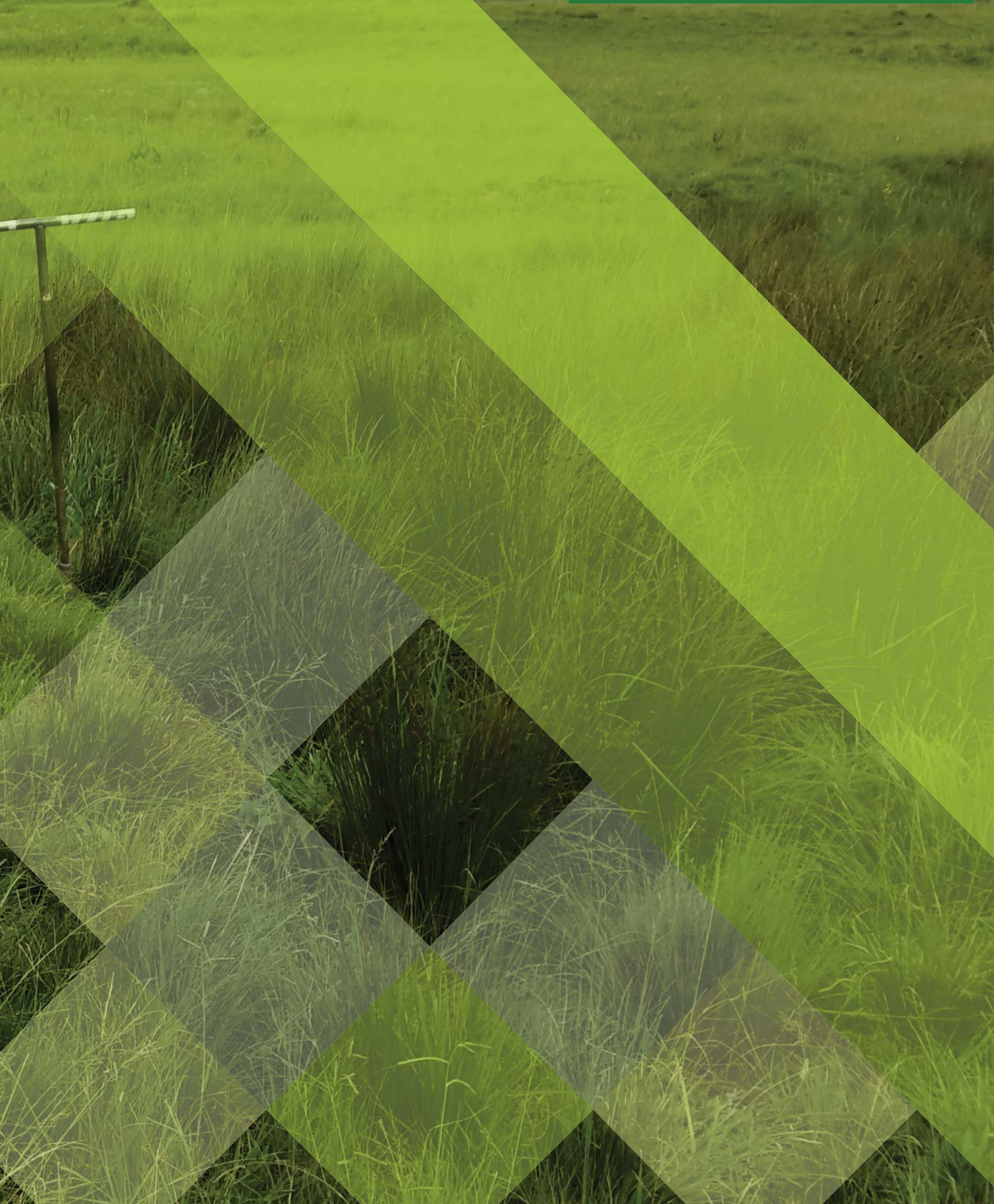
WET-Health (Version 2.0)
A REFINED SUITE OF TOOLS FOR ASSESSING THE PRESENT ECOLOGICAL STATE OF WETLAND ECOSYSTEMS

DM Macfarlane, DJ Ollis and DC Kotze

TECHNICAL GUIDE



WATER RESEARCH COMMISSION

TT 820/20

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A REFINED SUITE OF TOOLS FOR ASSESSING THE PRESENT ECOLOGICAL STATE OF WETLAND ECOSYSTEMS

-- TECHNICAL GUIDE --

Report to the
WATER RESEARCH COMMISSION

by

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WRC Report No. TT 820/20

May 2020

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The publication of this report emanates from a project entitled: *Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems* (WRC Project No. K5/2549).

This report is a technical guide for a revision of the original version of WET-Health. The technical guide for the original version of WET-Health (*WRC Report No. TT 340/09*), which was published by the Water Research Commission in 2009 as part of the Wetland Management Series, should thus be superseded by this report.

ISBN 978-0-6392-0150-4
Printed in the Republic of South Africa

EXECUTIVE SUMMARY

WET-Health Version 2 consists of a series of three tools developed to assess the Present Ecological State (PES) or "ecological health" of wetland ecosystems of different hydrogeomorphic types at three different levels of detail/resolution. These tools build on previous assessment methods, including WET-Health Version 1 and Wetland-IHI, in response to the need that was identified to develop a refined and more robust suite of tools for the assessment of the PES of wetland ecosystems in South Africa. The suite of tools was developed through extensive engagement with key stakeholders to clarify user requirements for different types of wetlands and levels of PES assessment, and the tools have been tested across a variety of wetland hydrogeomorphic types and landuse contexts. Thus, WET-Health Version 2 has achieved the main project aim of integrating the existing Wetland PES assessment tools into a single suite of tools which are in line with user requirements and which address the shortcomings of the previous methods.

The conceptual basis and structure of the method

WET-Health is designed to assess the PES of a wetland by scoring the perceived deviation from a theoretical reference condition, where the reference condition is defined as the un-impacted condition in which ecosystems show little or no influence of human actions. In thinking about wetland health or PES, it is thus appropriate to consider 'deviation' from the natural or reference condition, with the ecological state of a wetland taken as a measure of the extent to which human impacts have caused the wetland to differ from the natural reference condition.

