the following steps:
   - In preparation for the third NBA (2018), the South African National Biodiversity Institute (SANBI) in collaboration with the CSIR conducted a rapid survey of available information on wetland ecosystem location, extent, type and condition that could strengthen the next version of NWM.
   - Inland wetland data sets were audited and compiled into a national layer.
   - A gap analysis and prioritisation of focus areas for mapping was undertaken.
   - Desktop mapping of focus areas was undertaken and NWM5 was prepared for use in NBA 2018.
2. Investigate the impacts of scale and regional environmental patterns on predictor variables informing probabilistic models of wetland occurrence, type and condition.

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[1] Ezemvelo KZN Wildlife, CAPE fine-scale plans, Kamieskroon, Niewoudtville, Overberg

1.3 Structure of the Report

An introduction to the study area, prominent issues, and the reasons for the project were given in Chapter 1.

Chapter 2 details the approach to data refinement undertaken by the project and covers the technical aspects of the methodology regarding the wetland data audit, desktop mapping, data review, and training. These methods accounted for the majority of the work and resulted in the project's primary output, namely, an improved spatial layer of wetlands for the district municipalities mapped.

During the implementation of the project, significant training and capacity-building were provided. Details of this training are given in Chapter 3.

Chapter 4 describes how once the desktop mapping had been collated, the data was reviewed by specialists and later integrated into NWM5.

2 Background

While ancillary data on the extent, type and ecological condition are increasingly recognised as important for regional wetland assessment studies, methods and studies regarding approaches to generate this information are limited worldwide. For example, Guidugli-Cook et al. (2017) pointed out that there are few studies in the United States of America (USA) that have assessed the ecological condition and extent of inland wetlands.

A situation assessment was used to determine areas where desktop mapping should focus. This included a survey emailed to relevant stakeholders over the course of more than a year (2016–2017). A wide range of wetland data sets were received for use in NWM5 and have been compiled as an inventory list in Appendix E of the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) report (Van Deventer, Smith-Adao, Petersen et al., 2018). Areas were selected for desktop mapping from the map of received data sets. These focus areas were selected due to a combination of being data-poor areas but having resources for mapping available.

A team of trained data capturers conducted desktop mapping for nine municipalities. The data capturers were trained in several capacity development initiatives detailed in Chapter 3. The data was reviewed by a team of wetland specialists from the Freshwater Consulting Group (FCG) and Wetland Consulting Services (WCS). The resulting data was passed to the CSIR (leading the inland aquatics component of the NBA 2018) to integrate into the NWM5 (Van Deventer, Smith-Adao, Mbona et al., 2018).

In 2016/2017, SANBI, in collaboration with the CSIR, undertook a data situation assessment study of the wetland data available that could be used to improve the NWM. A survey was sent to a distribution list with a membership of over a 1000 people; however, there was a low response rate with only 23 responses received. The need for these spatial data sets of inland wetlands is important because of discrepancies between NWMs and field assessments. In the USA, Guidugli-Cook et al. (2017) noted large discrepancies between the National Wetland Inventory (NWI)-mapped wetlands and field assessments of wetlands. They also reported that the United States NWI could be improved by using wetland mapping accuracy assessment, including prediction of wetland ecological condition (Finlayson & Spiers, 1999). Given the considerable data gaps for area of wetland classes, even the most recent other estimates of global wetland extent are likely to be underestimated (Davidson & Finlayson, 2018).

Fundamental to setting conservation targets for landscape features such as wetlands and prioritising wetland systems for rehabilitation, is a sound spatial layer of wetland occurrence (location and extent) that includes information on wetland hydro-geomorphic (HGM) type and ecological condition. This requires a complementary process of baseline wetland mapping and probabilistic model development. Wetland mapping provides a testing and verification data set for model development, while probabilistic model development provides an ancillary data layer for regional prediction of wetland occurrence and ecological condition.

From the results of the survey, not all available data sets had an HGM type. For the purpose of ecosystem assessment, HGM type represents wetland ecosystem types. Obtaining fine-scale HGM type would be time-consuming; therefore, alternative methods to model and predict the extent and HGM type would enhance wetland maps.

In South Africa, regional studies using climatic, topographic and hydrological variables to estimate the probability of wetlands occurring showed encouraging results. Good prediction accuracy for both occurrence and extent was achieved in both a subtropical to temperate region, namely, KwaZulu-Natal (KZN) (Hiestermann & Rivers-Moore, 2015) as well as a semi-arid region (Melly et al., 2016). Here, results indicated that a multiple logistic regression model could be applied successfully across rainfall and topographic gradients and for a range of wetland sizes. However, when the studies were compared, it was clear that while some predictor variables were common to both regions, the application of this approach at a national scale would first require developing regional models because each model also incorporated region-specific variables. Model accuracy also differed between Level 4A HGM unit types, which highlighted the need for a more accurate wetland HGM classification.

Prioritising wetlands for conservation and/or rehabilitation action is achieved more efficiently when not only the occurrence and HGM units are identified, but when the ecological condition is also known. Again, the use of multiple logistic regression models to predict condition at a regional scale using landscape-scale predictors (land use, proximity to major roads, elevation) has already shown promise (Rivers-Moore & Cowden, 2012). Such an approach could be expanded by developing regional models of ecological condition based on HGM unit.

3 METHODOLOGY

3.1 Aim 1: Methods for Accuracy Assessment and Improving Quality of Current NWM4

3.1.1 Situation assessment

To understand the availability, gaps and limitation regarding existing wetland data, a survey based primarily on an electronic questionnaire and a workshop at the National Wetlands Indaba 2015 was compiled, which formed the basis of the situation assessment. The survey initially took place between October 2015 and December 2015 but was extended until end of February 2016. During the National Wetlands Indaba of 2015, the draft wetland data-gathering questionnaire/survey form was discussed and enhancements were integrated to improve its approach.

The questionnaire was circulated electronically and asked for the following information (Appendix A):

- Satellite imagery, resolution and year used to map existing wetlands.
- Whether the capture method used digitising or modelling scale.
- Data capture experience (i.e. specialist, field and skill).
- Approach to determine existing wetland integrity (desktop or field-truthing).
- Data accuracy assessment, limitation and gaps.
- Existing wetland digitising approach (wetland typing or system).
- Wetland assessment and reporting approach.
- Wetland associated flora and fauna species identified and ecosystem functionality.

The questionnaire was emailed to several mailing lists. The survey was available and could be submitted online through Google Forms. After receiving the survey responses, the information was divided into two portions. SANBI followed up on one half and the CSIR the other half (Van Deventer, Smith-Adao, Mbona et al., 2018; Van Deventer, Smith-Adao, Petersen et al., 2018).

3.1.2 Training and capacity-building approach and design

The mapping teams in Cape Town and Pretoria held several training workshops between August 2016 and May 2017, which covered a range of topics and were led by a range of mentors /wetland specialists.

The country was divided into three mapping regions:

- Winter rainfall.
- Summer rainfall arid.
- Summer rainfall mesic.

The first main training session was held in Cape Town for all data capturers in August 2016. Two other training sessions were held in January–February 2017 for team members in each area (Table 1) for the winter rainfall area and the summer rainfall are. The training sessions were followed by fieldwork in both areas.

Other training of interns and staff was undertaken on an ad hoc informal basis using phone calls, meetings and emails. The CSIR created a Google Group platform, which was used to secure technical advice and functioned as a discussion forum to share methods and ideas. The group comprised several wetland specialists, wetland mapping interns, project team, and the freshwater reference committee for the NBA 2018.

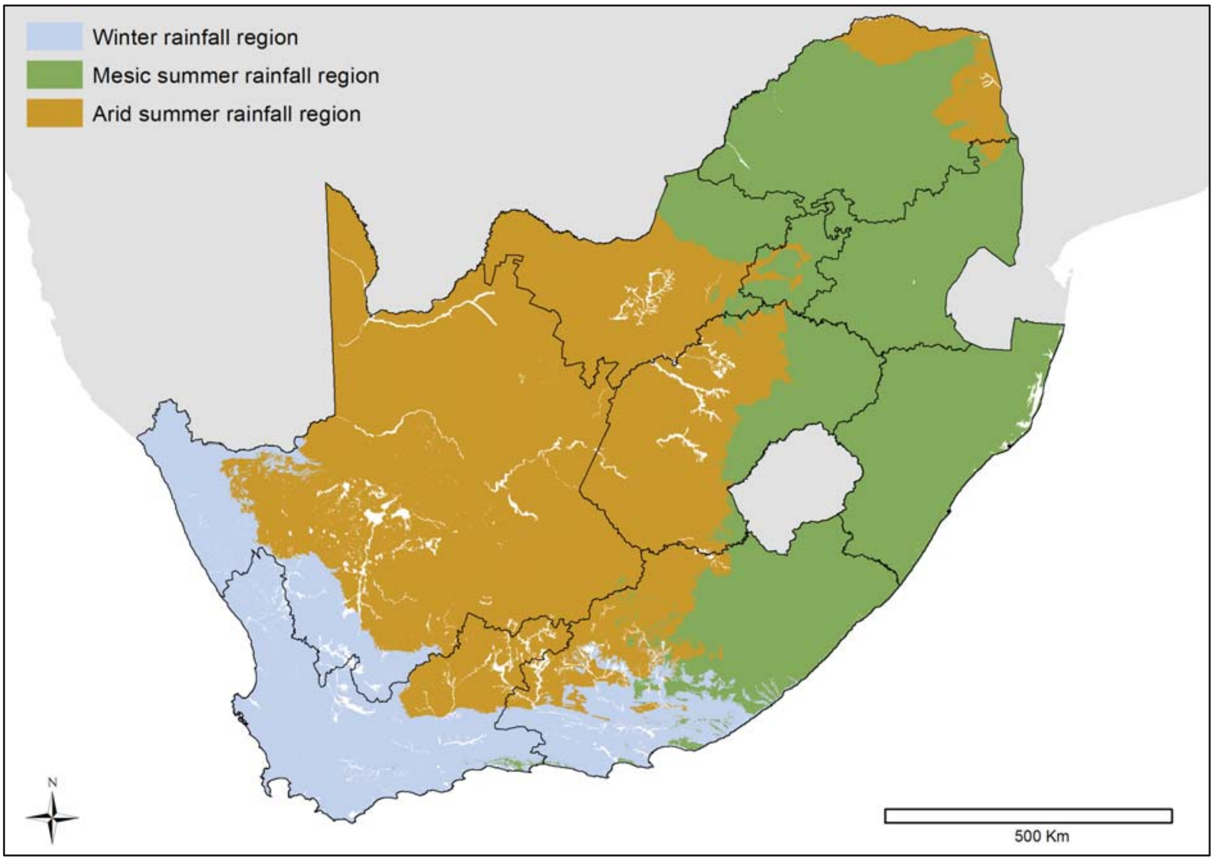

Figure 1: The three mapping regions

Table 1: List of training conducted for the data capturing team

Date	Location	No. of attendees	Mentors/tutors	Training topics
16–20 Aug 2016	Kirstenbosch Botanical Garden, Cape Town	12	Namhla Mbona Heather Terrapon Anisha Dayaram Kate Snaddon	Wetland identification and delineation; wetland classification system; geodatabase and polygon editing tools.
2–4 Feb 2017	CSIR, Stellenbosch	7	Kate Snaddon Dean Ollis Tumisho Ngobela	Mapping different HGM types; fieldwork.
18 Jan 2017	WCS office, Pretoria	7	Dieter Kassier	Identification of seeps on imagery; wetland typing.
22–26 May 2017	CSIR, Pretoria	7	Heidi van Deventer	Geodatabases; topology; statistics and pivot tables; coordinate systems.

3.1.3 Desktop mapping and verification methods

A document was prepared for the purpose of creating the first SAIIAE, as well as updating the NWM to version 5 (NWM5) in preparation for the NBA for 2018 (Van Deventer, 2016). Following the training workshop, data capturers began to capture wetlands in the focus areas allocated to them using the guidelines documented in Van Deventer (2016). Several data sets were provided to guide data capturing. The guidelines for mapping wetlands in South Africa, which was in draft format at the time of the update, was also provided (Job et al., 2018).

For this mapping, the intent was to use the most recent images that had national coverage. The 50 cm colour orthophotography through the ArcGIS online viewer from the Department of Rural Development and Land Reform: Directorate National Geo-spatial Information (DRDLR:NGI) was freely available for the update and dated back to between 2012 and 2013. SPOT[2] imagery was also used in some instances, which also dated back to between 2012 and 2013. Unfortunately, these images were largely taken during the dry season (possibly to avoid cloud cover) and were therefore less suitable for mapping wetlands.

The duration of data capturing took approximately three to four months per focus area, which was 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. Nine district municipalities were selected within the country as focus areas based on the availability of resources and the situation assessment results. These included the municipalities listed in Table 2.

Table 2: List of district municipalities selected as focus areas for this project

Priority district	Size of focus area (ha)
Eastern Cape – Amathole	2 111 716.4
Eastern Cape – Buffalo City	275 028.1
Free State – Lejweleputswa	3 228 698.2
KZN – uMgungundlovu	960 227.6
Limpopo – Vhembe	2 559 639.1
Mpumalanga – Ehlanzeni	2 789 557.3
Northern Cape – Frances Baard	1 283 566.3
Western Cape – Eden	2 333 107.3
Western Cape – Cape Winelands	2 147 328.1

Updated mapping was undertaken for the targeted district municipalities and the data was forwarded to the consulting wetland specialists (FCG and WCS) for review. The wetland data sets were reviewed by SANBI according to the criteria listed in Table 25 of “Review protocol of desktop mapped wetland data” (Appendix B). Following the initial review, the data sets were passed to the wetland specialist appointed for the area to be reviewed further according to the same criteria listed in Appendix B with additions of any other comments. During the review process, the wetland specialists added some more wetlands to the maps and also corrected the wetland typing as assigned by junior data capturers when required. The specialists sent additional comments to the team, which were addressed by the data capturers.

[2] Satellite Pour l'Observation de la Terre

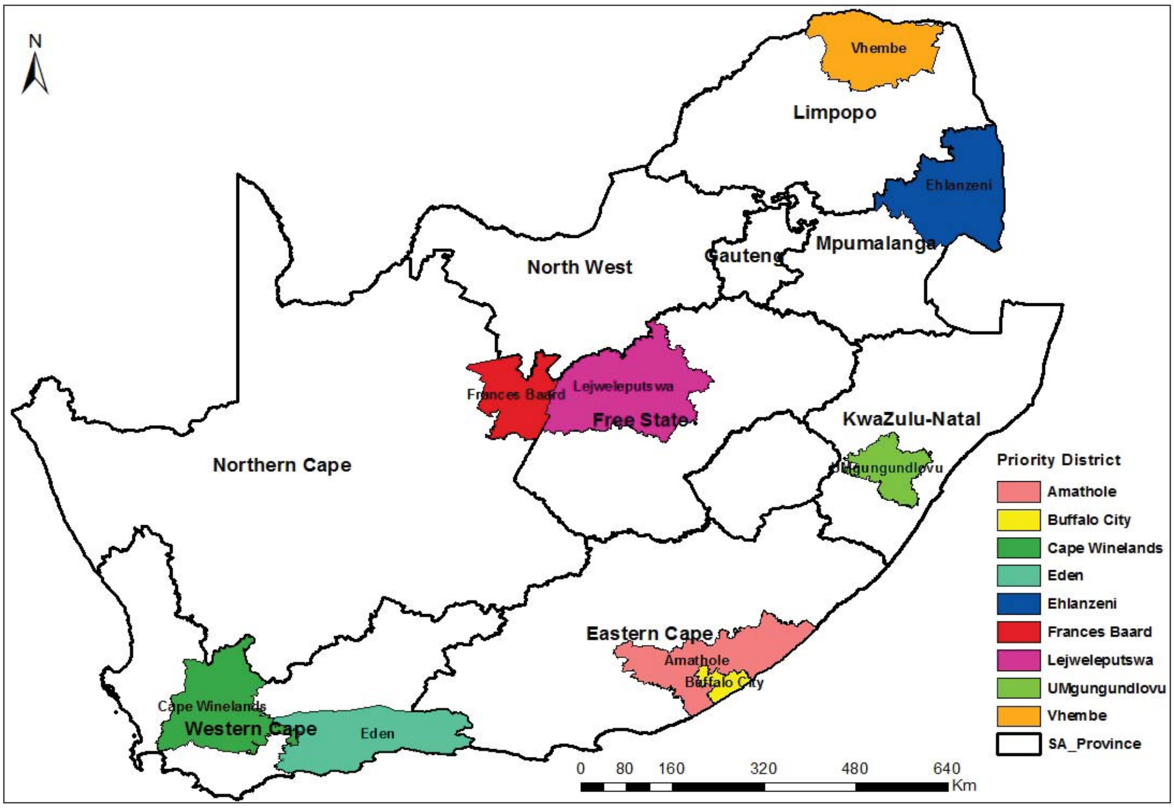

Figure 2: Map of district municipalities selected as focus area

3.1.4 Review protocol for the focus districts

WCS and FCG were appointed by SANBI to provide wetlands specialist support for the update of the NWM for areas of desktop mapping. A review protocol of desktop mapped wetland data was compiled for the purpose of reviewing desktop mapping of wetland data sets. The wetland data sets were firstly reviewed at SANBI according to the criteria listed in Table 25 of Appendix B. All topology-related errors were attended to before passing the data to wetland specialists. Thereafter, a selected subset was passed on to several volunteer wetland specialists or provincial ecologists for review according to the same criteria listed in protocol with additions of any other comments.

A rapid desktop review of the wetland mapping was undertaken by overlaying the data sets on suitable aerial imagery (typically Google Earth imagery) and assessing the wetland data sets in terms of presence/absence accuracy and spatial accuracy. This was done via visual inspections by wetland specialists and was based to a large degree on expert opinion; typically this exercise involved panning across the delineated wetland boundaries and observing for errors in terms of the following:

- Wetland areas that have been omitted.
- Areas incorrectly identified as wetlands.
- Overestimation of wetland extent.
- Underestimation of wetland extent.

For each focus area data set, a point shapefile with review comments was produced and returned to SANBI. Comments related to typing errors, overestimation/underestimation of wetland extent and omission errors. Some of the issues were:

- As part of the review process, wetland polygons that had not been typed at Level 4A of the Classification System (Ollis et al., 2013) were typed where possible by the reviewers, or otherwise addressed through the comments provided as a point shapefile.

- Where large and/or important wetland systems were found to have been omitted from the district municipality data sets, as many of these wetlands as possible were mapped. However, with limited time, this was the exception.
- Seep wetlands in the Ehlanzeni District Municipality had generally been covered poorly in the various iterations of the NWM, which was largely due to difficulty (for unexperienced eyes) in identifying and delineating the more seasonal and temporary seep wetlands. For large parts of the country, seep wetlands comprise only a small percentage of the overall wetland area, and omitting seep wetlands might not result in significant errors. However, in the Mesic Highveld Grassland Bioregion, seep wetlands are often the most extensive wetland type, and omitting these wetlands could result in missing as much as 70% of the wetland area. In a comparison with fine-scale data across a 31 000 ha region near eMalahleni (Witbank), it was found that the NWM4 missed 68% of wetland area, the bulk of which were seep wetlands. This applied specifically to the grasslands of the Mpumalanga Province, the eastern part of the Free State Province, Gauteng Province and northern parts of the KZN.

A total of 849 points were received from the reviewers and addressed across all focus areas by the data capturers. The FCG amended the Cape Winelands District at desktop level and therefore no points were received to correct.

3.1.5 Integrating spatial data from focus areas and a wide range of other sources into the updated NWM

No data capturing was undertaken in the remainder of the provinces, except for a selected number of floodplains, the eight limnetic depressions, and wetlands within Ramsar sites (Van Deventer, Smith-Adao, Mbona et al., 2018). Some assistants who were mapping wetlands in the focus areas continued with integrating wetlands in the remainder of the provinces.