Whilst wetland features vary considerably from one wetland to the next, wetlands are all broadly influenced by their climatic and geological setting and by three core inter-related drivers, namely hydrology, geomorphology and water quality. The biology of the wetland (in which vegetation generally plays a central role) responds to changes in these drivers, and to activities within and around the wetland. The inter-relatedness of these four components is illustrated schematically in **Figure 1** below and forms the basis of the modular-based approach adopted in WET-Health Version 2.

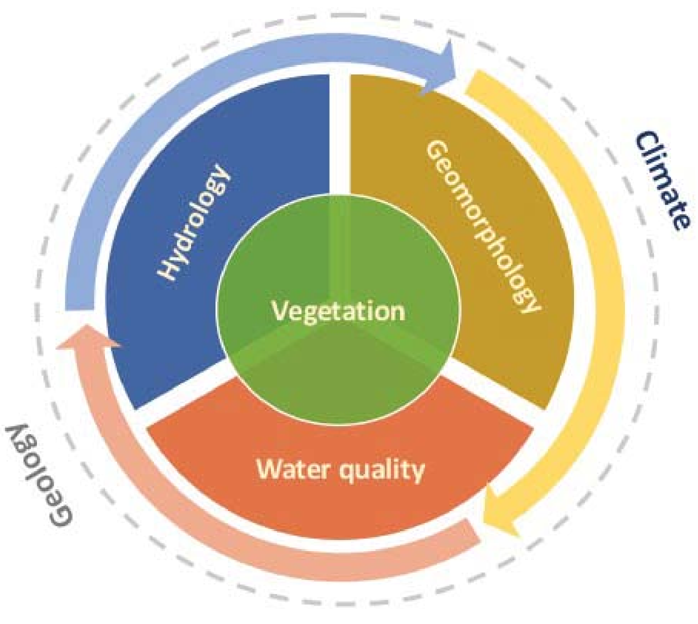

Figure 1. Diagram representing the four key components of Wetland PES considered in WET-Health Version 2.

In WET-Health, the natural reference condition of a wetland is inferred from conceptual models relating to the selected hydro-geomorphic (HGM) wetland type, the selected hydro-geological type setting and knowledge of vegetation attributes of similar wetlands in the region. PES is then assessed by evaluating the extent to which anthropogenic activities have altered wetland characteristics across the four inter-related components of wetland health, as follows:

- ***Hydrology*** is defined in this context as the distribution and movement of water through a wetland and its sediments. This module focuses on (i) changes in water inputs that result from human alterations to the catchment which affect water inflow quantity and pattern, and (ii) modifications within the wetland itself that alter the water distribution and retention patterns of the wetland (e.g. artificial drainage channels). These aspects are then integrated into a composite score that reflects the overall change in wetland hydrology.
- ***Geomorphology*** in this context is assessed by assessing changes to (i) geomorphic processes and (ii) the geomorphic structure of the wetland. Geomorphic processes in this context, refers to those physical processes that are currently shaping and modifying wetland form and evolution, whilst geomorphic structure refers to the three-dimensional shape of sediment deposits on which wetland habitat is established. Whilst catchment drivers (similar to those assessed in the hydrology module) are integrated as part of the assessment, impacts are ultimately assessed based on an understanding of the degree to which within-wetland geomorphic processes and the associated structure of the wetland have been altered by anthropogenic activities. The module also accounts for differences in geomorphic processes in wetlands characterised by clastic (minerogenic) sedimentation and those characterised by organic sediment accumulation (peat).
- ***Water quality*** is defined as the physico-chemical attributes of the water in a wetland. It is assessed based on considering both potential diffuse runoff from landuses within the wetland and from the areas surrounding the wetland, together with point-source discharges of pollution entering directly into the wetland and/or into streams that flow into that wetland.
- ***Vegetation*** is defined in this context as the structural and compositional state of the vegetation within a wetland. This module evaluates changes in vegetation composition and structure as a consequence of current and historic on-site transformation and/or disturbance. Whilst the assessor needs to have some knowledge of vegetation in a particular region, the method does not require the assessor to be able to identify all wetland plant species. The emphasis is rather on identifying alien and ruderal (weedy) species that indicate disturbance, and assessing their occurrence relative to common naturally occurring indigenous species, including those that are naturally dominant in the wetland.

In order to undertake such an assessment, the wetland must be mapped, together with different “external areas of influence” making up the catchment of the wetland. The predefined “external areas of influence” include the area immediately adjacent to a wetland to account for impacts associated with the local upslope catchment (with a 200 m wide GIS buffer around the wetland recommended to represent this area), and the broader remaining catchment area that includes all portions of the catchment beyond the 200 m GIS buffer areas. In the case of more detailed assessments (at Level 1B and Level 2, as explained below), the areas along the edges of the inflowing channels of a wetland up to the catchment boundary are also delineated and considered separately to account for the increased impact of landuses close to influent streams relative to those occurring further away (again, a 200 m wide GIS buffer adjacent to inflowing streams is recommended to represent this area). This approach is used to account for variation in the natural functioning of different HGM types by applying different relative weightings to activities in each of the external areas of influence.

A standardised approach to scoring impacts has been adopted, which involves quantifying the extent and intensity of impacts to determine an overall “magnitude of impact” score. The extent of impact is measured as the proportion of a wetland and/or area of influence in the catchment that is affected by an activity, expressed as a percentage. The intensity of impact is estimated by evaluating the degree of alteration that results from a given activity, with scores ranging from 0 (no impact) to 10 (critical impact). The assessment accounts for a broad variety of stressors, including catchment alterations (e.g. extent of tree plantations in the catchment) and impacts in the wetland itself (e.g. the excavation of artificial drainage furrows). These impacts are assessed either directly by rating response indicators (e.g. species composition of the vegetation relative to its natural composition) or by assessing stressor indicators (e.g. extent of landcover in the catchment or the density, depth and orientation of artificial drainage furrows), to estimate impacts on wetland condition. Given the lack of baseline reference-wetland studies in South Africa, WET-Health focuses mainly on stressor indicators, but uses some response indicators, particularly when assessing impacts to the composition of wetland vegetation.

Indicators are aggregated in structured algorithms to derive an overall impact score for each component of wetland health. The algorithms are not simulation models but are designed to generate an index that reflects the extent of departure from natural reference conditions. The indicators are combined in a way that represents the authors' understanding of their relative importance at the time of developing this method. The rationale behind the selection of each indicator is provided, together with the rationale for combining the scores for the different areas of influence and indicators into a final impact score. Although the relationship of the aggregated scores and indicators of the method to the underlying processes have not been validated in a quantitative sense, the assumptions behind the method are provided and are supported by the international literature. Therefore WET-Health is open to progressive refinement where specific assumptions are found to be inadequate or incorrect.

The impact scores that generated are translated into PES scores, which reflect the similarity to the natural reference condition. The PES scores are then used to place a wetland into one of several Ecological Categories that are consistently applied across all freshwater assessments in South Africa. These categories (and associated ranges of PES scores) are as follows:

- Ecological Category A: Natural (90-100%)
- Ecological Category B: Largely natural with few modifications (80-89%)
- Ecological Category C: Moderately modified (60-79%)
- Ecological Category D: Largely modified (40-59%)
- Ecological Category E: Seriously modified (20-39%)
- Ecological Category F: Critically modified (0-19%)

Whilst scores for each component of wetland PES are calculated separately, individual scores from each component may also be combined into an overall PES score by weighting the component scores according to a pre-defined formula, as follows:

[Overall (Combined) PES Score] = ([(Hydrology score) x 3] + [(Geomorphology score) x 2] + [(Water Quality score) x 2] + [(Vegetation score) x 2)] ÷ 9).

This formula is refined by doubling the weighting for hydrology in situations where the wetland's hydrology has been seriously or critically modified (Ecological Category E/F). This reflects the overriding importance of hydrology in maintaining wetland processes.

Levels of assessment

Three different levels of assessment have been developed to account for a broad range of user requirements, ranging from regional assessments involving thousands of wetlands through to detailed site-based assessments used to identify specific stressors and impacts on a single wetland for management and rehabilitation planning. In each instance, the assessment is based initially on a landcover assessment that seeks to provide an initial indication of wetland condition based on a generic understanding of the impacts of different landuses on catchment and wetland processes and characteristics. The assessment is refined for more detailed assessments by integrating finer-scale mapping, and a combination of additional desktop and site-based indicators to refine and improve the accuracy of the assessments. The following three levels of assessment are catered for in the method:

- ***Level 1A (desktop-based, low resolution)***, is an entirely desktop-based assessment and uses only pre-existing landcover data (i.e. no interpretation of aerial imagery by an assessor is required) and for which default impact intensity scores have been allocated for each component of wetland PES. In many cases, particularly when applied at a national level, it is not possible to delineate the upslope catchment of each of the individual wetlands. Instead, the landcover types in a GIS buffer around a wetland and within a "pseudo-catchment" selected to represent the true catchment (such as a sub-quaternary catchment) is used as a coarse proxy of the impacts on the wetland arising from its upslope catchment. Impacts arising from the wetland and catchment are then integrated through structured algorithms to provide a coarse indication of wetland health.

- ***Level 1B (desktop-based, high resolution)***, is also largely desktop-based using pre-existing landcover data but makes a few finer distinctions than Level 1A in terms of landcover types and usually requires interpretation of the best available aerial imagery in order to do so. This also allows the pre-defined land-cover types to be mapped more accurately. Furthermore, the upslope catchment of each wetland can be individually delineated at this level, and landcover in this area is used as a proxy of the impacts on a wetland arising from its upslope catchment. As for Level 1A, impacts arising from within individual wetlands are inferred from landcover types occurring within the delineated wetlands.
- ***Level 2 (rapid field-based assessment)***, starts with landcover mapping, but is refined by assessing a range of catchment and wetland-related indicators that are known to affect wetland health. Impacts arising from the upslope catchment of a wetland are inferred from landcover mapping but are refined based on additional information (e.g. for plantations, the user must indicate whether the trees making up the plantations are eucalypts or pines and/or wattle). Landcover types occurring within the wetland are used as the starting point for assessing human impacts arising from within the wetland. However, this initial assessment is refined considerably by sub-dividing the wetland into relatively homogenous "disturbance units" and answering a suite of site-based wetland questions which provide a more direct assessment of change (e.g. the density, depth and orientation of artificial drainage channels, and the texture of the soil in the wetland).

Accounting for differences and evaluating the anticipated trajectory of change

WET-Health Version 2 caters for differences in the inherent vulnerability of wetlands to anthropogenic impacts. This is accounted for in the method by introducing a range of modifiers that account for aspects such as the wetland's climatic setting, linkage to regional aquifers and susceptibility to erosion. Differences between HGM types are also specifically accounted for by varying the weightings of different indicators to account for differences in sensitivity to anthropogenic impacts and the relative importance of different areas of influence in driving natural wetland processes.

It is recognised that the method may not adequately cater for every situation, and expert review and refinement of impact scores is encouraged based on additional information and expert interpretation. This is accommodated in the Level 1B and Level 2 assessments by allowing the assessor to review and moderate scores with appropriate justification.

Whilst the main emphasis of the assessment is on assessing PES, a more thorough understanding of wetland health requires not only a diagnosis of current condition but also requires an evaluation of the trajectory of change. This is particularly relevant to detailed assessments that are undertaken to inform management actions and decision making. The likely trajectory of change is therefore also integrated into the Level 1B and Level 2 assessments. This involves simply rating the following categories: large improvement (↑↑), slight improvement (↑), remains the same (→), slight decline (↓) and large decline (↓↓) for each component of wetland health. The overall health of a wetland is then presented for each module by jointly presenting the PES category and the likely Trajectory of Change, e.g. C↓.

Key changes made to WET-Health Version 2.0

WET-Health Version 2.0 has a similar structure to the original version but has been comprehensively revised, incorporating elements of the Wetland IHI method and previous work undertaken to infer impacts on wetlands based on landcover types in the wetland and its catchment. Some specific changes made to the method, in going from Version 1 to Version 2.0, include:

- A stronger emphasis on landcover information and the mapping of landuses, particularly for desktop assessments;

- The explicit provision of two desktop-based levels of assessment (i.e. Levels 1A and 1B), with the spreadsheet for Level 1A purposefully designed to cater for the assessment of multiple wetlands (up to 2 000) at a time for broad-scale applications;
- More focussed integration of differences in wetland type, and an expansion of the method to specifically cater for wetland types not previously accommodated;
- A comprehensive revision of the geomorphology module, which now clearly differentiates between impacts to geomorphic structure and impacts to geomorphic processes;
- The addition of a water quality module, which was not included in the previous version;
- An overhaul of the spreadsheets, with the inclusion of additional drop-down boxes for the selection of options and many more automated calculations, in an attempt to make the spreadsheets more user-friendly;
- Restructuring of the spreadsheet for a Level 2 assessment to facilitate more rapid data entry and avoid duplication, by grouping the indicators that need to be considered into a list of "catchment questions" and a list of "wetland-related questions", instead of grouping the indicators by module;
- Integration of new research and information to refine scoring guidelines.