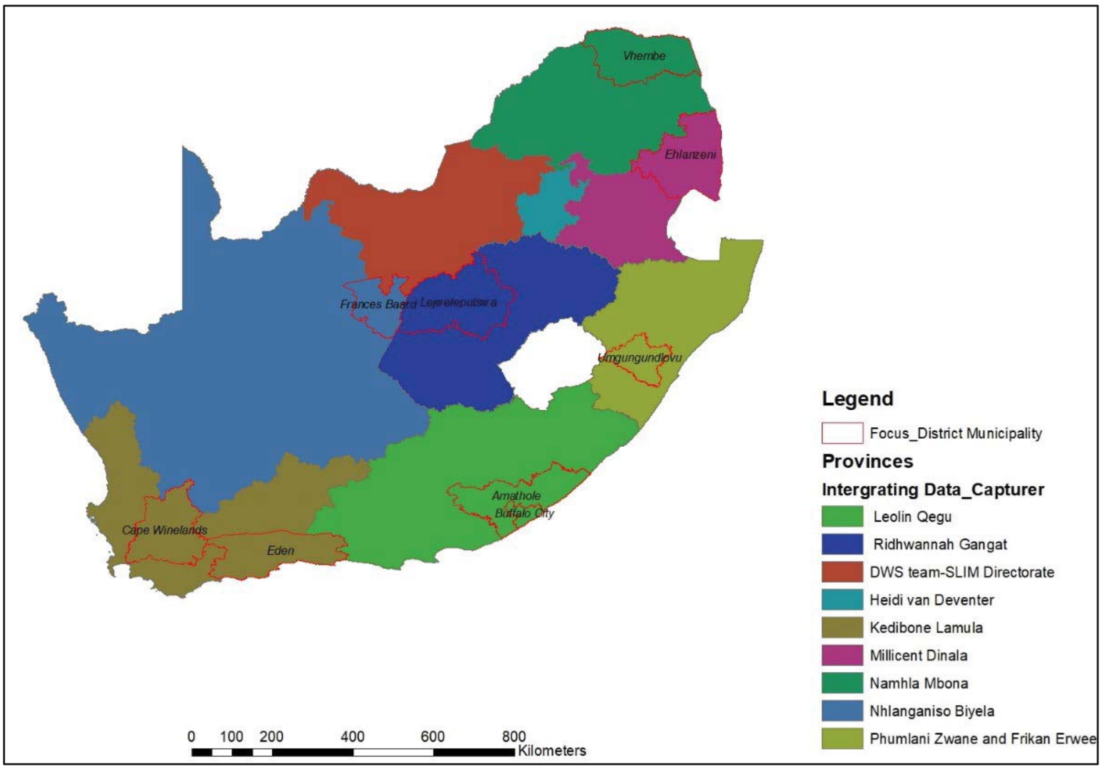

Figure 3: A map outlining the integration responsibilities

For each province, data sets received from different stakeholders during the wetland data situation assessment were integrated (period 1 April 2017 to 16 March 2018). The focus area wetland data set was also integrated after incorporating feedback from wetland specialists.

3.2 Aim 2: Methods for Improving Predictive Modelling of Wetlands

3.2.1 Study areas

We identified study regions that covered the winter, all-year and mid-summer rainfall regions for South Africa (Figure 4). The availability and usefulness of wetland occurrence, HGM type and ecological condition data was assessed for the following areas based on discussions with relevant wetland practitioners:

- Drakenstein Local Municipality based on discussions with Mr Dean Ollis – wetlands have been thoroughly mapped and classified by HGM type for this area.
- City of Cape Town (CoCT) Metropolitan Municipality based on discussions with Dr Liz Day – wetlands have been thoroughly mapped and classified by HGM type for this area. A shapefile containing in excess of 7500 wetland HGM type has been downloaded from the CoCT data portal. The ecological condition for each HGM type is available for 107 or 1.42% of the polygons, making this data set impractical to use for modelling the ecological condition per HGM type. This data has potential for verifying ecological condition models.
- Breede Valley Local Municipality has a good data set of wetlands by HGM type based on field assessment by Dr Donovan Kotze.
- HGM ecological condition data for the KZN Province – this remains the most comprehensive known data set of wetland condition based on HGM type with > 400 data points distributed across the province.

While falling in the same rainfall region, the three Western Cape municipality study areas represented excellent wetland data sets that covered a rainfall gradient from relatively wetter in the west to relatively drier in the east. The full spectrum of HGM types across a range of altitudes was represented. Table 3 shows the allocation of data per study region for model testing and development, and model verification for occurrence, type and ecological condition models.

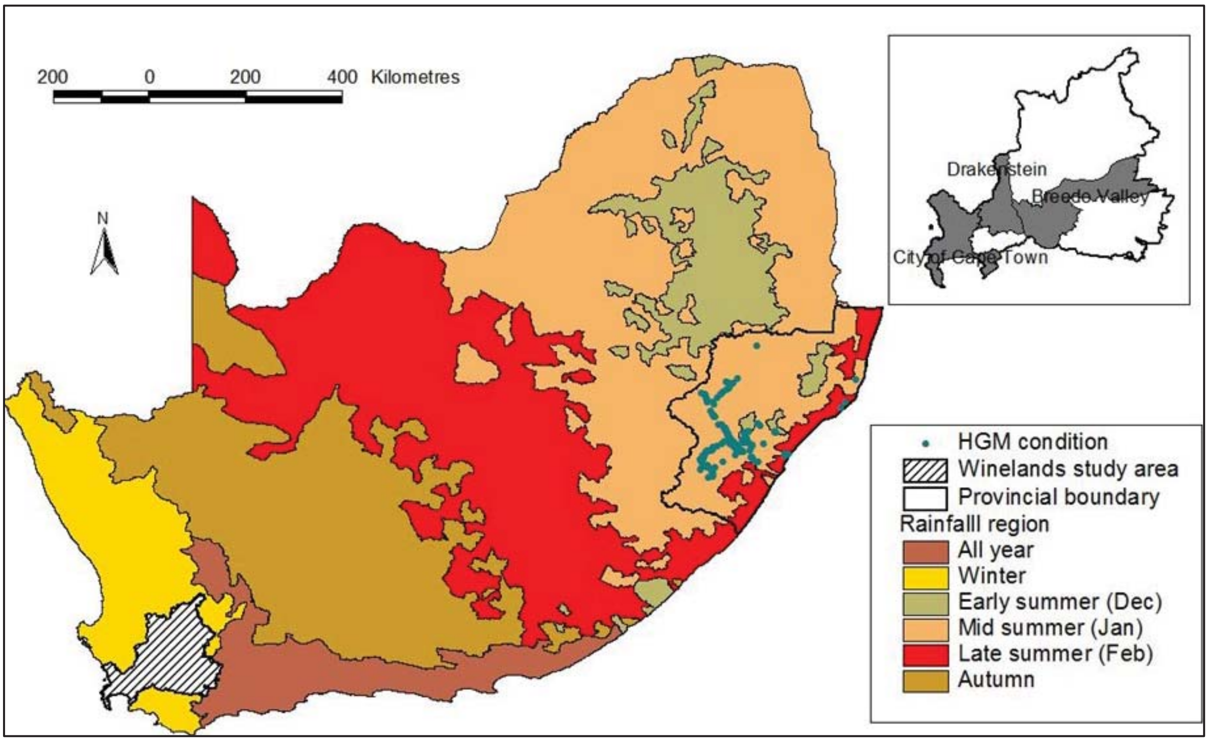

Figure 4: Location of local municipalities for testing and verification of probability models of occurrence, type and condition for wetland HGM types. The occurrence and type study modelling area consists of the CoCT and Cape Winelands district municipalities (Winelands study area)

Table 3: Study regions for testing and verification of probability models of occurrence, type and condition for wetland HGM types

	Occurrence		HGM unit		Condition	
	Test	**Verification**	**Test**	**Verification**	**Test**	**Verification**
Breede		✓				
Drakenstein	✓	✓	✓	✓		
Cape Town	✓	✓	✓	✓		✓
KZN					✓	

3.2.2 Data sets

Candidate data sets were identified for consideration in the modelling process as shown in Table 4. These data sets included both raster images and vector shapefiles. Their appropriateness for use in modelling wetland type, occurrence and condition is indicated against each variable.

Table 4: Variable list, data source, availability and relevance for modelling wetland HGM occurrence, type and condition

*** denotes optimal model terms for earlier studies (Hiestermann and Rivers-Moore 2015; Melley et al. 2016).**

Variable	Source	Occurrence	Type	Ecological condition
Altitude	30 + 90 m digital elevation model (DEM) (USGS, 2018)	X*		X
Annual heat units	Schulze (1997)	X		
Aspect	DEM-derived	X		
Basin length	DEM-derived			X
Compactness	Wetlands shapefiles		X	X
Dams	1:50 000 provincial maps			X
Drainage density	Catchments and 1:500 000 rivers coverage			X
Drainage shape	SQ4 catchments			X
Edge-area ratio	Wetlands shapefiles		X	X
Evaporation	Agrohydrological Atlas	X		
Flow accumulation	DEM-derived	X*		
Flow direction	DEM-derived	X*		
Groundwater	Colvin et al. (2007)	X*		
HGM type area	Calculated from wetland coverages		X	X
Hydromorphic soil		X		
Landform/terrain units	Schulze (1997)	X*	X	X
Land use	SANBI Biodiversity GIS portal			X
Local rainfall		X*		

Variable	Source	Occurrence	Type	Ecological condition
Longitudinal geomorphic zone	Department of Water and Sanitation (DWS) zones		X	
Annual evapotranspiration	Schulze (1997)	X*		
Mean annual precipitation	Schulze (1997)	X*		
Mean annual temperature	Schulze (1997)	X*		
Population density	Census data (Statistics SA, 2001)			X
Rail-1000	1:50 000 DRDLR:NGI issued in 2016			X
Rainfall intensity	Schulze (1997)			X
Relief ratio	DEM-derived		X	X
Road density	1:50 000 roads-derived			X
Road-1000	1:50 000 provincial maps			X
Slope	DEM-derived	X*	X	X
Soil depth	Schulze (1997)	X*		
Soil moisture	Schulze (1997)	X		
Solar radiation	Schulze (1997)	X*		
Stream order	DWS layers to quinaries			X
Summer heat units	Schulze (1997)	X		
Winter heat units	Schulze (1997)	X		

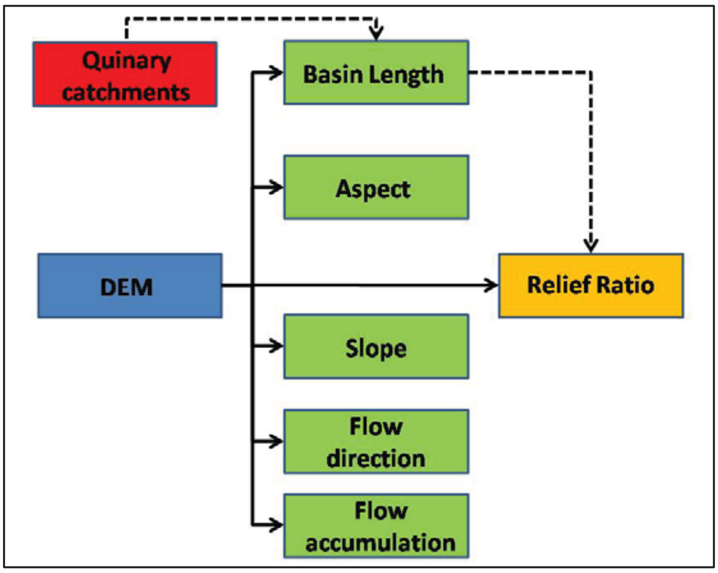

Figure 5: Topographical variables derived from a DEM base layer

3.2.3 Occurrence of wetlands

Data sets used were the wetlands coverage for the CoCT metropolitan municipality (n = 7272 polygons) and the Drakenstein Local Municipality (n = 4237 polygons). Data was described using box-and-whisker plots, bar charts and pie charts, which were used to describe the number of area of HGM type per data set. Next, data was screened for differences between regions using morphological metrics (shape, area, fractal dimension, perimeter:area ratio) using a principal component analysis (PCA) (McCune & Mefford, 2011). The purpose of this analysis was to provide an objective basis for either combining data sets or keeping them separate. HGM types were standardised in the CoCT and Drakenstein data sets to floodplain, seep (hillslope and valley head seep), depression (depression, isolated and depression-linked channel), channelled, and unchannelled valley bottom. Only inland wetlands were considered and estuarine ecosystems were excluded from analyses.

Thereafter, a point coverage was derived of wetland presence and absence. Here, we assumed that the study region had been mapped extensively and that points outside of wetland polygons were highly likely to indicate wetland absence. A point coverage of wetland centroids was derived, which was intersected with a point coverage generated using the "random" routine in Idrisi (Clark Labs, 2009). A presence/absence point coverage (n = 14 000; 7000 presence and 7000 absence points) was randomly split into a model training and model testing data set using the Random function in Excel™ (=RND()).

The point coverage was converted to a 90 m resolution (= void-filled 3 arcminute) raster image (USGS, 2018). We assessed the 30 m/1 arcminute DEM, but found that missing data was too extensive in certain image tiles to fill. Using a combination of the Crosstab and Extract functions, values for each variable for each sample point were generated, and then collated into a single spreadsheet. An initial screening of the maximal variables was undertaken using PCA (McCune & Mefford, 2011; Table 5). Subsequently, a multiple logistic regression model was derived using a stepwise regression in the statistical software R using the training data set (R Development Core Team, 2009). The model output was converted to a probability surface for the Cape Winelands study area using model coefficients and relevant raster images in Idrisi's image calculator. Model coefficients were included in a logistic regression model of the format of Equation [1]. Receiver operating curves (ROC) and the area under ROC curves (AUC) were used to compare prediction accuracy for training and test data using suitable software (Medcalc Software, 2013).

$$p(y) = \frac{exp^{\alpha+\beta x}}{1+exp^{\alpha+\beta x}} \quad [1]$$

Table 5: Maximal variable list for wetland occurrence model

Variable	Explanation	Data source
Apan	Annual A-pan evaporation	Schulze (1997)
Aspect	Aspect in degrees	DEM-derived
Elevation	Elevation	USGS (2018)
Flow	Flow direction	DEM-derived
Groundwater	Groundwater depth	Colvin et al. (2007)
Heat Units (annual)	Annual heat units	Schulze (1997)
Heat Units (summer)	Summer heat units	Schulze (1997)
Heat Units (winter)	Winter heat units	Schulze (1997)
MAP	Mean annual precipitation	Schulze (1997)
Rainfall conc.	Rainfall concentration	Schulze (1997)
Run-off	Flow accumulation	DEM-derived
Slope	Slope in degrees	DEM-derived
Soil depth	A-horizon soil depth	Schulze (1997)
Soil PAW	Soil potential available water	Schulze (1997)

Variable	Explanation	Data source
Solar radiation	Mean annual solar radiation	Schulze (1997)
Terrain	Terrain units (broad)	Schulze (1997)
Tmean13c	Mean annual air temperature	Schulze (1997)

3.2.4 HGM types of wetland

Polygons for Level 4A HGM units for the Cape Winelands study area (n = 11 379) were attributed in terms of the following traits:

- Elevation.
- Aspect (degrees).
- Log (area) (m^2).
- Fractal dimension.
- Slope (degrees).
- Groundwater depth (metres below ground).
- Log (perimeter).
- Relief ratio.
- Shape (area: perimeter ratio).

Box-and-whisker plots were used to describe HGM units by morphometric variables and to select variables that were useful in categorising HGM units. These were also assessed using a PCA. Next, HGM types were qualitatively categorised in terms of metric traits (high, medium and low) for seven metrics, including elevation, zone, Strahler stream order, shape, relief ratio, groundwater depth, slope (Colvin et al., 2007; Frimpong et al., 2005; Gordon, McMahon & Finlayson, 1992; Horton, 1932, 1945; Schumm, 1956), with HGM signatures illustrated using a radar plot. Aspect was considered independently by calculating the frequency of HGM units for 90° aspect arcs (north = 315°–45°, etc.), plotted in a radar plot.

Based on the optimal list of variables (slope, groundwater, elevation, relief ratio), a Bayesian network model was developed based on four causal nodes, using Netica (Norsys Software Corporation, 2010). Node states and thresholds are provided in Table 6.

Continuous data was reassigned to node states using logical if/then statements within a spreadsheet. Each data record constituted a case instance. Data was split into training and test data using the same approach as for the occurrence but with a 75%/25% split (train n = 8533; test n = 2846). Once the Bayesian network had been constructed, conditional probabilities were calculated using the case file. Model sensitivity to findings relative to the HGM node was evaluated, and verification was undertaken by testing cases against an independent case file.

Table 6: Node states and thresholds

Node	State	Threshold
Elevation	Low/Medium/High	Low < 200 > Medium < 500 > High
Slope	Flat/Steep	Flat < 5 > Steep
Relief ratio	Low/High	Low < 0.25 > High
Groundwater depth	Shallow/Deep	Shallow < 8 > Deep

3.2.5 Ecological Condition of wetlands (update numbers)

Wetland data previously split into training and testing data sets in Rivers-Moore and Cowden (2012); were combined(n = 459). Land cover classes for the KZN Province were reclassified according to the categories in Table 7. The maximal variable set from Rivers-Moore and Cowden (2012) was used, with data recalculated for quinary catchments (Table 8). Variables additional to the previous models were rainfall concentration and groundwater depth. Data was recalculated where relevant for quinary rather than quaternary catchments. Rather than calculating probabilities per quaternary catchment, probability surfaces were generated using the raster calculator in Idrisi. Models were then applied to the Winelands study area for seep and floodplain HGM types. Model verification was not possible at this stage beyond comparing floodplain degradation probabilities to existing present ecological status (PES) scores.

Table 7: Land cover classes for the Ezemvelo KZN Wildlife 90 m resolution land cover data set, and their reclassification into HGM units or types for the ecological condition models of wetlands

Code	Land cover	Model class
1	Water natural	N/A
2	Plantation	Forestry
3	Plantation clear-felled	Forestry
4	Wetlands	N/A
5	Wetlands-mangrove	N/A
6	Permanent orchards (banana, citrus)	N/A
7	Permanent orchards (cashew) dryland	N/A
8	Permanent pineapples dryland	N/A
9	Sugarcane – commercial	Sugarcane
10	Sugarcane – emerging farmer	Sugarcane
11	Mines and quarries	N/A
12	Built-up dense settlement	N/A
13	Golf courses	N/A
14	Low density settlement	N/A
15	Subsistence (rural)	N/A
16	Annual commercial crops dryland	Commercial – dryland
17	Annual commercial crops irrigated	Commercial – irrigated
18	Forest	Natural
19	Dense bush (70–100 cc)	Natural
20	Bushland (< 70 cc)	Natural
21	Woodland	Natural
22	Grassland/bush clumps mix	Natural
23	Grassland	Natural
24	Bare sand	Degraded
25	Degraded forest	Degraded
26	Degraded bushland (all types)	Degraded
27	Degraded grassland	Degraded

Code	Land cover	Model class
28	Old cultivated fields – grassland	Degraded
29	Old cultivated fields – bushland	Degraded
30	Smallholdings – grassland	Degraded
31	Erosion	Degraded
32	Bare rock	N/A
33	Alpine grass-heath	Natural
34	National roads	N/A
35	Main and district roads	N/A
36	Water dams	N/A
37	Water estuarine	N/A
38	Water sea	N/A
39	Bare sand coastal	N/A
40	Forest glade	Natural
41	Outside KZN boundary	N/A
42	Railways	N/A
43	Airfields	N/A

Table 8: Maximal variable list for wetland HGM models. *denotes significant variables ($p < 0.05$) in Rivers-Moore and Cowden (2012); T/F = True or False for presence of a major road or railway line within a buffer of 1000 from a wetland.