Conclusions and recommendations

The development of the elements listed above all represent important findings of the project and should contribute significantly to the generation of new knowledge relating to the ecological condition of wetlands in South Africa. This knowledge represents both the knowledge distilled into the tools themselves, as well as how the tools are anticipated to better equip practitioners and scientists in the future to add more effectively to the pool of knowledge relating to the PES of South Africa's wetlands.

Whilst the development of the refined suite of tools making up WET-Health Version 2.0 is thought to represent a significant advancement in the practice of wetland assessment in South Africa, it is important to emphasise that some assumptions of the revised method remain largely untested and should be validated and refined through further research and testing. As such, it is recommended that research on factors affecting the various components of wetland condition should be actively encouraged and be used to provide recommendations for further refinements to the method. Application of the method in other countries should also be actively encouraged, since the underlying principles and associated scoring system are likely to be valid, particularly in other temperate regions.

It is strongly recommended that a User Manual should be produced for WET-Health Version 2, to accompany and support the Technical Guide that has been produced in the current report. In addition, training material should be developed and a series of training courses should be rolled out across the country for WET-Health Version 2, once the User Manual has been produced. This will greatly facilitate the proper application of the tools, and should lead to more robust wetland PES assessments in South Africa with better consistency between assessors.

ACKNOWLEDGEMENTS

The authors would like to thank the following Reference Group members for their valuable input and constructive discussions at Reference Group meetings:

Umesh Bahadur	– Department of Environmental Affairs
Craig Cowden	– Groundtruth Consulting
Dr Helen Dallas	– Freshwater Research Centre (FRC)
Shaddai Daniel	– Department of Water & Sanitation (DWS)
Fiona Eggers	– Groundtruth Consulting
Dr Andrew Gordon	– Previously DWS
Dr Michael Grenfell	– University of the Western Cape (UWC)
Jeanne Gouws	– CapeNature
Retief Grobler	– Imperata Consulting
Nancy Job	– South African National Biodiversity Institute (SANBI), previously UFS
Wilna Kloppers	– Department of Environmental Affairs & Development Planning (DEA&DP)
Prof Pieter Le Roux	– University of the Free State (UFS)
Namhla Mbona	– SANBI
Dr Dirk Roux	– South African National Parks (SANParks)
Heidi van Deventer	– Council for Scientific & Industrial Research (CSIR)
Dr Damian Walters	– Ikhwane Wetland Science

In addition, the project team would like to thank Mr Bonani Madikizela and Ms Gerda Kruger of the Water Research Commission (WRC) for their administrative assistance throughout the duration of this project.

The following people are gratefully acknowledged for their contribution to this report, in particular:

- Dr Michael Grenfell (UWC) for contributing to and reviewing the Geomorphology chapter, and for assisting with the development of the conceptual model for the Geomorphology module.
- Dr Heather Malan (FRC) for thoroughly reviewing draft versions of the report and providing valuable guidance.
- Tumisho Ngobela (FRC) for providing contributions relating to the desktop-based “Level 1” assessments, especially in relation to GIS aspects.
- Dr Eddie Riddell, Dr Piet-Louis Grundling and Dr Althea Grundling for valuable inputs to Appendix A on the development of a conceptual model of how water enters, passes through and leaves a wetland.

Special thanks are also due to:

- Prof William Ellery (Rhodes University), Dr Damian Walters (SANBI) and Ryan Edwards (Eco-Pulse) for contributing to the development of the revised Geomorphology module.
- Dr Justine Ewart-Smith (FRC) and Dr Heather Malan (FRC) for contributing to the development of the Water Quality module.
- Dr David Clark for assistance in providing a practical method for estimating dam volume in the Hydrology Module.
- Prof Pieter Le Roux (UFS) for valuable hydropedological perspectives shared on the development of the tools.
- Dr Nacelle Collins for testing and investigating ways to improve the usability of the tools developed for desktop-based assessments.
- All those who attended and gave input at the stakeholder workshop in November 2016, as well as other stakeholders who provided valuable input during the early stages of the project. Particularly significant contributions were made by Mark Rountree (Fluvius Consulting), Gary Marneweck (Wetland Consulting Services), Ian Bredin (INR) and Nancy Job (SANBI).
- The Eco-Pulse Team for ongoing support and willingness to test and apply working drafts of the methods.
- FRC interns who assisted with various tasks on the project, especially Toni Olsen, Philip Frenzel and Terriann Thavar.
- Janette Lumley (FRC administrative assistant) for helping with administrative tasks and the minutes of the final Reference Group meeting.

Lastly, the project team wish to acknowledge the developers of both Wetland-IHI and the original version of WET-Health, and the authors of the reports accompanying these assessment tools. These tools and accompanying documentation have been extremely influential as key informants for the current project.

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LIST OF ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit (ex-University of Natal, South Africa)
ALARM	Automated Land-based Activity Risk Assessment Method (DWA, 2013)
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CVB	Channelled valley-bottom wetland
CVB-chan	Channelled valley-bottom wetland not laterally maintained
CVB-lat	Channelled valley-bottom wetland laterally maintained
DAFF	Department of Agriculture, Forestry & Fisheries
DEM	Digital Elevation Model
DEP	Depression
DEP-endo	Endorheic depression (i.e. without flushing)
DEP-exo	Exorheic depression (i.e. with flushing)
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
DWS	Department of Water & Sanitation
EIA	Environmental Impact Assessment
FOSS	Free Open Source Software
FP	Floodplain wetland
FRC	Freshwater Research Centre
GIS	Geographical Information System
GMI	Groundwater Management Institute
HGM	Hydro-geomorphic
IBI	Index of Biotic Integrity
ICLEI	International Council for Local Environmental Initiatives (also known as Local Governments for Sustainability)
IHI	Index of Habitat Integrity
KZN	KwaZulu-Natal
LC	Landcover
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MS	Microsoft©
N	Nitrogen
NBA	National Biodiversity Assessment
NFEPA	National Freshwater Ecosystem Priority Areas
NGI	National Geospatial Information
NGIS	National Groundwater Information System
NLC	National Land Cover (dataset)
NWMP	National Wetland Monitoring Programme
P	Phosphorus
PES	Present Ecological State
PET	Potential Evapo-transpiration

REMP	River EcoStatus Monitoring Programme
SADC	Southern African Development Community
SANBI	South African National Biodiversity Institute
SCS-SA	Soil Conservation Services for Southern Africa
SQ4	Sub-Quaternary (catchments)
SUDS	Sustainable Urban Drainage Systems
TDS	Total Dissolved Solids (or Total Dissolved Salts)
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
UVB	Unchannelled valley-bottom wetland
WQ	Water Quality
WRC	Water Research Commission
WWTW	Wastewater Treatment Works

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1. INTRODUCTION

1.1. Background and aims of the project

Determining the Present Ecological State (PES) of wetland ecosystems (see **Box 1.1**) is central to wetland-related management and decision-making in South Africa. It is also a legal requirement for a number of water resource management processes, specifically those established through the National Water Act (Act No. 36 of 1998) such as Ecological Reserve determination[1], and EcoClassification and EcoStatus determination[2].

BOX 1.1: What is "PES"?

Present Ecological State, or PES, is the formally recognised term for the present ecological condition of inland aquatic ecosystems in South Africa. The following definition, adapted from a definition for "wetland condition" put forward by the United Stated Environmental Protection Agency (US EPA 2004), encapsulates the meaning of the term:

The PES refers to the current state, compared to reference or best state, for the physical, chemical, and biological characteristics* of an ecosystem.

*Synonymous with "resource quality characteristics" (as per the National Water Act, No. 36 of 1998)

Whilst a range of tools have been developed to inform the assessment of wetland PES, the Wetland Index of Habitat Integrity (Wetland-IHI, after DWAF, 2007) and WET-Health Version 1 (Macfarlane *et al*., 2008) have, in recent years, become the most widely applied across the country. There has been some confusion regarding which of these tools to use under various scenarios and, in an attempt to address this, a WRC project (K5/2192) was initiated to conduct a gap analysis for wetland integrity assessment methods used in South Africa (Ollis & Malan, 2014). The findings of the gap analysis by Ollis & Malan (2014) highlighted strengths and weaknesses of both the WET-Health Version 1 and Wetland-IHI approaches, and showed that there are concerns with the consistency of scores achieved when either of these tools is applied by different users. A recently completed project to develop the framework for a National Wetland Monitoring Programme (NWMP) for South Africa (WRC Project K5/2269) subsequently identified the need to address the gaps and limitations of the existing wetland PES assessment methods amongst the high-priority needs for the implementation of the NWMP (Wilkinson *et al*., 2016).

The current project (WRC Project K5/2549) was formulated to address the clear need that has been identified for a refined suite of tools for the assessment of the PES of wetland ecosystems in South Africa. More specifically, the project focussed on the development of a suite of tools that integrates aspects of the existing tools into a nationally-applicable approach for the rapid assessment of Wetland PES, which as far as possible builds on the strengths and addresses the weaknesses of these existing tools. The ultimate goal was to provide a robust, rigorously tested suite of tools that can be used to categorise the present ecological condition of all wetland types.

The primary aims of the project were as follows:

(1) To engage with key stakeholders to clarify user requirements for a wetland PES assessment tool (or suite of tools), and to agree on a framework for different types of wetlands and levels of PES

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[1] A good explanation of the "Ecological Reserve", in the context of wetland ecosystems, is provided in the Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0) by Rountree *et al*. (2013).

[2] These concepts, and the relevant procedures, are explained in the River EcoClassification Manual for EcoStatus determination (Version 2) by Kleynhans & Louw (2008).

assessment;

(2) To integrate the existing Wetland PES assessment tools into a single suite of user-friendly tools, in line with user requirements, and to address the shortcomings of the existing methods; and
(3) To undertake iterative testing of draft versions of the PES assessment tools so as to continually refine and improve the tools that are developed.

1.2. Naming the refined suite of tools

The refined suite of Wetland PES assessment tools that have been developed through the current project have been named "WET-Health Version 2.0", motivated by the following reasons:

- The overarching framework for the tools remains largely unchanged from that of WET-Health Version 1 (Macfarlane *et al*., 2008).
- Large parts of the original WET-Health tools and accompanying guideline document have been retained in this update.
- WET-Health, as a brand, has a growing reputation locally and internationally (with numerous citations in journal articles, theses and consulting reports).
- The main tool produced through the current project includes an assessment of both PES and Trajectory of Change, which together provide an indication of "wetland health" as in WET-Health Version 1.
- The update of WET-Health Version 1 would be in line with the current update of the original version of the WET-EcoServices tool (Kotze *et al*., 2008) as part of another WRC project (Project K5/2737), both of which form part of the "Wetland Management Series" produced by the WRC.

Further motivation is provided by the statement in the document for the original version of WET-Health that, "it is hoped that WET-Health will be refined in subsequent versions to update and improve the assessment procedure" (Macfarlane *et al*., 2008, p. 17).

Notwithstanding the naming of the refined tools that have been produced, it is important to acknowledge, up-front, that the refinements were also informed by the ideas and approach of the Wetland-IHI previously developed for DWAF (2007).

1.3. Purpose and scope of WET-Health Version 2.0

The purpose of WET-Health Version 2 is to provide guidance for assessing the Present Ecological State (PES) or health of wetlands at three different levels of detail/resolution. It does this by means of three tools:

- Level 1A assessment, a desktop-based tool of low resolution based an automated assessment of nationally available landcover data;
- Level 1B assessment, a desktop-based tool using higher resolution landcover data and some "heads up" interpretation of aerial imagery of the study area by the assessor, as well as potentially involving limited field verification; and
- Level 2 assessment, a field-based rapid assessment tool which begins with a Level 1B assessment and refines this assessment through the rapid evaluation of a set of field indicators.

Whilst the tools have been customised specifically for application in the South African context, they cater for a broad suite of wetland types from depressions to floodplain systems and address a broad suite of impacts that are common to most wetlands worldwide. The application and testing of the tools in other regions is therefore strongly encouraged, particularly where locally developed tools are not available.