Variable	Term	Units	Description
x1	Stream order	N/A	Calculated by assigning the highest stream order to occur in each quaternary catchment
x2	Population density	people/km²	Population density per catchment (2001 census)
x3	Road-1000	T/F	Wetlands falling within 1 000 m buffer of main road
x4	Rail-1000	T/F	Wetlands falling within 1 000 m buffer of main rail
x5	Slope		
x6	Altitude	m amsl	
x7*	Plantation	%	Forestry plantation (includes clear-felled areas)
x8*	Sugarcane	%	Sugarcane (commercial and emerging farmer)
x9*	Dense_sett	%	Built-up dense settlement
x10*	Low_sett	%	Low density settlement
x11*	Agric_dry	%	Agricultural cultivation (dryland)
x12*	Agric_irri	%	Agricultural cultivation (irrigated)
x13*	Natural	%	Natural land classes
x14*	Degraded	%	Degraded land classes
x15*	Dams	%	All inland dams

Variable	Term	Units	Description
x16	Dams-no.	N/A	Number of dams per quaternary catchment (1:50 000 scale)
x17	Basin length		Straight distance from basin outlet to farthest point on drainage divide (Frimpong et al., 2005)
x18	Drainage shape		Area divided by square of basin length (Gordon et al., 1992)
x19	Relief ratio		Difference in altitude divided by basin length (Gordon et al., 1992)
x20	Drainage density	km/km^2	Density of rivers per quaternary catchment (1:500 000 scale)
x21	Road density	km/km^2	Density of roads per quaternary catchment (1:50 000 scale; no footpaths)
x22	Rainfall concentration	mm	
x23	Groundwater depth	m	Depth below surface

4 RESULTS

4.1 Aim 1: Results of Accuracy Assessment and Improvement of Quality of NWM

4.1.1 Survey responses and situation assessment results

The results of the survey and the subsequent development of the SAIIAE were reported by Van Deventer, Smith-Adao, Petersen et al. (2018). A total of 85 data sets were identified and subsequently compiled through the process; involving input from over 100 authors and ten institutions (government, non-profit organisations and academic) (Van Deventer, Smith-Adao, Petersen et al., 2018, Appendix 1). The data included fine-scale wetland mapping information with a spatial extent of nearly 5 million ha.

The government project contributed over 70% of the data, but research projects (including WRC projects) contributed significantly with over 12% of the data. Despite the wealth of existing data gathered through this process, it is clear that much work remains as less than 8% of subquaternary catchments in South Africa have complete wetland data sets. These catchments are mostly in Gauteng, Mpumalanga and the Western Cape. The survey showed that accuracy assessment reports and confidence ratings are rarely available and that wetland extent remains relatively poorly represented for most of South Africa (Van Deventer, Smith-Adao, Petersen et al., 2018).

The information collected was then summarised as follows:

- The total extent of wetlands (hectares) mapped by various organisations.
- Approaches used for wetland mapping across the country, including heads-up digitising, modelling or prediction or remote sensing classification.
- The availability of technical information and metadata.
- Availability of condition assessment of wetlands.
- Studies that had flora and fauna information.

Table 9: List of respondents to the survey

Province	Affiliation	Position	Contact	Gaps and limits
Western Cape	CoCT	GIS officer	Amalia Pugnalin	Municipality context
Western Cape	Stellenbosch University	Student	Alanna Rebelo	Specific site level
KZN	Public	Vegetation specialist	René Glen	National and still incomplete
Gauteng	Private/mining	Junior GIS	Simone Liefferinkat Sibanye Gold Ltd	Specific site level
Western Cape	University of Cape Town	Specialist	Prof. Jenny Day	Specific site level; Research the 1980s
Gauteng	Ekurhuleni Municipality	Specialist	Dr Steve Mitchell	Specific site level
KZN	University of South Africa	Student	Prof. LR Brown/ Ms ML Pretorius	Maputaland area, site specific
Eastern Cape	Private/consulting	Specialist	Doug Macfarlane	Specific site level
Western Cape	University of Cape Town	Student	Fyn Corry	Extensive site level

Province	Affiliation	Position	Contact	Gaps and limits
Western Cape	South African National Parks (SANParks)	Specialist	Dirk Roux	Site level and not all SANParks in Western Cape
Eastern Cape	Department of Forestry and Fisheries	GIS officer	Tamara Nofemele	Provincial coverage but similar to NFEPA map
Northern Cape and Eastern Cape	Freshwater Consulting Group	Specialist	Kate Snaddon	Partially maps quinary
Eastern Cape	Nelson Mandela Metropolitan University	Specialist	Denise Sachael	Municipality
KZN	eThekwini	Specialist	Warren Botes	Municipality
Limpopo	Eskom	Specialist	Vince – LEDET	Provincial

This subsection of the results is aimed at presenting wetland data availability in the country followed by the gaps in existing wetland data and associated limitation in the form of spatial and graphic interpretation. After following up on the survey responses, data sets were received.

Due to the low response received in the survey, it was impossible to determine the available wetland data per province accurately. However, most respondents indicated that using available NFEPA wetland data (NWM4) is popular. Regarding capturing techniques and assessment extent, prioritisation and validation of the responses varied and could not be established in certain provinces due to minimal/ absent partaking from members.

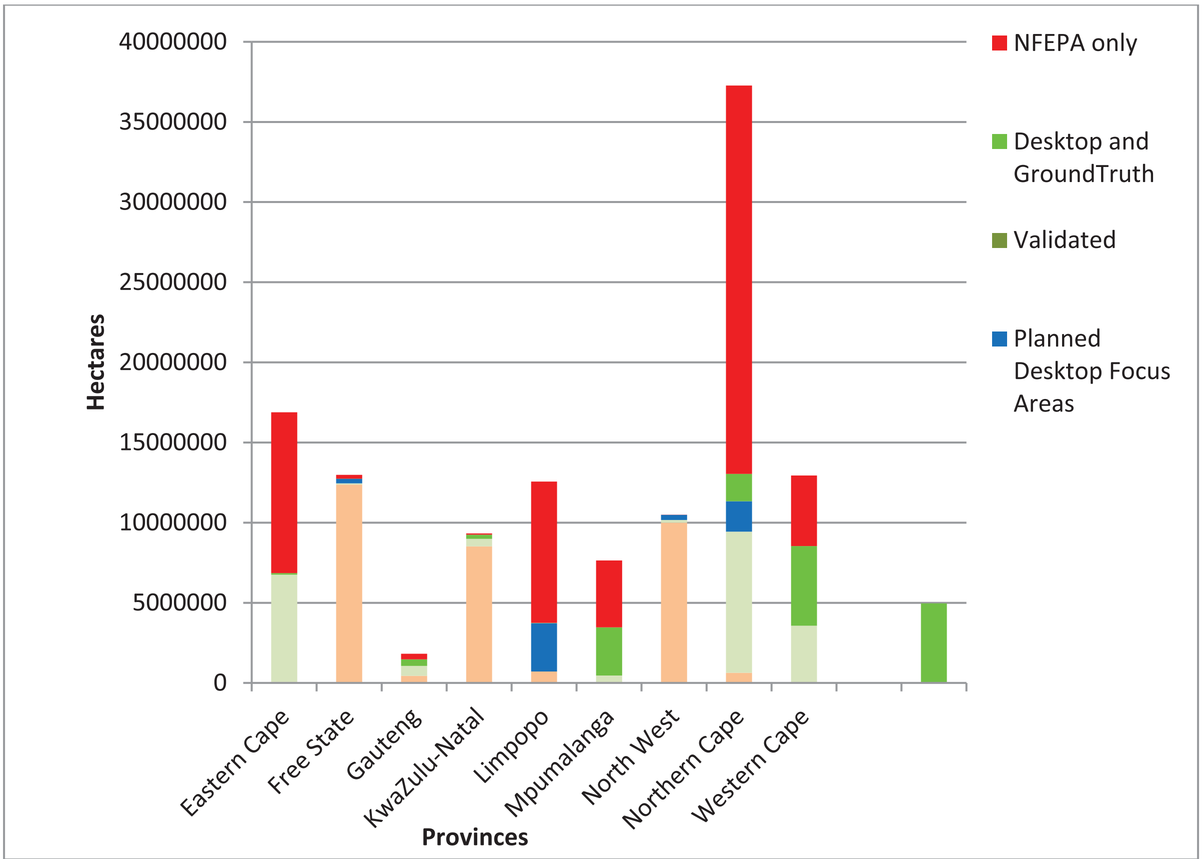

Figure 6: Provincial wetland data availability, capturing technique and validation per survey response

The results showed that most of the available wetland data is that of NFEPA (NWM4), followed by site-specific digitally modelled and fine-scale wetland data (see Figure 7). Most shapefiles submitted by respondents have the required metadata. Some data sets had a link to a published report (e.g. WRC reports) or provided a citation for the data, and very few had work published in scientific journals.

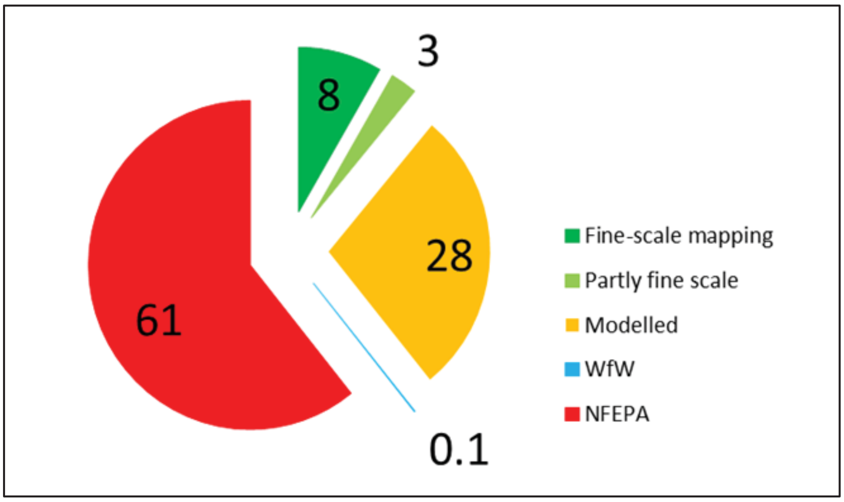

Figure 7: Wetland data availability response on extent covered percentage for the country

Furthermore, most available wetland data sets were captured using modelling techniques, followed by a combination of desktop and ground-truthing. It is also apparent that some institutions have their own wetland data sets that were not shared in time for the project. SANParks have their own wetland data sets for some of the parks and the data was included. Most data available was site specific, and conducted on a project-specific basis by either an institution or private sector. However, the available data accuracy was unclear and posed some limit on data usage for the NWM5 update.

4.1.2 Results of the improvement of the NFEPA wetlands (NWM4) to NWM5

After removing commission errors from the NFEPA wetlands, adding new data sets, and mapping the focus areas for NWM5, the extent of natural inland wetlands increased by 123 (Van Deventer, Smith-Adao, Mbona et al., 2018). A comparison was done between the NFEPA wetlands (Wetlands_19Sept2010.shp) and the final NWM5 to assess differences. The two files were unioned in ArcGIS 10.3 and the hectares updated. Both feature classes in the geodatabase had the Albers equal-area projection for South Africa as prescribed by the NBA 2018.

The combined data set of the NFEPA wetlands and NWM5 totalled 5 202 676 ha, with about 1.3 million ha (or 25% of the combined data set) of inland wetlands mapped in both of the layers (see Table 10; Figure 8). NWM5 mapped an additional 1.3 million ha of inland wetlands that had not been represented in the NFEPA wetlands (omission errors in the NFEPA wetlands data set). Nearly 700 000 ha of inland wetlands mapped in the NFEPA wetlands, however, were not included in the NWM5 because they were considered to be terrestrial (commission errors). Approximately 80 000 ha of artificial wetlands and polygons typed as ‘donuts’ in the NFEPA wetlands data set was also included in the NWM5, following the notion that the full, historical extent of wetlands should be captured in the NWM. More than 1.1 million ha of rivers have also been added to NWM5, while minor ecotone changes (< 0.3%) accounted for estuarine systems in the NFEPA wetlands layer being mapped as inland wetlands in NWM5 and vice versa.

Table 10: Comparison between the NFEPA wetlands and NWM5

Category	Inland wetlands	Estuaries	Rivers
Agreement between NFEPA wetlands and NWM5	1 299 680.7 (25%)	164 585.3 (3%)	197 520.4 (4%)
Commission errors in NFEPA wetlands	677 365.1 (13%)	1 998.9 (< 0.05%)	
Omission errors in NFEPA wetlands	1 308 760.7 (25%)	24 305.2 (< 0.5%)	938 170.4 (18%)
Artificial wetlands and donuts included as inland wetlands in NWM5	37 804.7 (0.7%)	4 452.1 (0.09%)	10 541.0 (0.2%)
Ecotone changes in NWM5	4 262.9 (0.08%)	8 036.2 (0.15%)	

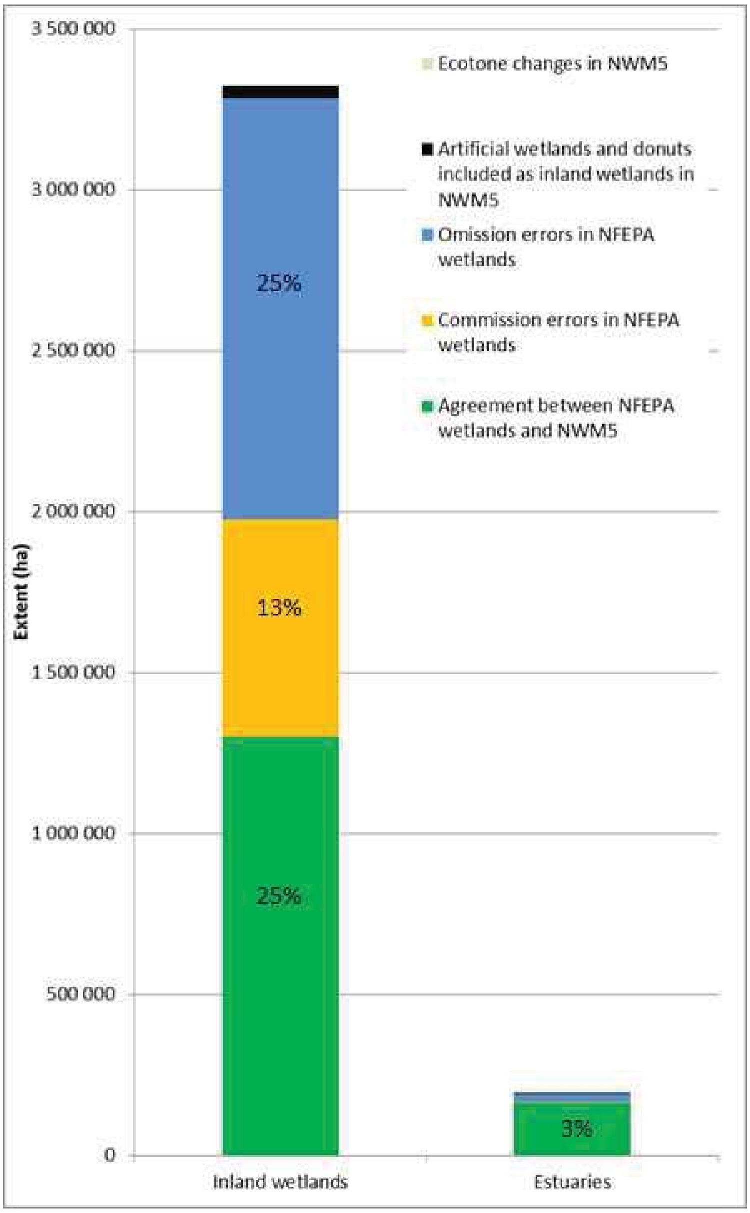

Figure 8: Comparison between the NFEPA wetlands and NWM5

NWM5 show improved representation of inland wetlands in the Mpumalanga Highveld region, the eastern parts of North West, part of Gauteng, the eastern parts of Limpopo and within the Western Cape (particularly for the CoCT Metropolitan Municipality and the Cape Winelands District, not shown on the map) (Figure 9). Similarities between the NFEPA wetlands and NWM5 are mostly distributed across all provinces, although the Eastern Cape and Limpopo provinces showed fever areas of agreement than KZN and the Overberg Region of the Western Cape. Several fine-scale wetlands data sets contributed to the improved representation of inland wetlands in the NWM5 compared to what was available at the time of production of the NFEPA wetlands data set (Van Deventer, Smith-Adao, Mbona et al., 2018; Van Deventer, Smith-Adao, Petersen et al., 2018). It is evident that the representation of inland wetlands increased from the NFEPA wetlands to the NWM5; however, further work is required to address remaining omissions across the country.

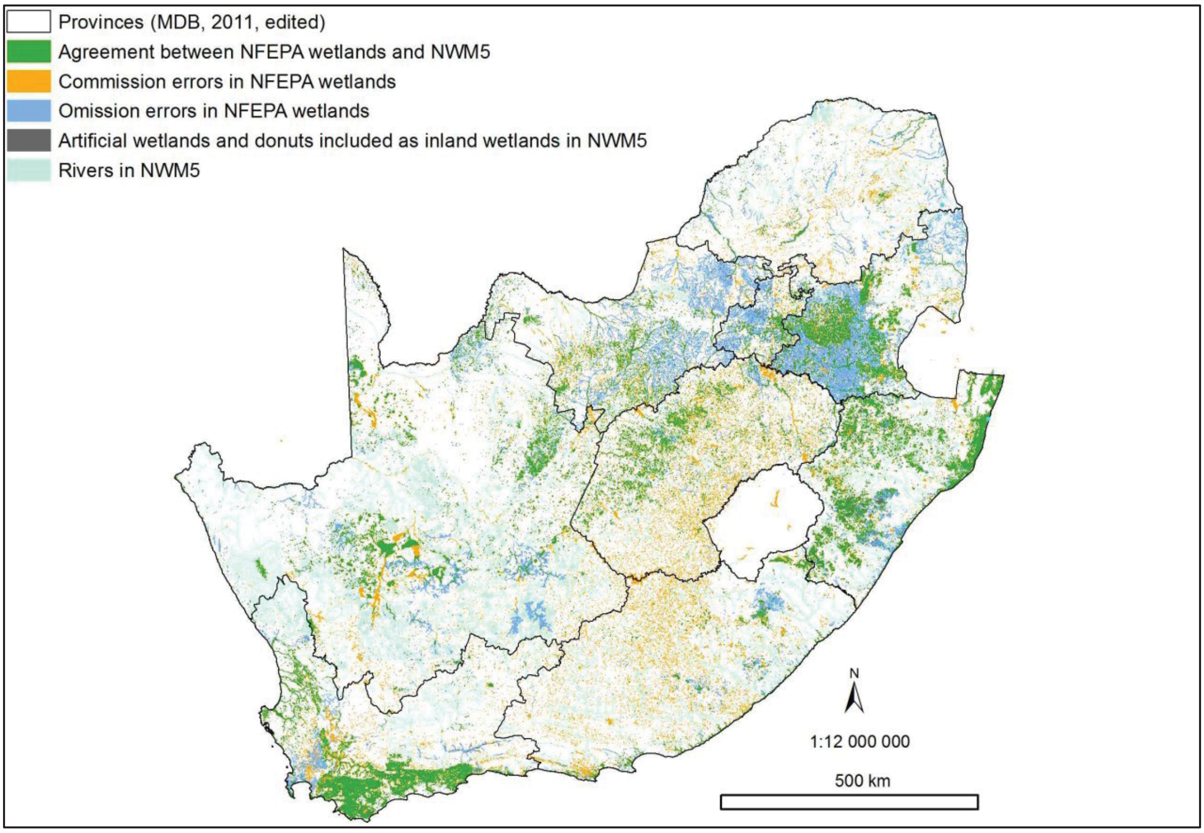

Figure 9: Geographic distribution of the agreement and differences between NFEPA wetlands and NWM5

During the integration, the following errors had to be addressed (listed in Van Deventer, Smith-Adao, Mbona et al., 2018):

- It appeared as if depression and artificial wetlands attributes were mixed. This may be a result of limited computer processing power in combining data at a national scale. Thus, extensive checking of these polygons across the provinces had to be done to ensure errors were eliminated. In future, processing should be considered only at provincial level unless processing power has improved.
- Polygons from the NWM3 appeared to have crept back in to NWM5.3 since some of the fine-scale wetland data sets included these. These were not necessarily eliminated across all provinces though some assistants did pick up this error visually and have attempted to eliminate these.
- 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 types.