1.4. Key changes made to WET-Health in going from Version 1 to Version 2.0

Whilst WET-Health Version 2.0 has a similar structure to the original version, it has been comprehensively revised, incorporating elements of Wetland IHI (DWAF, 2007) and the landcover-based methods of Malan *et al*. (2013) and Kotze (2016a, b). Some key changes made to the method, in going from Version 1 to Version 2.0, include:

- A stronger emphasis on landcover information and the mapping of landuses, particularly for desktop-based assessments;
- The explicit provision of two desktop-based levels of assessment (i.e. Levels 1A and 1B), with the spreadsheet for Level 1A purposefully designed to cater for the assessment of multiple wetlands (up to 2 000) at a time for broad-scale applications;
- More focussed integration of differences in wetland type, and an expansion of the method to specifically cater for wetland types not previously accommodated;
- A comprehensive revision of the geomorphology module, which now clearly differentiates between impacts to geomorphic structure and impacts to geomorphic processes;
- The addition of a water quality module, which was not included in the previous version;
- An overhaul of the spreadsheets, with the inclusion of additional drop-down boxes for the selection of options and many more automated calculations, in an attempt to make the spreadsheets more user-friendly;
- Restructuring of the spreadsheet for a Level 2 assessment to facilitate more rapid data entry and avoid duplication, by grouping the indicators that need to be considered into a list of "catchment questions" and a list of "wetland-related questions", instead of grouping the indicators by module as before;
- Integration of new research and information to refine scoring guidelines.

The changes to WET-Health in Version 2.0 are thought to represent a significant advancement in the practice of wetland assessment in South Africa. At the same time, however, it is important to emphasise that some assumptions of the revised method remain largely untested and should be validated and refined through further research and testing. As such, research on factors affecting the various components of wetland condition should be actively encouraged and be used to provide recommendations for further refinements to the method.

1.5. Purpose of the current report

The main purpose of this report is to describe the refined methods that have been developed, and to explain the suite of accompanying spreadsheet tools that have been compiled.

It is important to note that this report is **not a User Manual** for the refined tools that have been developed, but rather a technical guide providing an explanation of the factors that have been included and the rationale behind the way in which scores have been derived in the tools.

Through the development and testing of the tools, and through engagement with stakeholders, the clear need for the compilation of a professionally published User Manual as a follow-on from the current project was confirmed.

2. APPROACH TAKEN TO DEVELOP THE REFINED TOOLS

2.1. Engagement with key stakeholders

In recognition of the critical importance of ensuring that the refined suite of wetland PES assessment tools was developed in a collaborative and participatory manner, a key focus of the first phase of the current project was to understand the user requirements and concerns of stakeholders. The approach that was taken during the first phase of the project was to have a number of informal and semi-formal meetings with groups of people or individuals who were identified to be key role players. More details about the approach that was taken and the meetings that were held are provided in a Workshop Proceedings Report that was produced by the project team (Deliverable 3 of WRC Project K5/2549)[3]. The report also provides a summary of the preliminary feedback received from stakeholders at that stage of the project.

In preparation for the formal engagement with key stakeholders, the project team completed a review of existing methods used, both in South Africa and internationally, for the assessment of the PES of wetlands. This review, which was summarised in an Inception Report prepared by the project team (Deliverable 2)[4], considered methods that have been developed for broad-scale (desktop-based) application and those that have been developed for site-specific, field-based application. The Inception Report also provided a description and comparison of the different theoretical approaches that can be followed in the assessment of the PES of wetland ecosystems.

2.2. Integration of existing Wetland PES assessment approaches into a suite of user-friendly tools

The engagement with stakeholders during the first phase of the current project revealed that there is an urgent and growing need in South Africa for methods to assess wetland PES at broad spatial scales. Considerable effort was thus directed towards the development of desktop-based ("Level 1") assessment tools that attempt to address this need, using the more detailed ("Level 2") tools as a point of departure. For these desktop-based assessment methods (see **Section 4**), the project team worked in collaboration with the project team responsible for compiling the 2018 National Biodiversity Assessment (NBA-2018).

Some of the existing tools from which aspects were integrated into the refined suite of tools that have been developed included the original version of WET-Health (Macfarlane *et al*., 2008), Wetland-IHI (DWAF, 2007), the Classification System for inland aquatic ecosystems published by SANBI (Ollis *et al*., 2013), the Decision Support Protocol developed by Ollis *et al*. (2014) to facilitate the rapid assessment of wetland ecological condition in South Africa, the landuse – water quality tool for wetlands developed by Malan *et al*. (2013), the Buffer Zone Guidelines for rivers, wetlands and estuaries (Macfarlane & Bredin, 2017a,b), and a method developed by Kotze (2016a,b) to assess wetland ecological condition based on landcover type.

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[3] Ollis D, Macfarlane D and Kotze D (2016). WRC Project K5/2549: Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems. Deliverable #3: Proceedings of Workshop Meetings. Unpublished report prepared for the Water Research Commission, November 2016. Available upon request from the Freshwater Research Centre (FRC) or the Water Research Commission (WRC).

[4] Ollis D, Macfarlane D and Kotze D (2016). WRC Project K5/2549: Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems. Deliverable #2: Revised Inception Report ("Starter Document" for Workshops and Discussions). Unpublished report prepared for the Water Research Commission, October 2016. Available upon request from the FRC or WRC.

The suite of tools that has been developed consists of a series of spreadsheets created in Microsoft Excel and the Free Open Source Software (FOSS) equivalent of MS Excel, LibreOffice Calc. All of the tools have been designed to automatically generate output scores and results, once the required input information has been entered into the relevant worksheets. This required the use of many formulae and cross-references to other cells or worksheets. As such, one of the main tasks during the preliminary phase of testing was to check for errors relating to all the calculations within the draft spreadsheets (mostly using "dummy data").

2.3. Testing and refinement

Working versions of the preliminary draft spreadsheet tools were applied to real-life test cases, mainly by the core members of the Project Team but also by a few wetland specialists not on the Project Team. Each test site/area was used to evaluate particular aspects of the tools and/or specific levels of assessment. Explanations of the way in which test sites/areas were selected and the tasks that were completed for each test site/area are provided below.