- Small slivers were merged with the larger polygon after exploding all features to ensure there were no multipart polygons.
- River channels still posed a contentious matter. Originally, the sand banks and flood bands of the DRDLR:NGI hydrological data was 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 reach 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 were true islands; however, in other instances these were data capturing errors resulting from DRDLR:NGI. Future updates should attend to these in more detail.

4.1.3 Summary of training and capacity-building

A team of 13 data capturers was assembled based on different collaborating institutions. The team was funded from this project and other sources. The team was trained at different workshops conducted in Pretoria and Cape Town. A list of training session is given in Table 11.

Table 11: Summary of training held around the three mapping regions

Date	Location	No. of attendees	Mentors/tutors	Training topics
16–20 Aug 2016	Kirstenbosch Botanical Garden, Cape Town	12	Namhla Mbona Heather Terrapon Anisha Dayaram Kate Snaddon	Wetland identification and delineation; wetland classification system; geodatabase and polygon editing tools; mobile GIS application.
2–4 Feb 2017	CSIR Stellenbosch	7	Kate Snaddon Dean Ollis Tumisho Ngobela	Mapping different HGM types; fieldwork, mobile GIS application.
18 Jan 2017	WCS office, Pretoria	7	Dieter Kassier	Identification of seeps on imagery; wetland typing.
22–26 May 2017	CSIR Pretoria	7	Heidi van Deventer	Geodatabases; topology; statistics and pivot tables; coordinate systems.

The use of ArcGIS Mobile and other online tools, such as ESRI's[3] ArcGIS Online and Quantum GIS's Qfield, was demonstrated. Other training for the capturing team was done on an ad hoc informal basis through phone calls, meetings and emails. The CSIR created a Google Group platform, which was used to get technical advice and functioned as a discussion forum to share methods and ideas. The group comprised wetland specialists within the country and the inland aquatics realm reference committee for the NBA 2018.

[3] Environmental Systems Research Institute

4.1.4 Overall summary of desktop focus areas

The accuracy in mapping the location and extent of wetlands in the focus areas was noticed. Also the HGM typing was improved during this mapping. Table 12 summarises the hectares mapped for each focus area in NWM5 compared to what is mapped in NWM4.

Table 12: Summary of wetland extent of NWM4 vs NWM5

Priority district	NWM4	NWM5	Size of focus area (ha)	Percentage of a district's area mapped as wetlands
Eastern Cape – Amathole	11 536.8	10 955.7	2 111 716.4	0.5
Eastern Cape – Buffalo City	959.3	746.6	275 028.1	0.3
Free State – Lejweleputswa	124 752.7	84 328.6	3 228 698.2	2.6
KZN – uMgungundlovu	26 674.3	49 138.0	960 227.6	5.1
Limpopo – Vhembe	11 912.9	27 039.4	2 559 639.1	1.1
Mpumalanga – Ehlanzeni	23 218.9	35 848.5	2 789 557.3	1.3
Northern Cape – Frances Baard	38 034.4	20 255.5	1 283 566.3	1.6
Western Cape – Eden	46 888.6	76 274.6	2 333 107.3	3.3
Western Cape – Cape Winelands	40 415.5	38 772.4	2 147 328.1	1.8

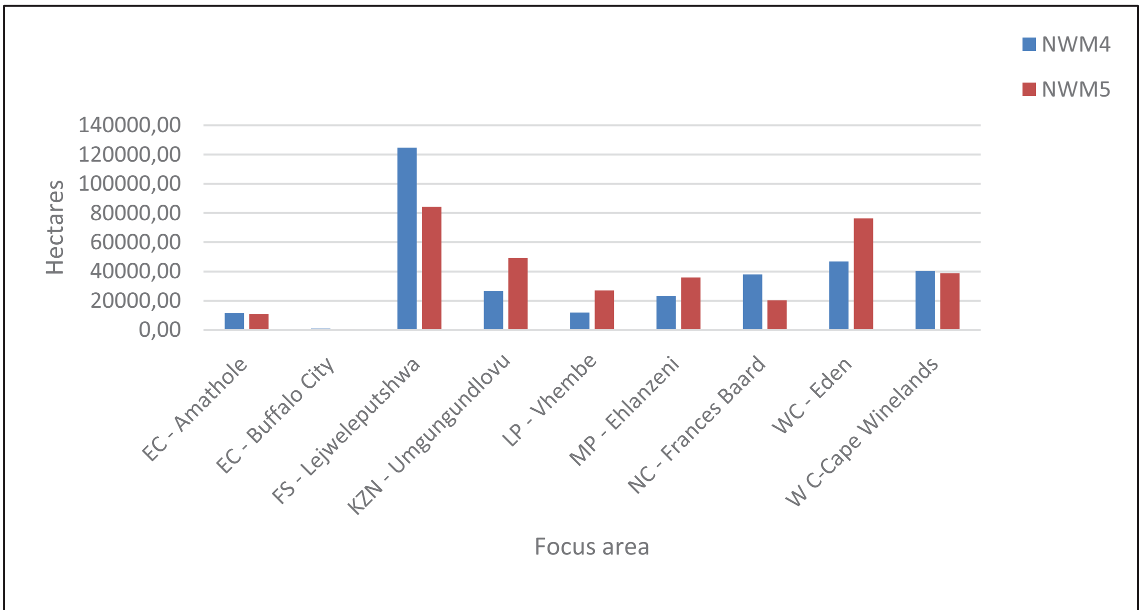

Figure 10: Comparison of wetland extent between NWM4 and NWM5 for focus areas

An increase in the extent (hectares or ha) of inland wetlands mapped in some of the focus district municipalities during this exercise compared to the NWM4 was noticed. Ehlanzeni District Municipality showed an increase of nearly 13 000 ha of inland wetlands. Most of the inland wetlands were typed as channelled valley bottom within this focus area (Figure 11). In Vhembe District Municipality, the extent increased by 15 000 ha with channelled valley bottom wetland being the dominant type. For uMgungundlovu District Municipality, the wetland extent increased by 22 000 ha compared to NWM4.

The commission errors (areas previously incorrectly mapped as wetlands) were also reduced within the focus area. In the Frances Baard District, a reduction in the extent (about 18 000 ha) of wetlands was observed when NWM5 was compared with NWM4. Most inland wetlands were typed as depression within this focus area.

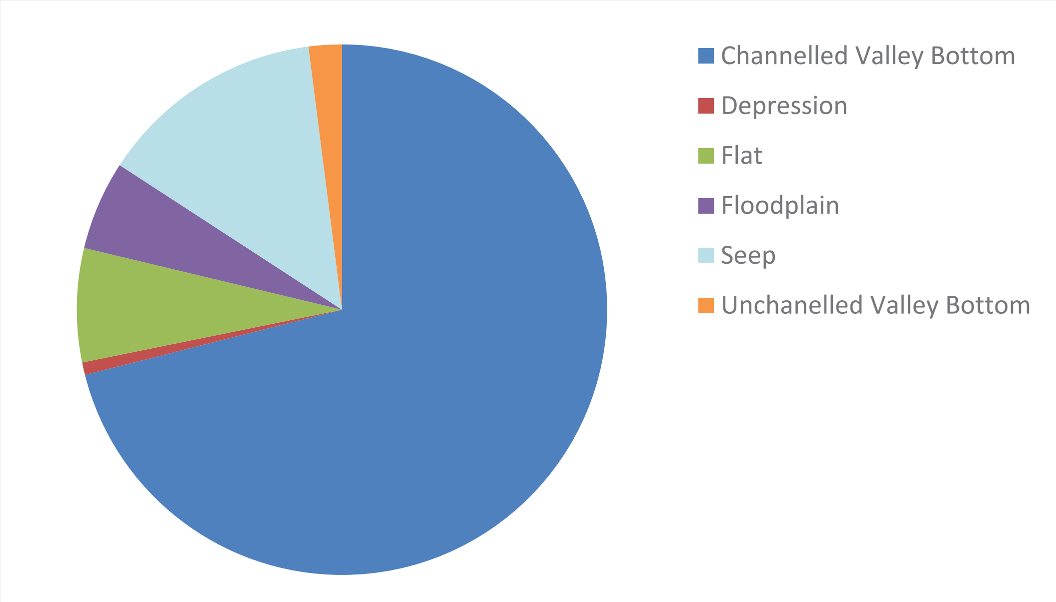

Figure 11: Total area (ha) of wetlands by HGM type for the Ehlanzeni municipality

From the comments received from review the following points were noted:

- Seep wetlands had generally been poorly covered in the various iterations of the NWM, largely due to difficulty (for unexperienced eyes) in identifying and delineating the more seasonal and temporary seep wetlands. For large parts of the country, seep wetlands comprise only a small percentage of overall wetland area and omitting seep wetlands might not result in significant errors. However, in the Mesic Highveld Grassland Bioregion, seep wetlands are often the most extensive wetland type, and omitting these could result in missing as much as 70% of the wetland area. In a comparison with fine-scale data across a 31 000 ha region near eMalahleni (Witbank), it was found that the NWM4 missed 68% of wetland area, the bulk of which were seep wetlands. This applies specifically to the grasslands of the Mpumalanga Province, eastern part of the Free State Province, Gauteng Province and northern parts of the KZN Province. The NWM4 as a national scale data set could not include all seeps; the current desktop method assisted in mapping them.
- Distinction between wetlands and riparian areas: Within the Savanna Bioregion it was found that many riparian areas have been mapped as wetlands, which overestimated the actual wetland extent. The bulk of smaller watercourses within the Bushveld area are likely to support riparian habitat rather than wetlands, especially if the systems are treed.

4.2 Aim 2: Results of Improving Predictive Modelling of Wetlands

4.2.1 Occurrence of wetlands

The Drakenstein and CoCT study areas showed a good range of HGM types, with seven types in the Drakenstein and 11 in CoCT. In the Drakenstein study area, the most dominant HGM type by area was "depression" (Figure 12), and "hillslope seep" by number (Figure 9). Similarly, depression wetlands dominated by area and number for the CoCT area (Figure 13).

Comparison of HGM types by area offered little distinguishing power between types (Figure 14). However, calculation of metrics for wetland shape and fractal dimension provided a first-order resolution for differentiating between broad HGM groups. However, while a gradient of HGM types by shape and fractal dimension is evident (Figure 15; Table 12), all shapes and fractal dimensions of the HGM groups are included within the 'depression' type. Importantly, there was little distinction between study zones for unchannelled and channelled valley bottom types (Figure 16; Figure 17; Table 13; Table 14), confirming that all three study regions could be combined in the terms of the modelling exercise.

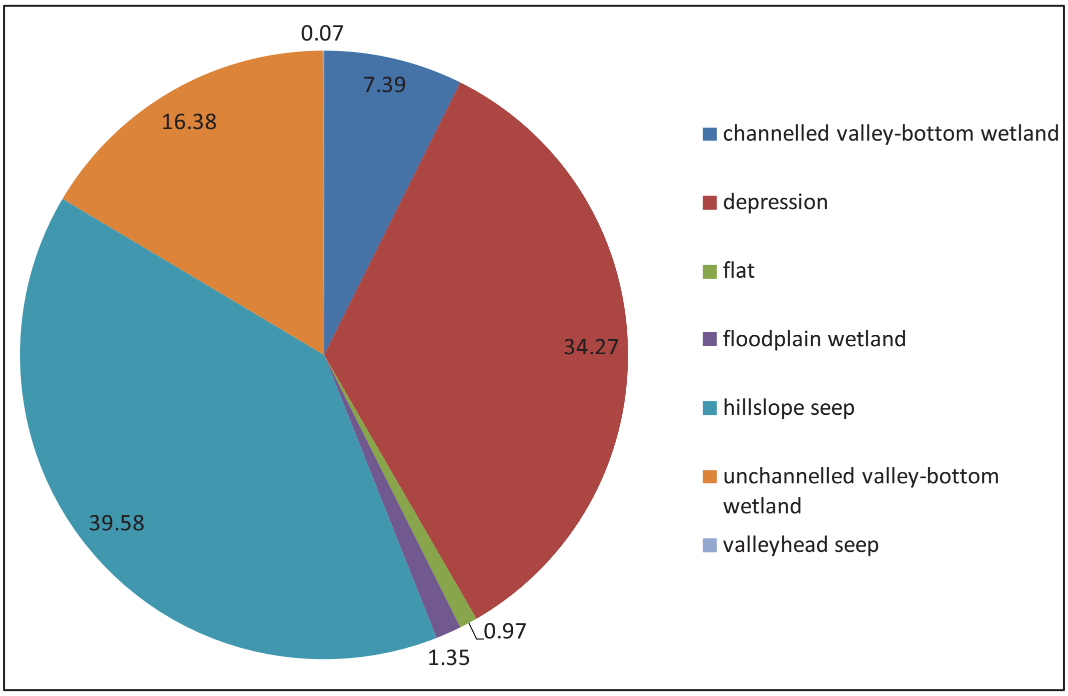

Figure 12: Proportion of wetlands by HGM type for the Drakenstein municipality

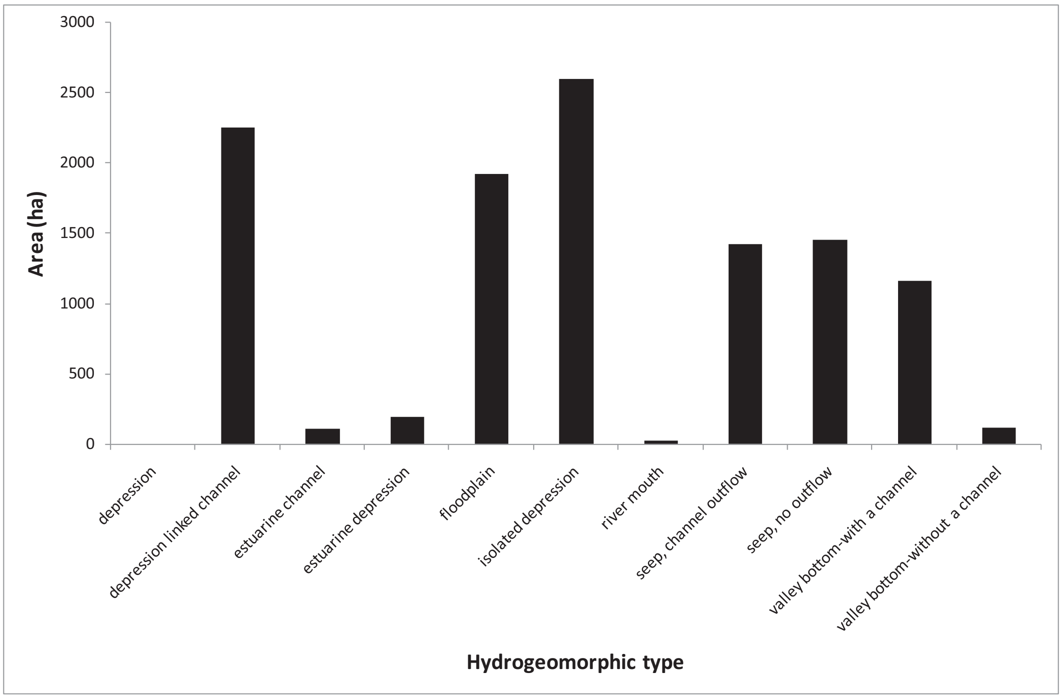

Figure 13: Total area (ha) of wetlands by HGM type for the CoCT municipality

$$Shape = \frac{Perimeter^2}{Area} \quad [2]$$

$$Fractal\ dimension = \frac{2 \times ln(Perimeter)}{ln(Area)} \quad [3]$$

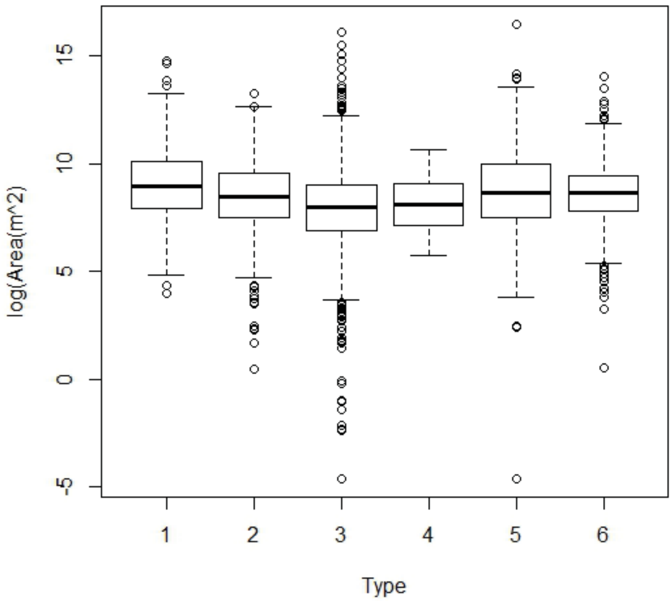

Figure 14: Box-and-whisker plot of HGM types by area (m^2) for the Drakenstein, Breede and CoCT municipalities combined (n = 11, 626): 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

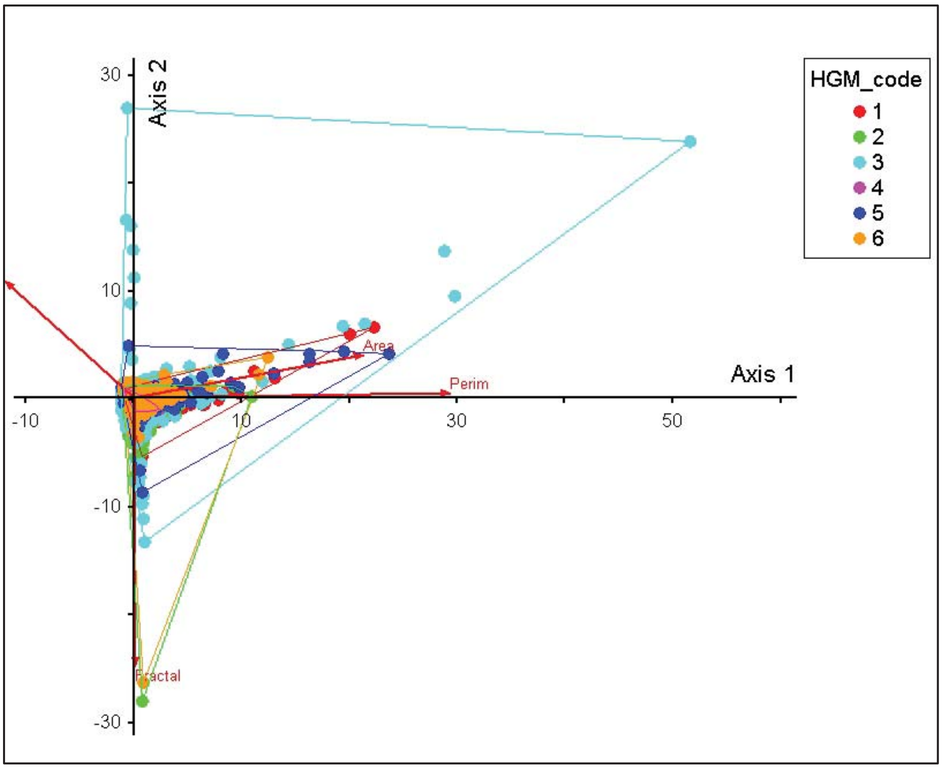

Figure 15: PCA for wetlands by HGM type based on area, perimeter, shape and fractal dimension; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

Table 13: Eigenvalues for PCA for wetlands by HGM type based on area, perimeter, shape and fractal dimension

Variable	1	2	3
% Cumulative Variance	**35.80**	**59.4**	**79.5**
HGM_code	−0.0261	0.1728	0.9697
Area	0.5828	0.3111	−0.1033
Perimeter	0.6841	0.1036	−0.0160
Shape	−0.4366	0.5100	−0.2189
Fractal	0.0322	−0.7762	0.0284

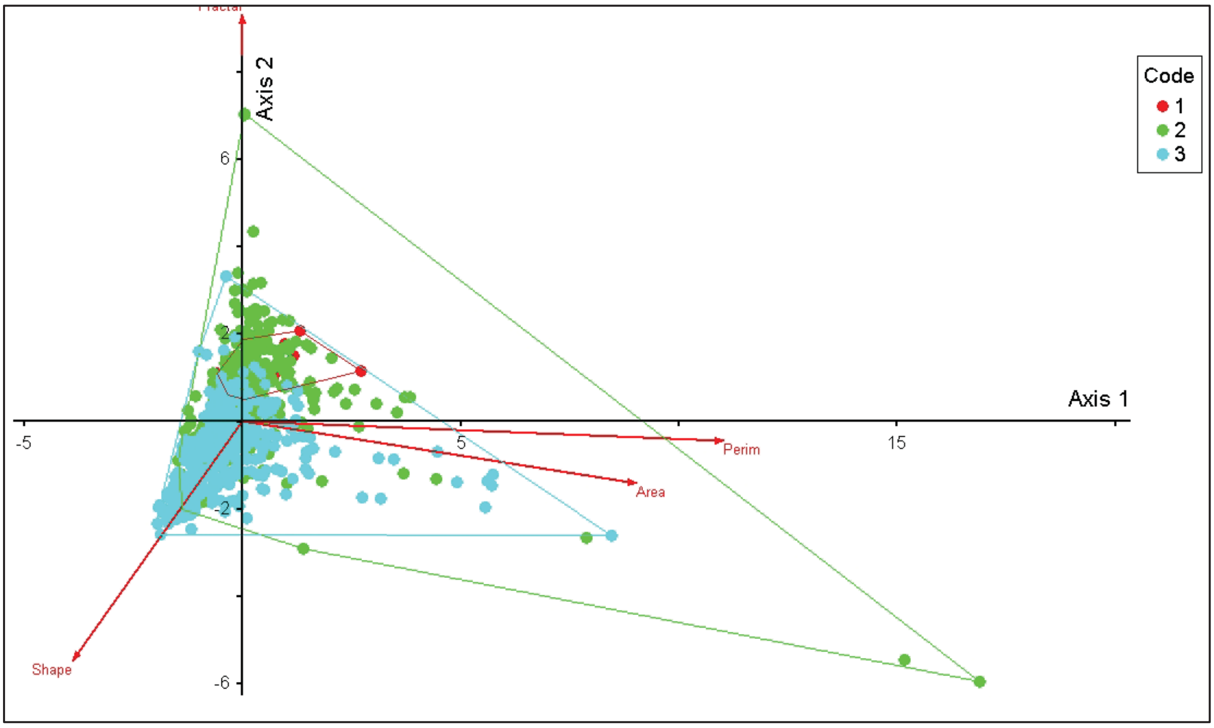

Figure 16: PCA for channelled valley bottom wetlands by municipality (1 = Breede; 2 = Drakenstein; 3 = CoCT) based on area, perimeter, shape and fractal dimension

Table 14: Eigenvalues for the PCA for channelled valley bottom wetlands by municipality (1 = Breede; 2 = Drakenstein; 3 = CoCT), based on area, perimeter, shape and fractal dimension

Variable	1	2
% Cumulative Variance	**39.1**	**71.1**
Code	−0.1412	−0.4063
Area	0.6081	−0.2665
Perimeter	0.6717	−0.1520
Shape	−0.3988	−0.5240
Fractal	−0.0032	0.6828

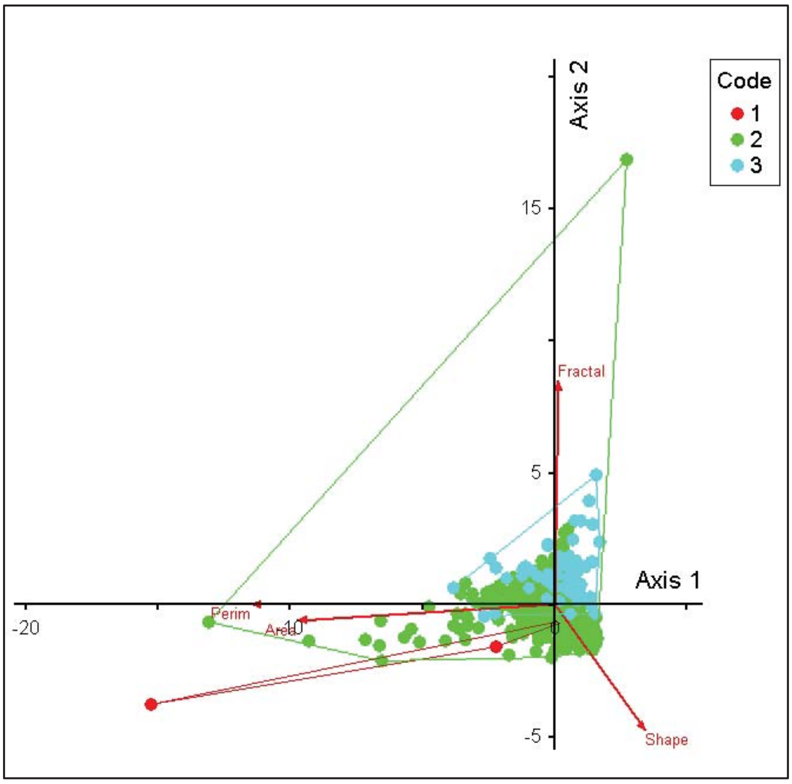

Figure 17: PCA for unchannelled valley bottom wetlands by municipality (1 = Breede; 2 = Drakenstein; 3 = CoCT) based on area, perimeter, shape and fractal dimension

Table 15: Eigenvalues for PCA for unchannelled valley bottom wetlands by municipality (1 = Breede; 2 = Drakenstein; 3 = CoCT) based on area, perimeter, shape and fractal dimension

Variable	1	2
% Cumulative variance	**39.9**	**64.4**
Code	0.0643	0.3115
Area	−0.6256	−0.2014
Perimeter	−0.6794	−0.0136
Shape	0.3715	−0.5578
Fractal	0.0700	0.7423

HGM types tended to be associated with upland versus lowland zones to varying degrees (Figure 18), and to a lesser degree with stream order (Figure 19). Data did not indicate clear binary states, but there were indications that using multiple variables in a probabilistic approach would be useful in automating typing of wetlands by HGM type.

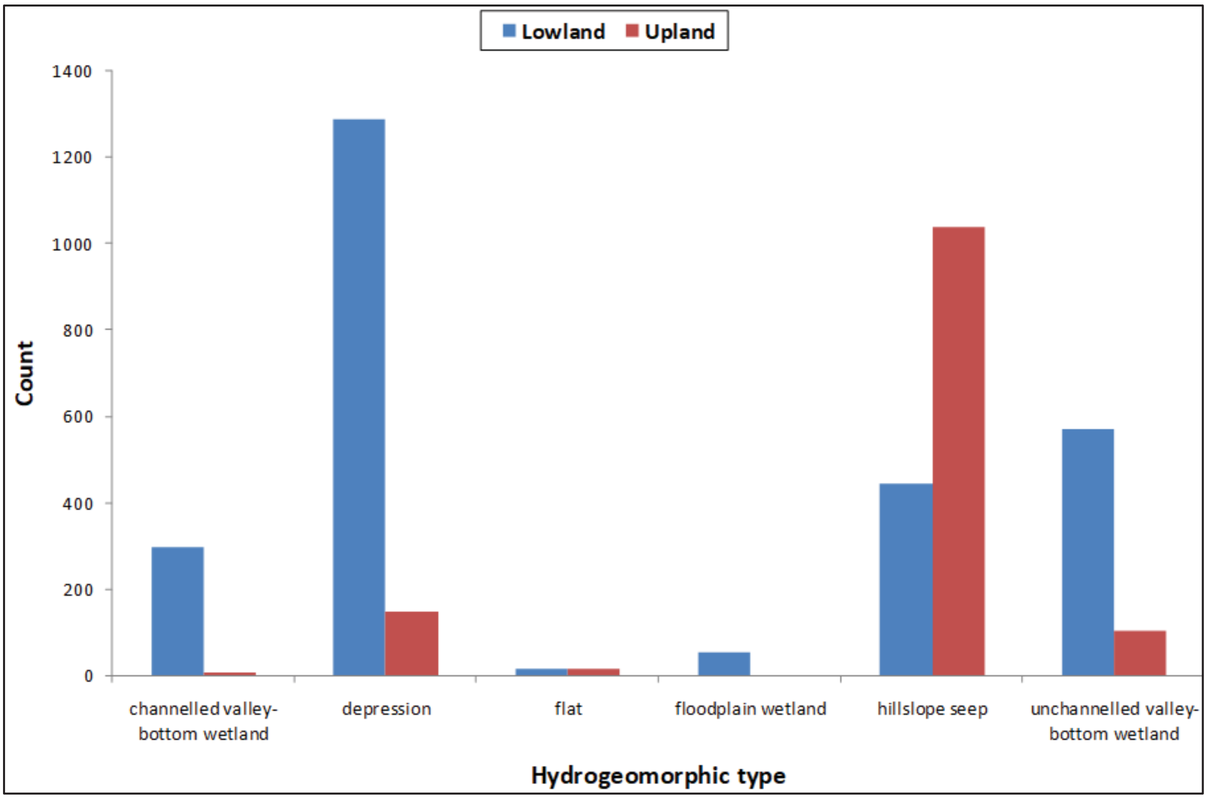

Figure 18: Count of wetlands by HGM type for the Drakenstein for upland versus lowland catchments

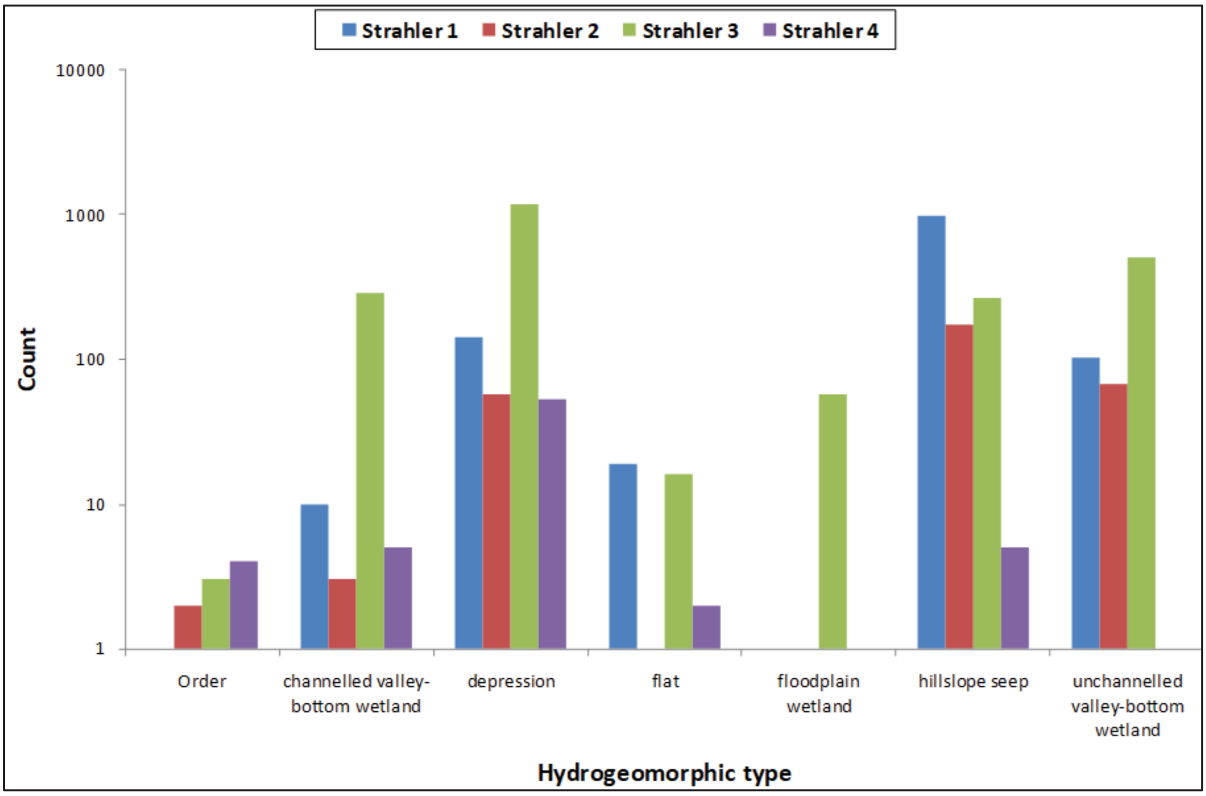

Figure 19: Count of wetlands by Strahler stream order for Drakenstein for upland versus lowland catchments

A PCA indicated little clear evidence to split data sets by HGM type for model development, and with good correlations between wetland occurrence and candidate predictor variables (Figure 20; Table 15). The optimal model at 90 m grid cell resolution included the variables elevation, run-off, groundwater depth, slope and mean annual precipitation (Equation 4; $p < 0.001$ for all model coefficients; residual deviance = 8717 on 6672 d.f.; ANOVA χ^2 $p < 0.001$). The spatial product of this equation is presented in Figures Figure 21–Figure 23, with the AUC from the ROC curves being 0.67 (Figure 24; Figure 25).

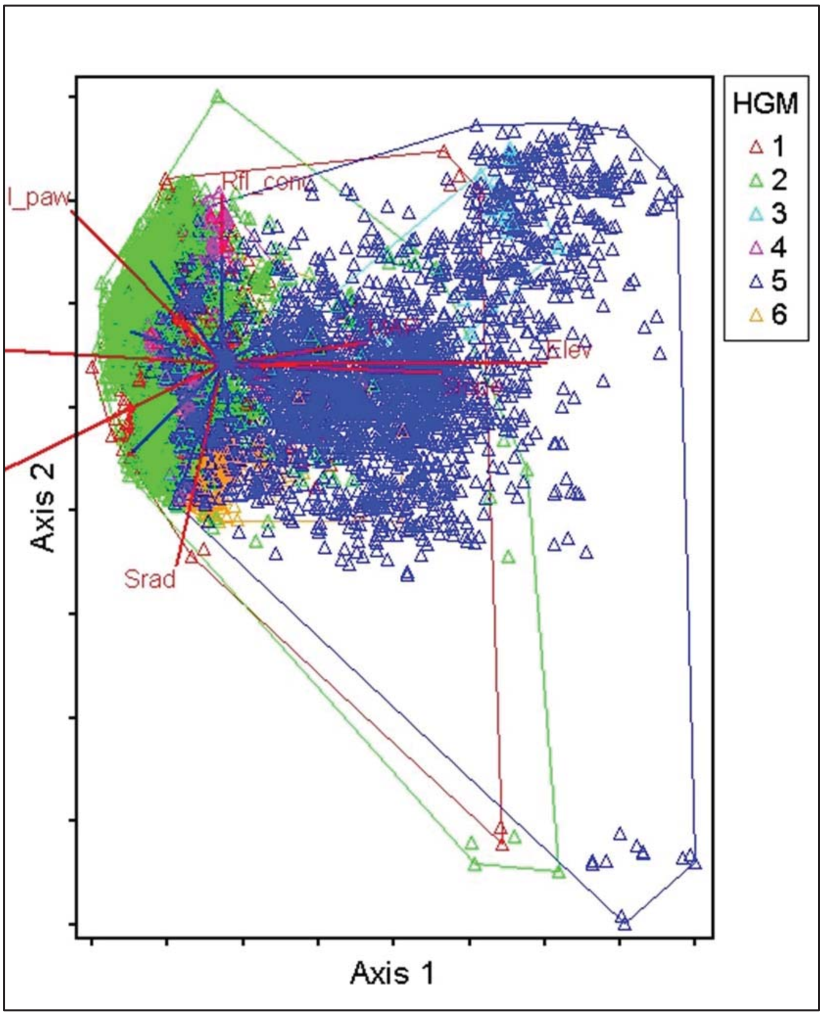

Figure 20: PCA of wetland occurrence by HGM type with vectors showing landscape variables with correlation > 0.3; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep (see Table 4.8 for eigenvalues)

Table 16: Eigenvalues for the PCA for wetlands based on landscape variables

Variable	1	2
% Cumulative Variance	**28.1**	**42.3**
HGM	0.3040	−0.1683
Aspect	0.0287	−0.2151
Elevation	0.4628	0.0237
Flow	0.0292	−0.1607
Groundwater	−0.0009	−0.0338

Variable	1	2
MAP	0.3109	0.1678
Rainfall concentration	0.0004	0.4686
Run−off	0.0440	−0.0410
Slope	0.3807	−0.1103
Soil depth	−0.4039	0.1430
Soil potential available water	−0.3158	0.4483
Solar radiation	−0.1731	−0.5145
Tmean13c	−0.3942	−0.3876

$$p(occur) = 0.8551 + 0.0008(elev) + 0.2006(\log(runoff) - 0.0363(slope) + 0.0007(MAP) - 0.1823(gwater)$$ [4]

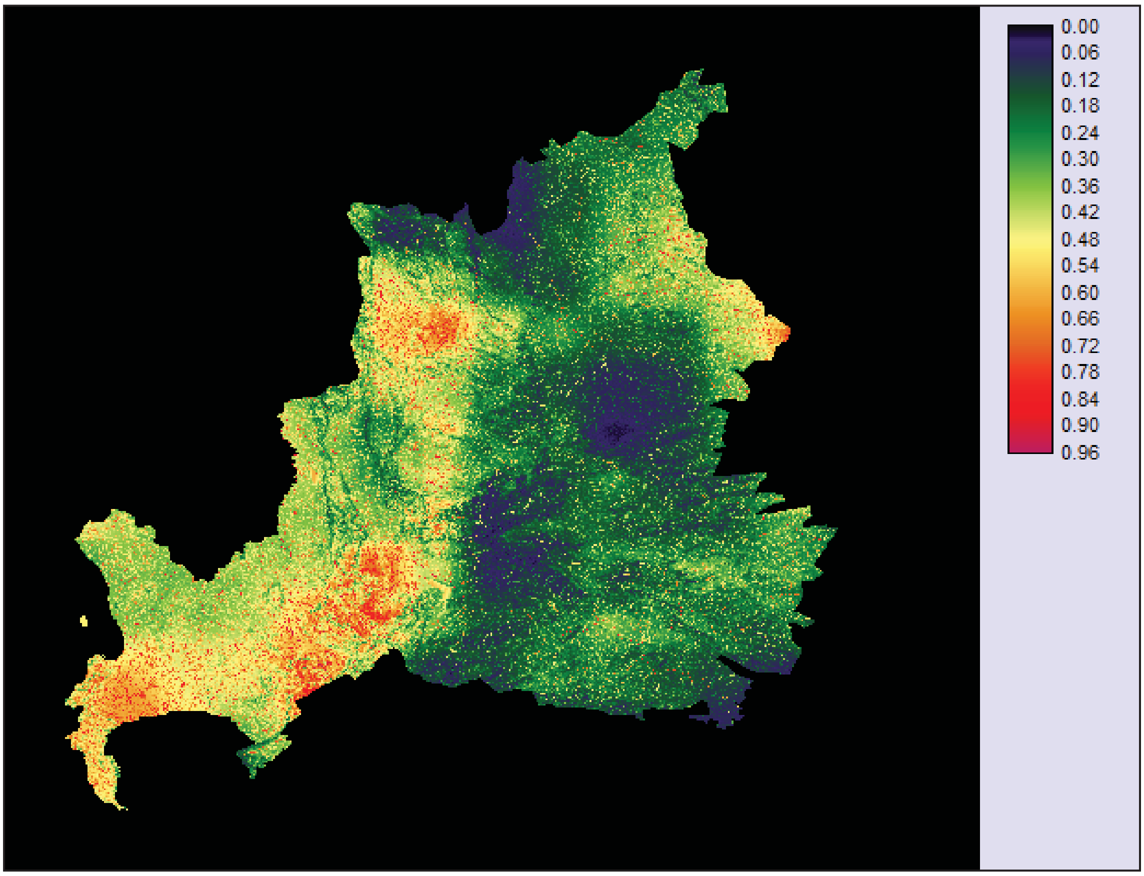

Figure 21: Probability of occurrence of wetlands in the Cape Winelands study area