Due to a limited budget being available for the testing of the draft suite of tools, opportunities were sought where the draft tools could be applied to test cases as part of, or in collaboration with, other research and consulting projects. Additional test cases were identified in areas where field-verified PES data were available from previous assessments, which could be compared against the desktop-based results of the draft tools. Through this process, the following sites/areas were selected for the preliminary testing of the draft tools:

- A valley-bottom wetland in a conservation area associated with the Wild Coast Sun, just south of Port Edward (Eastern Cape Province), where the 2017 National Wetlands Indaba was held. An optional field trip to this wetland formed part of the programme for the Indaba.
- The Mnquma Local Municipality within the Amathole District Municipality (Eastern Cape), where Eco-Pulse Environmental Consulting Services were busy with a desktop-based wetland mapping and condition assessment for the Municipality on behalf of ICLEI involving more than 1000 wetlands in the study area (Eco-Pulse Consulting, 2018).
- A selection of wetlands near to Worcester in the Breede River catchment (Winelands District Municipality, Western Cape), for which field-verified delineations had previously been completed.
- A selection of wetlands in the Mgeni Sponge area near the headwaters of the Mgeni River (KwaZulu-Natal), for which field-verified PES data were available from a wetland health assessment of KZN's priority wetlands (Macfarlane *et al*., 2011).
- A selection of wetlands on the Bokkeveld Plateau near to Nieuwoudtville (Northern Cape), for which baseline monitoring data were available from assessments completed by the Mondi Wetlands Programme for the Northern Cape Department of Environment and Nature Conservation (Job *et al*., 2011).
- A selection of arid-zone wetlands near to Kenhardt in the Hantam Local Municipality (Namakwa District Municipality, Northern Cape), for which field-verified PES data were available from an Environmental Impact Assessment completed by the Freshwater Consulting Group (Snaddon, 2016).
- A selection of wetlands (mostly pans) in the Mpumalanga Highveld region, where GroundTruth Consulting were busy with field-based wetland assessments.
- Kolofini Wetland within the Mnqunu Local Municipality (Eastern Cape), which is a valley-bottom wetland prioritised for rehabilitation intervention through the ICLEI project relating to wetlands in the Amathole District and for which field-verified PES data were available.
- Papenkuils floodplain wetland in the Breede River Valley near Worcester (Western Cape), for which field-verified PES data were available.
- A dune-slack wetland on the coastal plain at Van Riebeekstrand along the West Coast (within the City of Cape Town, Western Cape), for which field-verified PES data were available from a previous

assessment completed by the Freshwater Consulting Group (Olsen & Ngobela, 2017).

The main aspects that were tested using the broader scale case-study examples were a comparison between the results from the desktop-based tool with those generated through application of the desktop-based wetland condition modelling method used in the National Freshwater Ecosystem Priority Areas (NFEPA) project (Nel *et al*., 2011), and a comparison of the desktop-based results with field-verified PES data. The latter was of more importance and value to the current project than testing one desktop-based method against another. The Worcester, Mgeni Sponge, Bokkeveld Plateau and Hantam Local Municipality study areas, where a selection of wetlands with field-verified PES data were available in each case, were used for this testing.

The more detailed, site-specific testing was done to interrogate the field-based tools, again using previously field-verified PES data as a point of comparison, and to evaluate the degree of congruency between the different levels of assessment (i.e. desktop versus field-based tools). This testing was undertaken using the Wild Coast Sun valley-bottom wetland, the wetlands (mostly pans) in the Mpumalanga Highveld region where GroundTruth Consulting were busy with field-based wetland assessments, the Kolofini valley-bottom wetland, the Papenkuils floodplain wetland, and the Van Riebeekstrand dune slack wetland. For the Kolofini, Papenkuils and Van Riebeekstrand cases, field-verified results from previous PES assessments based on WET-Health Version 1 were available as a point of comparison. For all the more detailed test cases, in addition to interrogating and evaluating the worksheets associated with the field-based tool, a comparison was also made between the results generated using the desktop-based and field-based tools.

Based on the above-mentioned (broad-scale and site-specific) test cases, a report on the preliminary testing and refinement of the draft suite of Wetland PES assessment tools was produced by the Project Team (Deliverable 5)[5]. The key findings of this preliminary case-study testing report were used to further refine the tools.

After a number of iterative refinements to the spreadsheet-based tools, and application to additional test cases, the final versions of the tools were re-applied to the previous case study wetlands. This allowed for a comparison of the outputs, to gauge whether there was an improvement in the results generated by the revised versions of the tools, and provided a final opportunity to make minor adjustments to the tools.

[5] Ollis D, Macfarlane D, Kotze D and Ngobela T (2018). WRC Project K5/2549: Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems. Deliverable #5: Report on preliminary testing and refinement of draft suite of Wetland PES assessment tools. Unpublished report prepared for the Water Research Commission, June 2018. This "case study report" is available upon request from the FRC or WRC.

3. ASSESSMENT FRAMEWORK FOR THE SUITE OF TOOLS

The overarching framework for the refined suite of Wetland PES assessment tools contained within WET-Health Version 2.0 is described in the sub-sections below. The framework is based on that of the original version of WET-Health (Macfarlane *et al*., 2008) and Wetland-IHI (DWAF, 2007), with adaptations introduced to facilitate application across a wide range of spatial scales and to improve alignment with the EcoClassification and EcoStatus procedures (after Kleynhans & Louw, 2008) of the Department of Water & Sanitation (DWS).

3.1. Consideration of four key components of Wetland PES

The ecological setting of a wetland is largely determined by the geology, topographic position, and climatic conditions under which the wetland was formed and is now located. Wetland features vary considerably from one wetland to the next, even within the same broad ecological setting, and are broadly influenced by three core inter-related drivers: (1) Hydrology, (2) Geomorphology and (3) Water quality (i.e. physico-chemical attributes). The biology of the wetland (in which vegetation generally plays a central role) responds to changes in these drivers, and to activities within and around the wetland. The inter-relatedness of these four components is illustrated schematically in **Figure 3.1** and forms the basis of the modular-based approach adopted in WET-Health Version 2.0.

Given the understanding of the key components affecting the ecological characteristics and functioning of wetland ecosystems, as summarised in **Figure 3.1**, the suite of tools developed for WET-Health Version 2.0 assesses wetland PES on the basis of four modules: (1) Hydrology, (2) Geomorphology, (3) Water quality, and (4) Vegetation. These modules apply at all three levels of assessment that have been catered for (i.e. Levels 1A, 1B and 2), as described in **Section 3.6**.