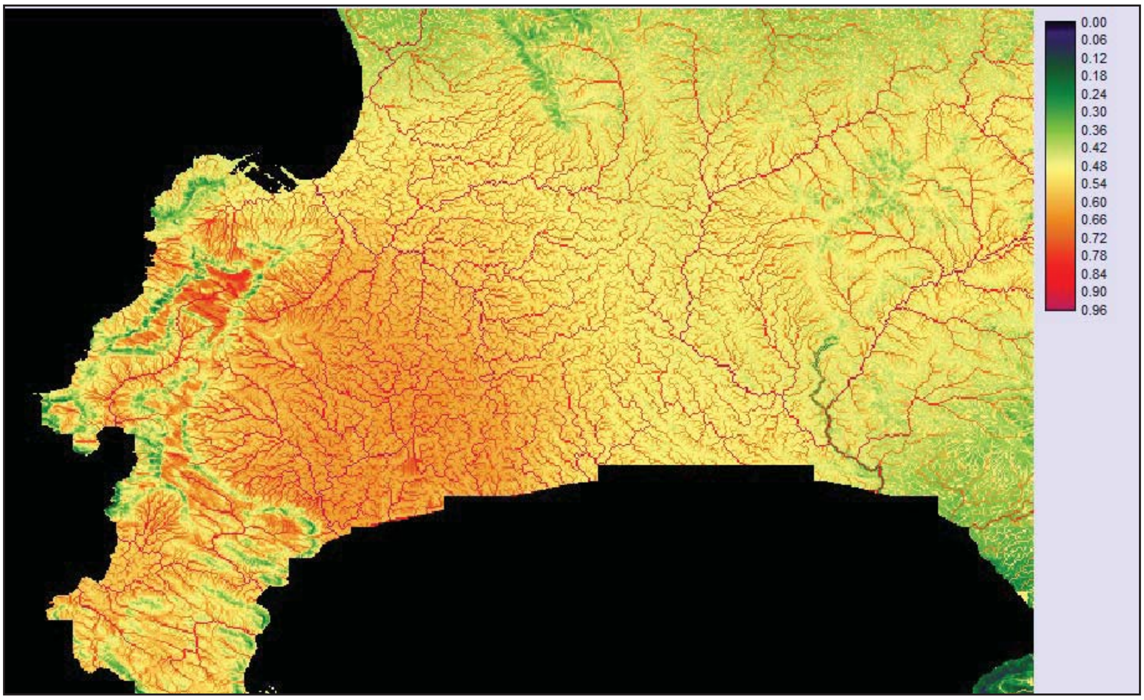

Figure 22: Larger scale image of Figure 21 showing probability of wetlands occurring in the Cape Peninsula

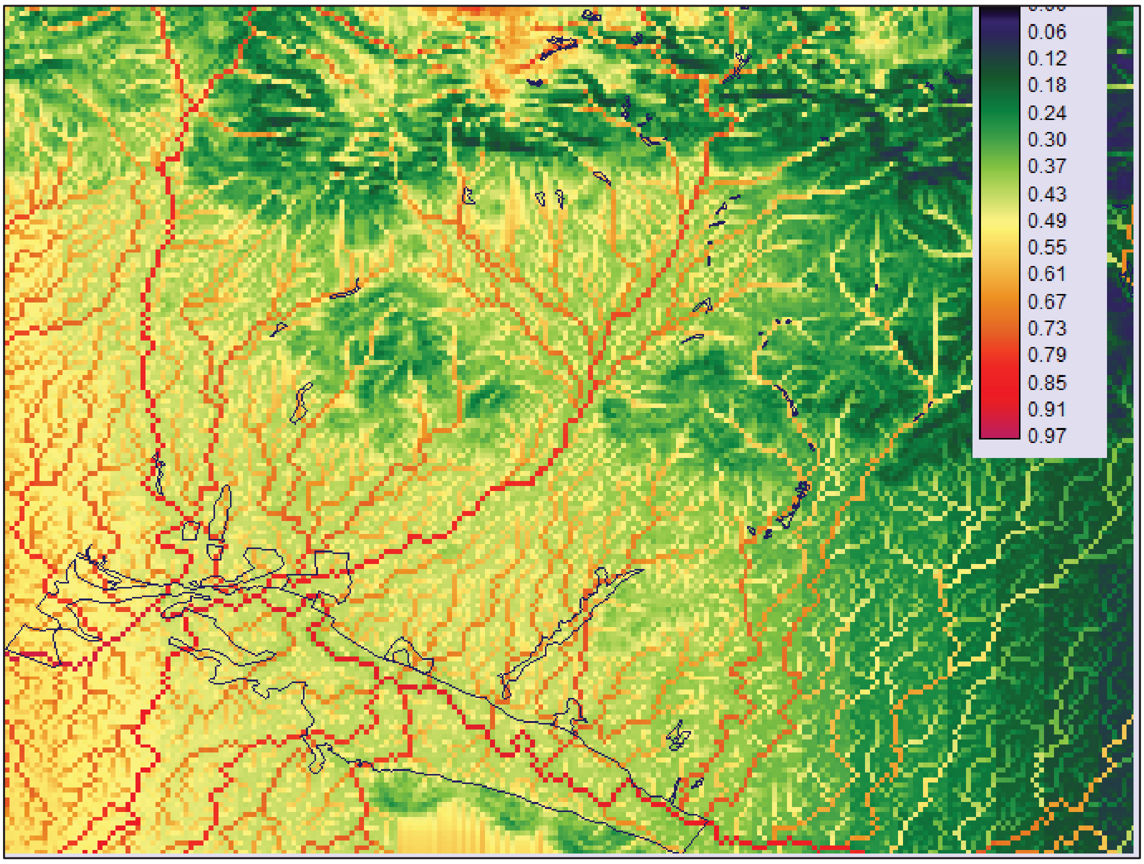

Figure 23: Probability of occurrence of wetlands with ground-truthed wetlands from the Breede municipality superimposed as blue polygons

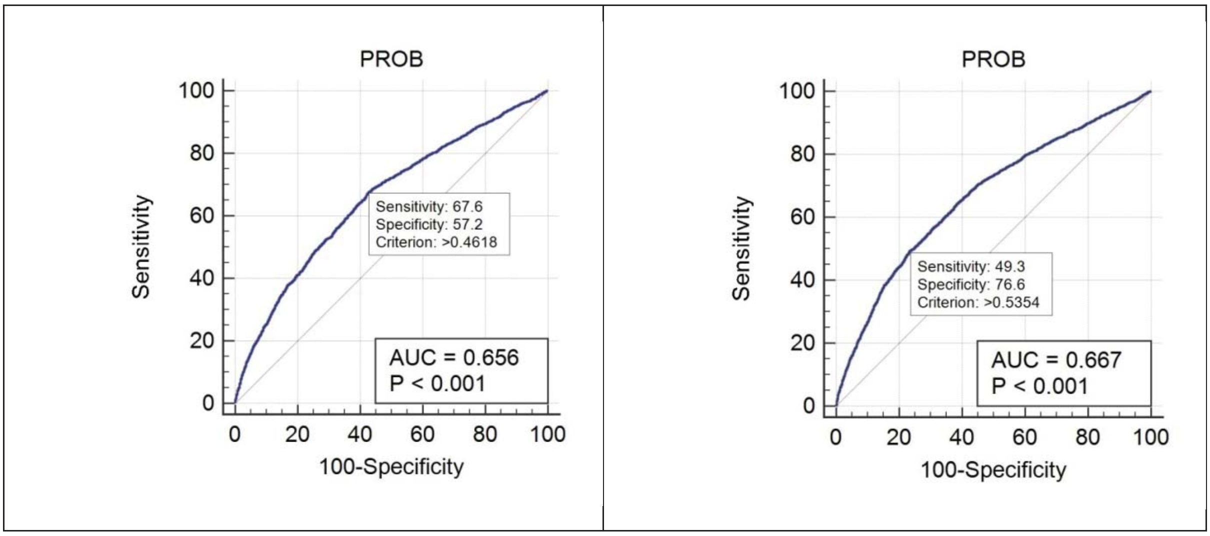

Figure 24: Characteristic ROCs comparing the prediction accuracy of the logistic regression predictive model of wetland occurrence in the Cape Winelands study area based on the training data (n = 7000; left); and test data (n = 7000; right)

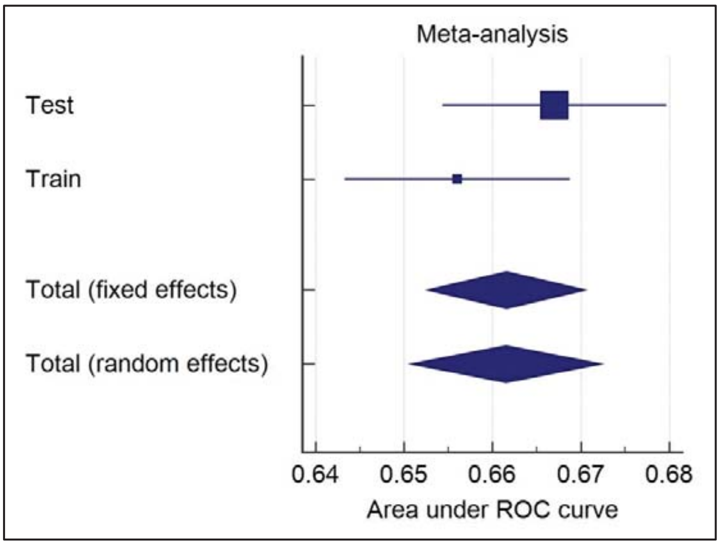

Figure 25: Forest plot of model effects for training and test data sets based on AUC and standard error of AUC

4.2.2 HGM types of wetlands

A PCA indicated that morphometric variables were useful in distinguishing HGM types (Figure 26, Table 16). Of the morphometric variables used, only five (elevation, groundwater depth, relief ratio, slope and shape) provided clear distinctions between HGM group types (see Figure 27–Figure 29 for examples). The frequency of wetlands by HGM type showed equal distribution between major compass points. When median HGM type characteristics for morphometric variables that offered a degree of distinguishing power were plotted on a radar diagram, each HGM signature was unique (Figure 30). The relationship between the most easily mapped topographic variables was linked by conditional probabilities in a Bayesian network (Figure 31). This model indicated that HGM type was most sensitive to elevation (Table 17), and that prediction accuracy was good (Table 18–Table 19) with an error rate of 32.5%.

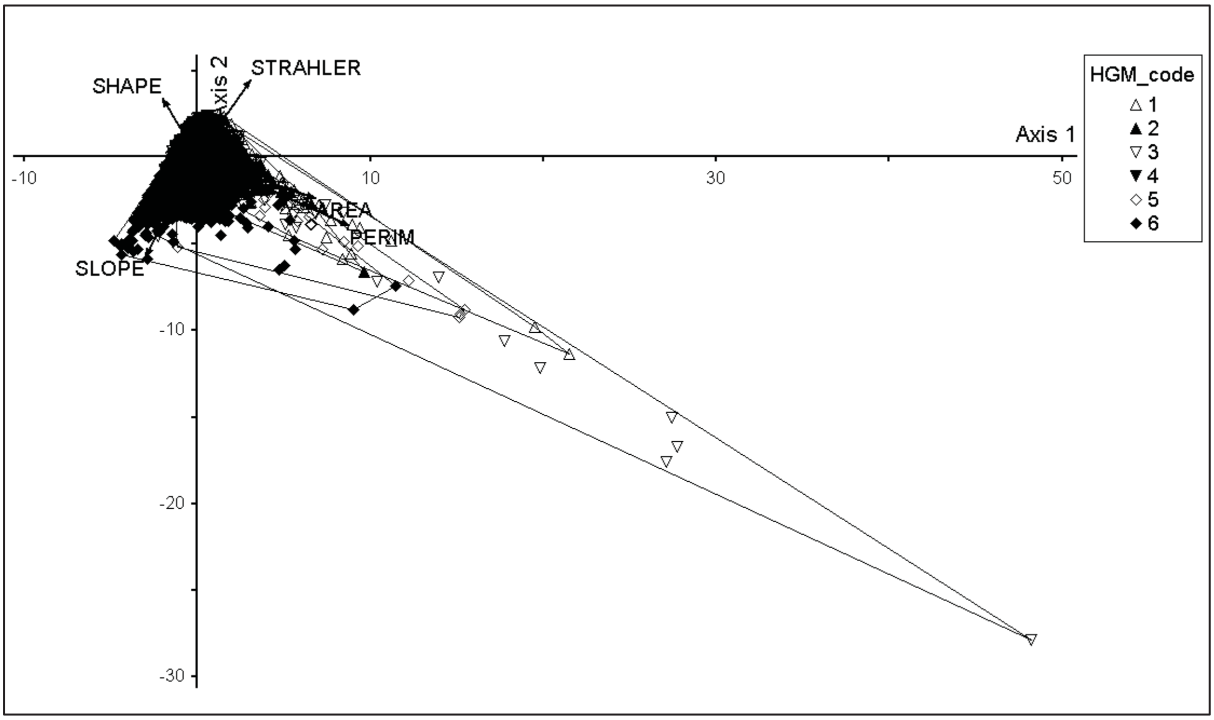

Figure 26: PCA of wetland HGM types based on polygon morphometry; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

Table 17: Eigenvalues for the PCA for wetland HGM types based on morphometric values of wetland polygons

Variable	1	2
% Variance	**16.6**	**32.9**
HGMcode	−0.3102	−0.4653
Area	0.5019	−0.3002
Perimeter	0.5677	−0.3849
Shape	−0.2714	0.3530
Fractal dimension	0.0020	0.0142
Aspect	−0.1308	−0.1180
Elevation	0.0180	−0.0082
Groundwater	0.0596	−0.0353
Slope	−0.3301	−0.4653
Strahler stream order	0.3394	0.4053
Relief ratio	0.1037	0.1564

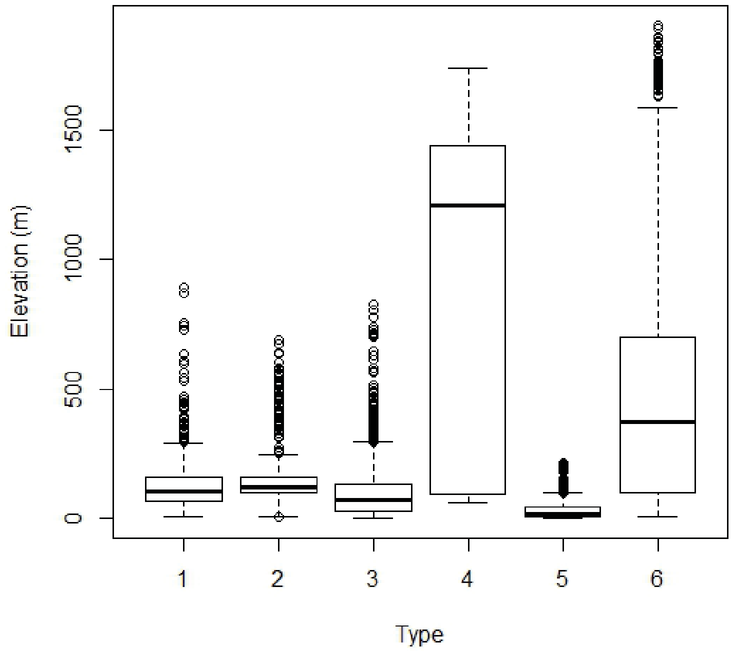

Figure 27: Box-and-whisker plot of wetland elevation per HGM type; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

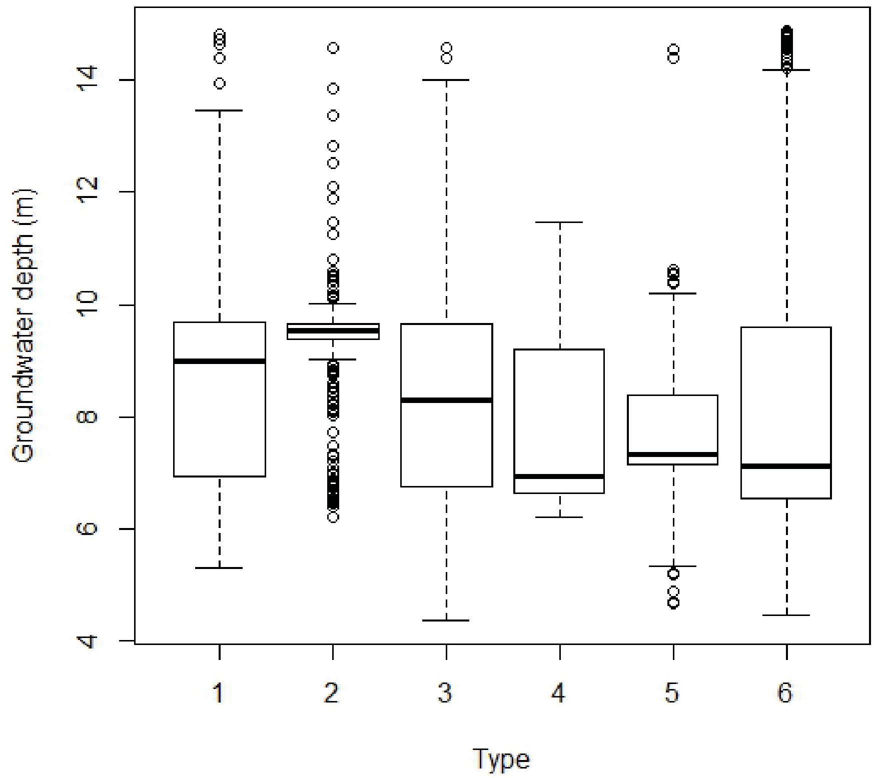

Figure 28: Box-and-whisker plot of wetland groundwater depths (m below ground) per HGM type; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

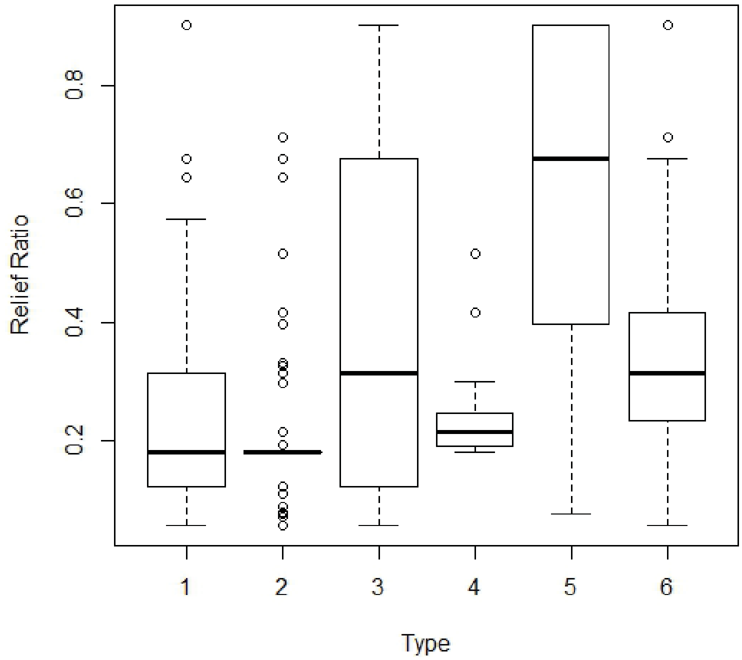

Figure 29: Box-and-whisker plot of wetland relief ratios per HGM type; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

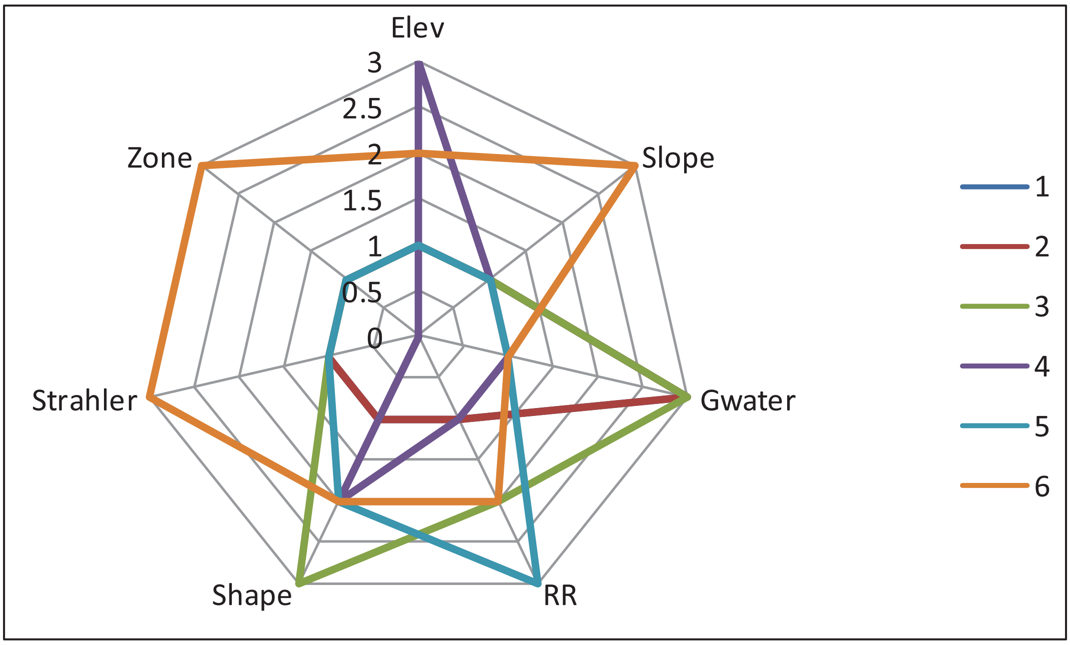

Figure 30: Radar plot of HGM signatures based on qualitative median scores of morphometric variables; 1 = channelled valley bottom; 2 = unchannelled valley bottom; 3 = depression; 4 = flat; 5 = floodplain; 6 = hillslope seep

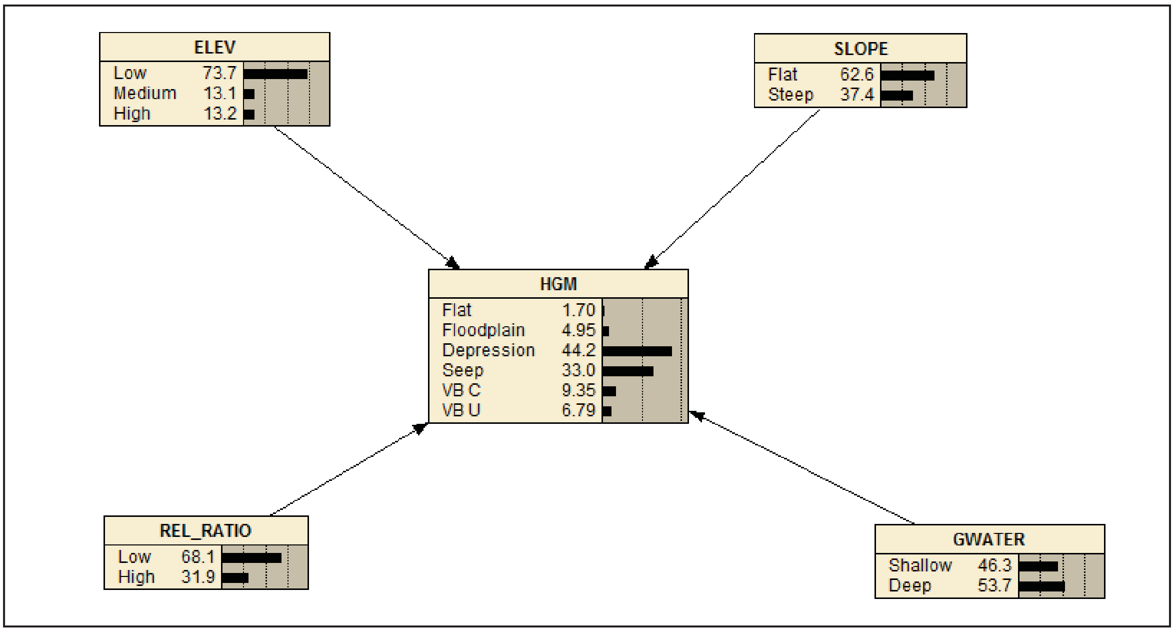

Figure 31: Bayesian network model for predicting wetland HGM type based on node states for elevation, slope, groundwater depth and quinary catchment relief ratio

Table 18: Node sensitivity relative to the "HGMtype" node

Node	Mutual info	Percent beliefs	Variance of beliefs
HGM	1.94597	100	0.482668
ELEV	0.12414	6.38	0.020413
REL_RATIO	0.06217	3.19	0.004363
GWATER	0.04121	2.12	0.004122
SLOPE	0.01463	0.752	0.001631

Table 19: Predicted versus actual assignment of wetland HGM types based on test cases

Predicted						Actual
Flat	Floodp	Depres	Seep	VB_C	VB_U	
0	0	3	5	0	0	Flat
0	0	113	3	0	0	Floodplain
0	0	1260	186	0	0	Depression
0	0	258	659	0	0	Seep
0	0	114	47	0	0	VB_C
0	0	172	26	0	0	VB_U

Table 20: Number of times the Bayesian network was 'surprised' for different probability values

State	< 1%		< 10%		> 90%		> 99%	
Flat	0.12	(3/2502)	0.28	(8/2844)	0	(0/0)	0	(0/0)
Floodplain	0.15	(1/685)	3.44	(91/2643)	0	(0/0)	0	(0/0)
Depression	0	(0/0)	1.49	(6/402)	0	(0/0)	0	(0/0)
Seep	0	(0/0)	0	(0/0)	4.68	(17/363)	0	(0/0)
VB_C	0.88	(1/114)	4.87	(123/2526)	0	(0/0)	0	(0/0)
VB_U	0.37	(4/1070)	1.67	(30/1793)	0	(0/0)	0	(0/0)
Total	0.21	(9/4371)	2.53	(258/10208)	4.68	(17/363)	0	(0/0)

4.2.3 Ecological condition of wetlands

Ecological condition models for valley bottom (channelled and unchannelled), floodplain and seep were all statistically significant [($p < 0.05$ for all coefficients, and $p < 0.001$ for most variables) (Table 19)]. Both seep and floodplain degradation probabilities were best predicted using univariate models based on elevation (Figure 32), with both HGM types more likely to be degraded at lower elevations. The condition of both valley bottom types required multivariate models, with only elevation and percentage plantation common to both. Channelled valley bottom wetlands had a more heterogeneous spatial degradation pattern than unchannelled valley bottom wetlands, with the latter more strongly linked to catchment boundaries (Figure 33; Figure 34). The potential degradation surface for seeps and floodplains in the Winelands study area indicated highest probabilities of degradation in the Cape Peninsula region. Model validation was only possible for floodplain wetlands. Of the 7272 wetland polygons in the CoCT data set, only 109 (1.5%) had PES scores. The breakdown of scores by HGM type only enabled floodplains to be assessed (n = 58). The majority of floodplain PES scores are C.

Table 21: Logistic regression terms to fit $\alpha + \beta x$ for models of the form of Eq. [4], to estimate probability of degradation for four HGM types, where x1 = slope; x2 = elevation; x3 = % plantation; x4 = % irrigated agriculture; x5 = groundwater depth; x6 = rainfall concentration; x7 = terrain unit; x8 = basin length; x9 = % natural vegetation

HGM type	Model	Residual deviance	Model χ^2
Valley bottom (channel)	6.686 + 0.373(x1) − 0.005(x2) + 0.051(x3) + 0.133(x4) − 0.153(x5)	126.57 on 141 d.f.	p < 0.001
Valley bottom (unchannelled)	−7.767 + 0.422(x6) + 0.113(x7) − 0.007(x2) − 0.0004(x8) − 0.049(x3) − 0.061(x9)	120.73 on 190 d.f.	p < 0.001
Floodplain	2.094 − 0.003(elev)	44.78 on 49 d.f.	p < 0.001
Seep	−5.680 + 1.574(log(popdens))	39.26 on 58 d.f.	p < 0.001
Seep – 2nd model	3.374 − 0.004(elev)		p < 0.001

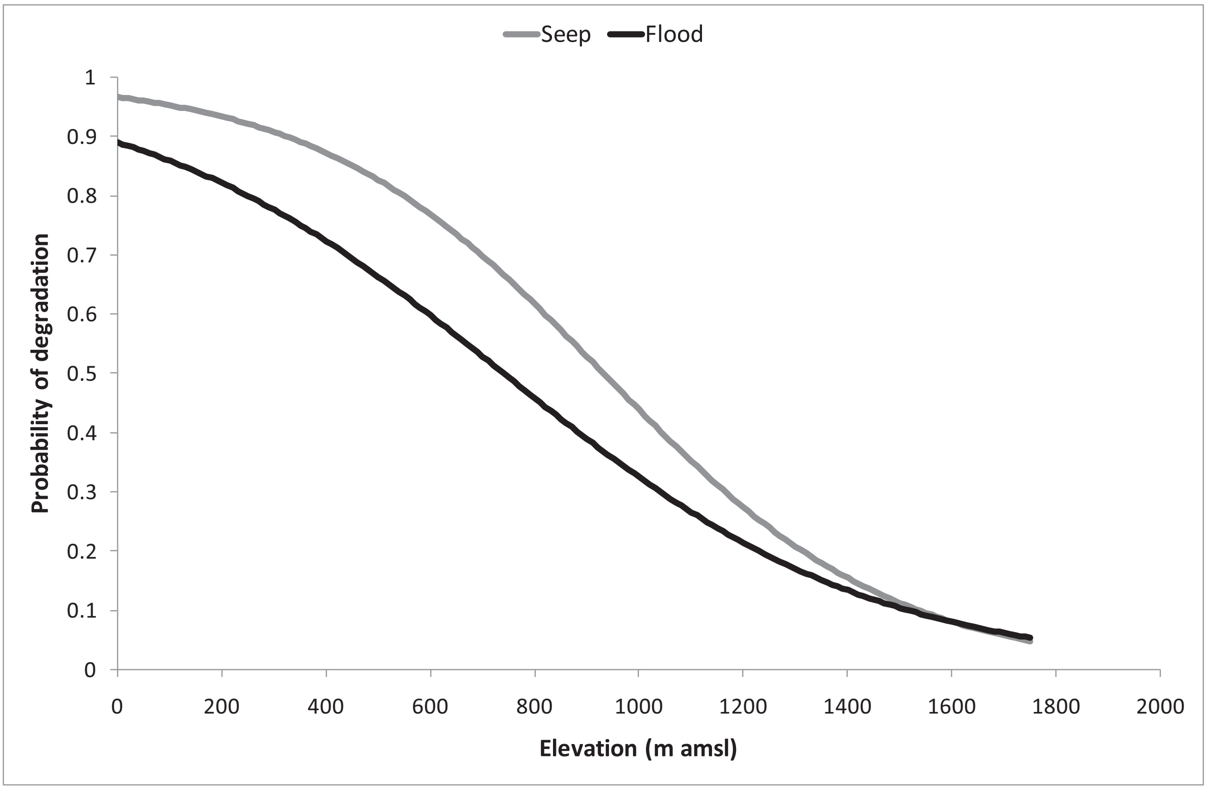

Figure 32: Probability of degradation of seep and floodplain wetlands based on elevation

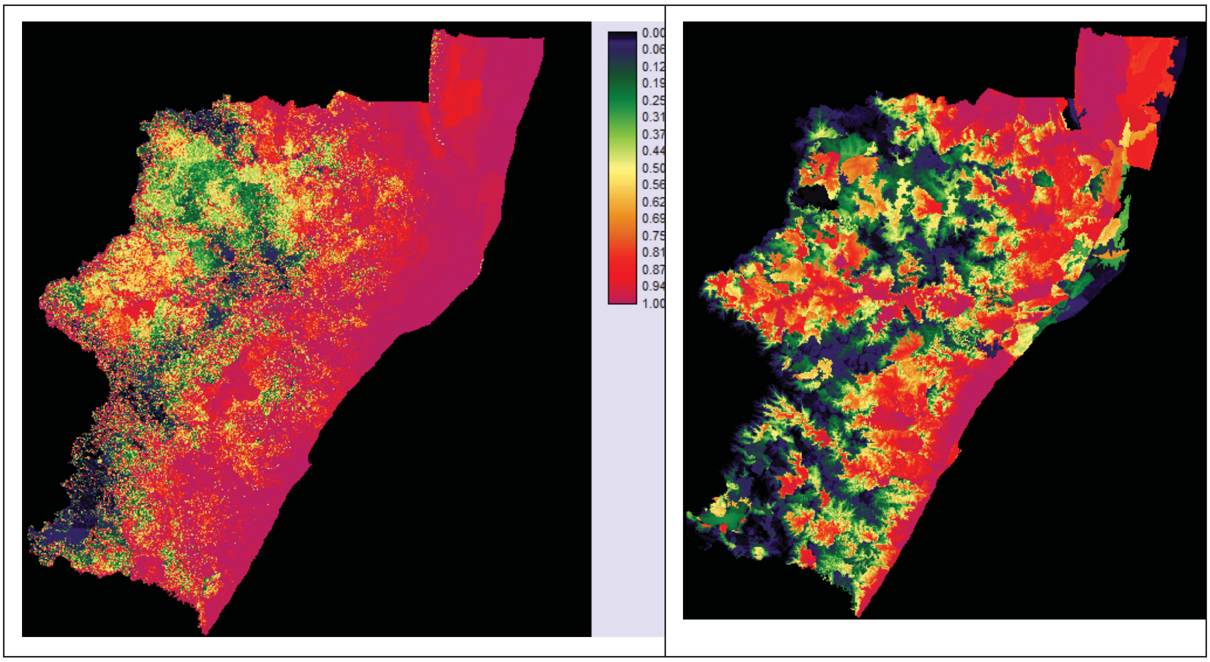

Figure 33: Probability of degradation of channelled and unchannelled (left) valley bottom wetlands in KZN based on the model

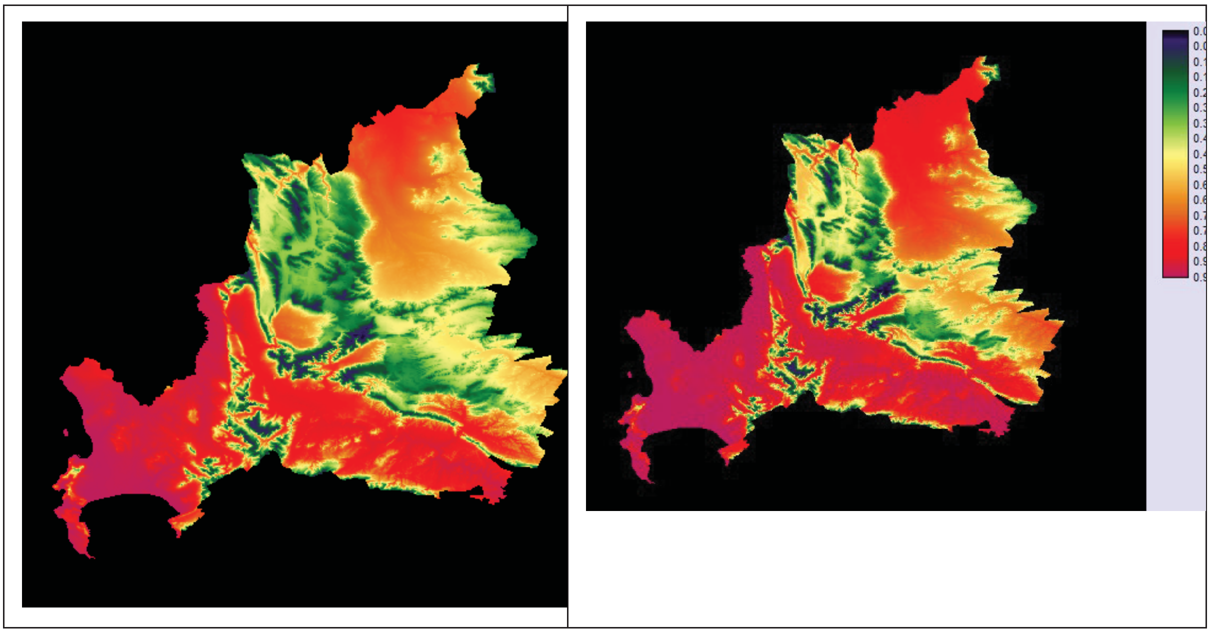

Figure 34: Probability of degradation for floodplain and seep (left) wetlands in the Cape Winelands study area

5 DISCUSSION

5.1 Utility of Situation Assessment In Implementation of Project

Spatial data related to the National Freshwater Inventory (SAIIAE) originates from a complex and multitude of data sources (Van Deventer, Smith-Adao, Petersen et al., 2018). The situation assessment of wetland data availability was useful in identifying sources of data to assist in improving the NWM. The aim was to understand the availability, gaps and limitation regarding the existing wetland data.

Fine-scale mapping of wetlands remains the preferred approach to update the NWM. The method of heads-up digitising is assumed to be more accurate, particularly for wetlands of smaller extent, certain wetland types, and more so in arid systems, than modelling or data derived from remote sensing classification methods (Van Deventer, Smith-Adao, Petersen et al., 2018). However, fine-scale mapping remains an expensive and time-consuming approach and a prioritisation strategy would be required to update data-poor areas across the expanse of South Africa sequentially and continuously.

From the survey results most projects submitted did not apply any wetland typing.

The situational assessment was conducted from October 2015 to December 2015 and later extended until February 2016; however, it yielded minimal response from the members of the various wetland forums. Those who responded showed gaps in existing wetland availability and could not supply all the requirements of the questionnaire.

The key constraints to collation of data was intellectual property issues (from academic sources) and proprietary data set issues (from commercial sources). The time-consuming task of data extraction and metadata preparation is also likely to be a constraint on data delivery. However, since this was a first attempt at a data audit, we are hopeful that the entities and institutions we pursued for data will respond in future.

Some of the received data sets were of limited value due to them not being finalised, not site or country specific, and requiring verification.

Finally, this process also showed that the NFEPA (NWM4) wetland map is still the most relevant used wetland available data set in most areas of the country. As a way forward, there is a need for a vigorous fine-scale wetland mapping project that should be conducted in all provinces in partnership with departments, institutions and private companies. The proposed fine-scale wetland mapping and monitoring could aid in updating available data sets and also creating data for areas, which are data-poor.

5.2 Successes/Failures of Training and Capacity-building Aspect of Project

In future, it is recommended that the desktop mapping team undergo thorough training with experienced desktop wetland delineators prior to commencing with delineating and typing wetlands.

A setback to all of the data sets reviewed was the general underrepresentation of seep wetlands. Often these were missed altogether in the mapping, and in other instances they were mapped and typed as part of other wetland systems.

It was noticed most of the data sets suffered from an inconsistent approach to mapping, though this is likely a result of the various data sets being amalgamated into the district municipality data sets. In many cases, one subcatchment had every drainage line and watercourse mapped, while the immediate adjacent subcatchment had only the wetlands around major rivers mapped.

Thorough training in recognition of wetlands from desktop is key to each desktop mapping process. Most members in the team had GIS qualifications/background and needed the wetlands ecology understanding. The training sessions provided the opportunity by using imagery and attending fieldwork. Additional GIS capacity and wetland skill have been grown from this project. The team learnt a great deal and we have built capacity in the wetland mapping community. Some of the data capturers are furthering their studies in topics related to wetlands for their master's degrees and PhDs.

5.3 Improvement of the National Wetland Data Sets from the NWM5 Process

For the areas of desktop mapping, the extent and typing accuracy improved. Commission and omission errors were eliminated.

The addition of new data sets and mapping in the focus areas for NWM5, the extent of natural inland wetlands, have increased by 123% (Van Deventer, Smith-Adao, Mbona et al., 2018). A comparison between the NFEPA wetlands and NWM5 showed that there was a 33% agreement between the two data sets; however, the NWM5 increased the extent of some rivers, estuaries and inland wetlands for large parts of the country. A total amount of 4 698 823.6 ha of inland aquatic ecosystems and artificial wetlands have been mapped in South Africa, constituting about 3.9 % of the surface area of the country (Van Deventer, Smith-Adao, Mbona et al., 2018). In parallel to the improvements in spatial extent, is important to consider the relative accuracy of the mapping and the typing of wetlands. Van Deventer, Smith-Adao, Petersen et al. (2018) categorised each subquaternary catchment (SQ4) in South Africa into seven categories ranging from not mapped or typed (G) at all to fully mapped and typed with infield verification (A). Overall, there has been an increase in the number of SQ4s in the categories D–B and a decrease in SQ4s categorised as E–G. Currently, only 8% of SQ4s are in category B, and much work remains to be done to increase this to over 50%.

5.4 Incorporation of Revised Wetland Data Layers into Key Projects

The improved spatial data gathered as part of this project is a key contribution to the NWM. The updated NWM (v5) is a crucial foundational data set that is utilised in a wide range of assessment, monitoring, planning and management applications. This project will thus directly support the NBA 2018 and allow for updating of the headline indicators of wetland ecosystem status (threat status and protection level).

The findings of the NBA inform our national reporting and international reporting; for example, environmental outlook reporting, reporting on international conventions such as Convention on Biological Diversity, Ramsar and sustainable development goals indicators. The NWM5 will also play a major role in environmental decision-making through its use in environmental impact assessment screening tools and systematic biodiversity plans and strategic environmental assessments. Beyond these key conservation applications, the NWM is widely used in research projects linked to aquatic biodiversity and hydrology.

5.5 Probabilistic Modelling Work

Models to predict wetland occurrence, HGM type and condition performed well. The prediction accuracy for the occurrence of wetlands in the Cape Winelands study area was comparable to the results of Melly et al. (2016; AUV = 0.67 versus 0.68), but less well than those for Hiestermann and Rivers-Moore (2016; AUC = 0.84). This would indicate that the logistic regression approach could be applied at a national scale using national data sets.

The Cape Winelands probability of occurrence data performed well for prediction of centroids, but appears to be less accurate for predicting extent with an apparent overemphasis on drainage lines. While models for the three regions in South Africa currently completed showed regional differences in variable requirements, common variables suggest that a generic variable list could be adequate to model wetland occurrence at a national scale (Figure 35). Most critical of all the variables is elevation since this was common to all models and was also the basis for a number of DEM-derived variables. Further motivation for a generic approach to model wetland occurrence, type and condition at a national scale is that all three model suites developed in this study also shared a common core variable list (elevation and groundwater depth), or used DEM-derived variables (Figure 36).

Prediction of HGM type is a completely novel approach that holds promise. Our approach circumvents the need to use a landform image, which has previously been a problem. We excluded wetland shape from this model because it was the only non-topographic predictor variable, and it assumes definition of HGM polygons prior to classification, which is a limiting assumption.

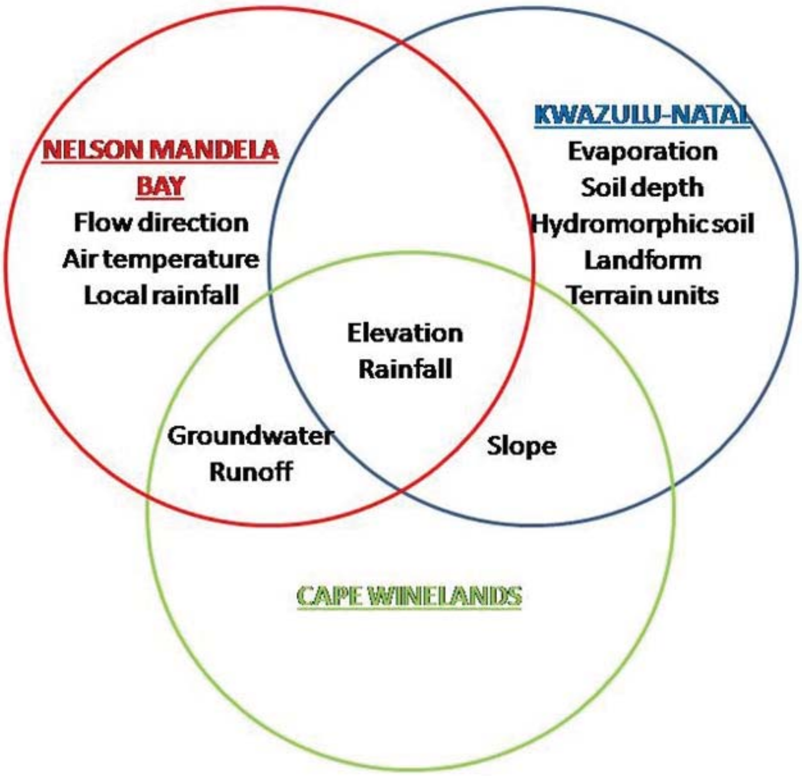

Figure 35: Venn diagram showing maximal model terms for the wetland probability of occurrence models for this study, KZN (Hiestermann & Rivers-Moore, 2015) and Nelson Mandela Bay (Melly et al., 2016)

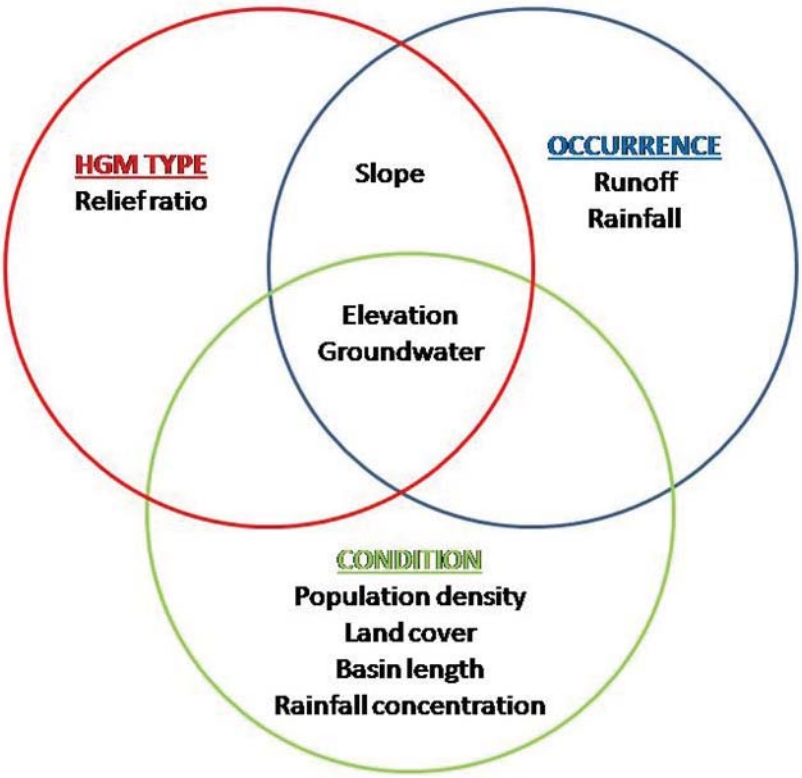

Figure 36: Venn diagram showing maximal model terms for the wetland probability of occurrence, HGM type and ecological condition of wetlands models for this study

The condition models are an improvement of the initial models by Rivers-Moore and Cowden (2012) as they are able to predict the probability of degradation of individual HGM type using a raster image, rather than a general probability per quaternary catchment. The seep and floodplain condition predictor variables remained unchanged from Rivers-Moore and Cowden (2012) to the current exercise, namely, population density and elevation respectively. Prediction of valley bottom wetlands remained similar in principle, with conditions for both channelled and unchannelled valley bottom wetland types requiring multiple and unique predictor variables.

While the variables for channelled valley bottom wetlands increased from only elevation and percentage plantation cover in the model by Rivers-Moore and Cowden (2012) to also including slope, groundwater depth and percentage irrigated agriculture, it was clear the percentage plantation is an important predictor of channelled valley bottom wetland condition. Similarly, percentage natural vegetation remained common to both the earlier and current models for unchannelled valley bottom wetlands, but with the other driver variables (population density, slope, percentage dryland agriculture, road density) being superseded by new predictor variables (rainfall concentration, terrain units, elevation and basin length). This is most likely to be a result of different predictor variables operating at different modelling scales; we would recommend the quinary catchment scale rather than the quaternary catchment scale for condition studies, as this provides better model resolution.

6 CONCLUSIONS

This project made a major contribution to the improvement of the NWM, a foundational data set of national strategic importance. The improved spatial data gathered as part of this project and feeding into the NWM will improve the NBA 2018, support better environmental decision-making, and improve conservation planning efforts. The implementation of the project included training, capacity-building and vital work experience for 13 young scientists and GIS technicians. As a result of the experience gained in this project, some technicians have embarked on further studies pertaining to wetlands.

Despite the improvements to the wetland spatial data (in the focus areas in particular), it is clear that further work is required to increase the quality (i.e. confidence level) of the map. These future efforts should maintain the momentum of this project and focus the improvement of the NWM in areas of high development pressure, areas of strategic importance for catchment management, and in conservation priority areas.

The models predicting wetland occurrence and HGM type, which were developed as part of this project, performed well. The modelling process included the novel approach of using Bayesian networks to predict HGM type. The condition models are an improvement on the initial models developed for KZN as they are able to predict the probability of degradation of individual HGM units using a raster image, rather than a general probability per quaternary catchment. These models are now being used in conjunction with more traditional desktop mapping methods to improve the wetland mapping and classification in independent studies, and future projects focused on the improvement of the NWM should adopt this combined approach of desktop mapping and modelling.

7 Recommendations

There remains a great deal of scope to improve the NWM, both in terms of spatial accuracy and confidence and in terms of HGM typing. To be feasible (from a cost and time perspective), these future efforts should be focused specifically on regions where this is high development pressure (human settlements, mining and agriculture) and/or in areas of strategic importance (such as Ramsar sites, critical biodiversity areas, strategic water source areas).

The sheer number and variety of wetlands scattered across South Africa make it obvious that any efforts going forward will need to be highly collaborative. But, as this project has discovered, highly capacitated central coordination of mapping efforts and GIS data management are crucial to the iterative improvement of the NWM. Moving the confidence from medium to high levels generally requires infield verification, a mammoth task and one which will require a sector-wide collaborative effort. Again, central coordination and data management are crucial if any of these collaborations are to succeed.

The situation assessment results were useful for mapping the areas that are data-poor, but the process also illustrated that many ad hoc projects are capturing wetland data, and this data rarely gets absorbed into national data sets. An important step to improving the inclusion of local wetland mapping efforts into the national inventory would be to design/develop a protocol linked to environmental impact assessments, environmental management plans, strategic environmental assessments, bioregional plans and water use licence applications that extract and centrally collate wetland mapping and typing information. A map showing areas that have received fine-scale wetland mapping should be served and updated annually, and the data should be made easily accessible. Areas that need further attention should be identified and highlighted in the map to encourage participation.

Ongoing training and capacity-building is necessary for stakeholders to fully understand and become familiar with wetland delineation methodology, and appreciate the scope of the efforts still required. The project involved 13 junior data capturers who were trained for wetland mapping. This capacity built should be nourished in the sector going forward.

This project used a combination of desktop mapping and data contributions from other projects. Several lessons have been learnt in respect of training the team; review of data or quality control; etc. From these lessons, an emerging recommendation is to investigate the use of citizen science to map and monitor wetlands. To this end, wetland inventory implementation and practice would benefit from standardised methodology and procedures at a national and provincial scale. The recently published Guidelines for Mapping Wetland in South Africa (Job et al., 2018) represents a good start to these efforts.

From a more technical perspective, we recommend the following research and model refinement:

- Regeneration of the flow accumulation image with actual rainfall data included rather than the default 1 mm applied.
- Translation of the HGM type model to a spatial product, and initial verification of this using Cape Winelands District wetland data as wetland polygons have been accurately attributed by HGM type in this region.
- Generation of HGM degradation probability maps by district municipality, which can act as degradation hypotheses through systematic field assessments.
- Test methods for fusing the desktop wetland mapping approach with a probabilistic modelling approach; develop workflows that use the models of wetland occurrence and HGM typing to streamline and direct desktop mapping efforts to improve efficiency and reduce costs.

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APPENDICES

Appendix A: Questionnaire used for the survey

SANBI
Biodiversity for Life
South African National Biodiversity Institute

Data audit for the Second National Wetland Inventory of South Africa

Introduction: SANBI is mandated by the Department of Environmental Affairs to integrate available wetland ecosystem and species data for the National Wetland Inventory of South Africa. This data includes ecosystem extent and type, and species associated with freshwater ecosystems. To this end SANBI is undertaking a data audit to better understand the state of wetland mapping and classification in South Africa. The data audit will be followed by a data collection and integration process to inform the third National Biodiversity Assessment (NBA) of 2018. **We would greatly appreciate 5 minutes of your time to fill in the questionnaire below or the online version at** http://goo.gl/forms/ob7cMvgr4z **by the 20th November 2015.** Any data made available for the purpose of the National Wetland Inventory will be acknowledged in full.

PROJECT SUMMARY INFORMATION		
Project name:		
Contact details: • Name • Tel • E-mail address		
Full citation or reference to use:		
Access / use constraints: (e.g. public/SANBI only/available for purchase)		
GEOGRAPHIC EXTENT		
Description of study area (e.g. Local / District Municipality, Provincial, Catchment, Region, Other - briefly describe)		
Extent of study area (Ha)		
DATA CAPTURING / COLLECTION		
WETLAND ECOSYSTEMS		
Data capturing technique	€ Desktop only € Desktop and field verification € Other:	
Data format	€ Points € Polygons	€ Shapefile € Google kml / kmz
Accuracy assessment	€ Detection accuracy € Spatial extent accuracy	€ Confidence rated € Other:
Wetland typing	€ National Wetland Classification System (Hydrogemorphic (HGM) types) € Other HGM types	€ Floristic € Combination: ______________________ € Other: ______________
Scale of data captured	€ < 1:10 000 € 1:10 000	€ 1:20 000 € > 1:50 000
Source imagery	Aerial / orthos: € Historic € Recent € NGI colour orthophotos (20 cm) € Other:	Satellite imagery: € Landsat (version): € SPOT (version): € Google Earth € Other:
Date of source imagery (range from start to end date)		
Method of data capturing:	€ Heads-up digitising	€ Image classification
Date of fieldwork verification	____________________	€ Metadata IS available € Metadata NOT available
SPECIES INFORMATION		
Was any species, relating to freshwater ecosystems, collected?		
€ Vegetation	€ Fish	€ Molluscs
€ Water birds	€ Amphibians	€ Insects € Other Aquatic invertebrates
€ Mammals	€ Crustaceans	€ Other: ____________________

Appendix B: Review protocol of desktop mapped wetland data

Author: Mbona Namhla, SANBI Date: 23 March 2017

The purpose of this document is to support the review of desktop mapping of wetland data sets. The NWM5 is currently under improvements as part of data sets to feed in the freshwater component of the NBA 2018. The NBA is due to be published in 2018/2019. The data capturing and integration of fine-scale wetlands data is currently taking place and 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 NWM5 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 capturers. The wetland data sets will be reviewed by SANBI according to the criteria listed in Table 25. Thereafter, it will be passed to the wetland specialist appointed for the area to be further reviewed according to the same criteria listed in Table 25 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 22: Prioritised areas for desktop fine-scale mapping of wetlands and data capturer responsible

District Municipality	Region	Data Capturer
Ehlanzeni (Mpumalanga)	Mesic	Millicent Dinala
uMgungundlovu (KZN)	Mesic	Phumlani Zwane
Vhembe (Limpopo)	Mesic and arid	Tebogo Kgongwana
Francis Baard (Northern Cape)	Arid	Gcobani Nzonda
Lejweleputswa (Free State)	Arid	Ridhwannah Gangat
Cape Winelands (Western Cape)	Winter rainfall	John April, Sinekhaya Maliwa and Bongiwe Simka
Amathole (Eastern Cape)	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 B-2). Historical and current imagery in Google Earth, the National Geo-spatial Information's 50 cm colour orthophotos available online and SPOT imagery from (January 2012) will be used to assess the extent and HGM types of wetlands in a systematic manner. Hydro-geomorphic types will be reviewed visually against existing fine scale and with also the use of ancillary data (e.g. contours, DEM) as specified on Van Deventer (2016a).

The data will later be integrated into fine-scale provincial wetland data sets and this will form NWM5.4 to be used in the NBA 2018.

Note: The NWM is defining wetlands using the Ramsar definition of wetland. This is the definition that has been used for all NWM 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 23: Proposed timeframe for data iterations

District municipality	Region	Data capturer	Date received by Namhla	Date received by specialist	Date received by data capturer
Ehlanzeni (Mpumalanga)	Mesic	Millicent and Tebogo	8 Mar 2017	13 Mar 2017	27 Mar 2017
uMgungundlovu (KZN)	Mesic	Phumlani	13 Feb 2017	14 Feb 2017	27 Feb 2017

District municipality	Region	Data capturer	Date received by Namhla	Date received by specialist	Date received by data capturer
Vhembe (Limpopo)	Mesic and Arid	Tebogo	07 Feb 2017	08 Feb 2017	21 Feb 2017
Francis Baard (Northern Cape)	Arid	Gcobani	13 Feb 2017	14 Feb 2017	27 Feb 2017
Lejweleputswa (Free State)	Arid	Ridhwannah	09 Feb 2017	10 Feb 2017	21 Feb 2017
Cape Winelands (Western Cape)	Winter rainfall	John, Sinekhaya, and Bongiwe	15 Feb 2017	16 Feb 2017	28 Feb 2017
Amathole (Eastern Cape)	Winter rainfall	Leolin	13 Jan 2017	18 Jan 2017	01 Mar 2017

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

Priority district: Ehlanzeni

Name of intern/data capture:

Filename of geodatabase and feature class to review (2): Enhlanzeni_DM2.gdb feature: National_Wetland_Map_5_2_Cli3

Table 24: Review table for wetland data extent

Dates	Signature
Date received by Namhla: 17 March 2017	
Date reviewed by Namhla: 22 March 2017	
Date sent to the Wetland specialist: 27 March 2017	
Date received from wetland specialist	
Revision submitted by intern/data capturer	
Date of final sign-off	

Table 25: 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.	24 holes; 204 slivers.	
Check if all attributes have been captured. Attributes must be checked up to Level 4A.	Report total number 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.	Fix eight unspecified, only one is a real polygon.	Fixed, all the invalid polygons have been discarded.

Criterion evaluated	Aspect/standard	Namhla review	Intern response
	Level 3, field CS_L3.	43 unattended.	Corrected, all features have been awarded a landscape type.
	Level 4A, field CS_L4A.	Done.	
	Date of the image.	4141.	Corrected.
	Data editor.	4113 tebogo.	Corrected.
	Edit date.	4140 null.	Corrected.
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.	What method has been followed for mapping? 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.	Are there any condition ratings?		

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

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 capturers and the quick issues that can be fixed.

Table 26: 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 4A.	Report total number 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.		

Criterion evaluated	Aspect/standard	Wetland specialist	Intern response
	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.	What method has been followed for mapping? 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 in 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 a points shapefile so that they are not to be captured again in future iterations of the wetland map.
- 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 in 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 27).The NGI (certain years) data has been used to build the NWM5.2 as documented on Van Deventer (2016b. 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 category of confidence. Use 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 category of confidence.

Table 27: 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.

List of References

Ollis, D.J., Snaddon, C.D., Job, N.M. and 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. (2016a) *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 No. CSIR/NRE/ECOS/IR/2018/0001/A.

Van Deventer., H. (2016b) *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.