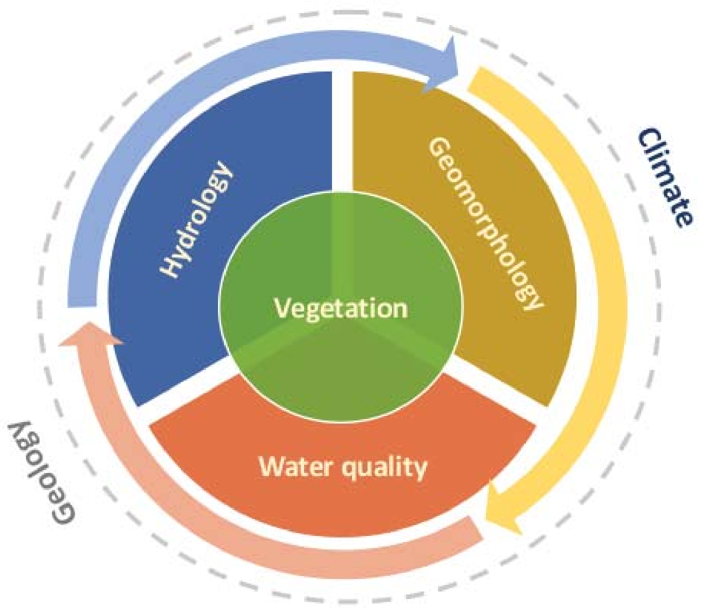

Figure 3.1. Schematic representing the four key components of Wetland PES considered in WET-Health Version 2.0.

3.2. Assessment relative to the natural reference state

For the suite of tools that have been developed, the PES is assessed against the natural reference state, which refers to an un-impacted condition in which ecosystems show little or no influence of human actions (Anderson, 1991). Indeed, the concept of wetland health or wetland PES is defined as a measure of the similarity of a wetland to a natural or reference condition (Macfarlane *et al*., 2008). In thinking about wetland health or PES, it is thus appropriate to consider 'deviation' from the natural or reference condition, with the ecological state of a wetland taken as a measure of the extent to which human impacts have caused the wetland to differ from the natural reference condition.

WET-Health Version 2.0 examines deviation from the natural reference condition for the four pre-defined components of Wetland PES discussed above. This premise, which is the frame of reference for most PES assessments, is important to bear in mind when applying the tools. In practice, however, it is often difficult to unambiguously define the natural reference state of a wetland. Some of the factors contributing to this difficulty are discussed below.

- Wetlands may vary greatly in terms of the key water inflows, throughflows and outflows sustaining a wetland. For example, some wetlands may be sustained primarily by inflows from a stream channel which flood across a wetland in major flood events, while other wetlands may be sustained primarily by sub-surface flows from the hillslopes adjacent to the wetland. See **Appendix A** for specific guidance in developing a coarse conceptual understanding the natural reference state of the hydrology of a wetland based a few key indicators.

- Wetlands are naturally dynamic systems, responding to changes at varying temporal and spatial scales. This is particularly evident in South Africa, with its geographically variable climate. Temporal variations range from daily, monthly and seasonal fluctuations (e.g. flood events), to long-term climate cycles (operating over time scales of decades, centuries and millennia). Wetlands are also a reflection of the geomorphological evolution of the landscapes in which they are found. Therefore, describing the natural reference state of a wetland requires considering the range of natural variability across broad time scales, rather than considering only a narrow "snap-shot" to represent the reference state. See **Appendix B** for guidance in identifying the typical range of geomorphic variability associated with different wetland types.

- Identifying the natural disturbance regime and the human influence on this regime may be difficult. Most of South Africa's wetlands evolved under natural disturbances, notably fire and indigenous grazers, and where these disturbances are removed then the impacts on the ecological state of a wetland are potentially profound (Kotze, 2013). Thus, maintenance of the minimally-impacted state of a wetland may require intentional human disturbances, which superficially appear to be negative impacts but are, in fact, maintaining a much closer-to-natural disturbance regime (and therefore a more natural wetland) than would be the case otherwise.

- Linked with the above issue, it is recognized that humans have long influenced disturbance regimes in southern Africa. Humans are, therefore, part of the natural disturbance regime of many southern African wetlands, albeit at a much lower intensity than is generally the case currently.

- Some landscapes have been so highly transformed by humans that no natural or minimally-impacted wetlands remain as representative examples that can be used to describe the reference condition of different types of wetland in a particular region. In such situations it may be more appropriate to refer to a "desired reference state", which would refer to some desired attainable state, for which key attributes would need to be described.

In WET-Health Version 2.0, the natural reference state of a wetland is inferred from the conceptual models relating to the selected hydro-geomorphic (HGM) wetland type (explained in **Sections 3.5 & 4.2**), the selected hydro-geological type setting (explained in **Section 4.7**) and the hydrological characteristics of the Quaternary catchment that the wetland is located in (explained in **Section 4.6**). As such, the assessor does not need to explicitly describe the characteristics of the perceived natural reference state of a wetland in order to apply WET-Health Version 2.0. In the tool that has been developed for more detailed field-based assessments, however, the assessor is required to provide a description of some additional indicators relevant to developing an understanding of the natural reference conditions (as explained in Step 2 under **Section 6.1**). In particular, information should be recorded about the characteristics of the channel associated with a wetland (if present), the natural wetness regimes of the wetland, and the broad vegetation attributes of the wetland (including notes about the suspected natural exposure to fires and grazing/trampling by indigenous herbivores). This information is not used by the tool to generate results, but rather serves to document the assessor's understanding of these aspects of the natural reference state.

3.3. Quantification of impacts

The overall approach used in WET-Health Version 2.0 is to quantify the impacts of human activity or clearly visible impacts on wetland condition, as far as possible, and then to convert the impact scores to a Present State score. The tools that have been developed attempt to standardise the way in which impact scores are calculated and presented across each of the modules. The standardised approach is to assess the spatial extent of impact associated with individual activities and then to separately assess the intensity of impact of each activity in the affected area. In some cases, particularly for desktop-based assessments, default intensity scores have been assigned to different types of impacts. The extent and intensity are then combined to determine an overall "magnitude of impact" score.

Extent, intensity and magnitude of impact are defined as follows:

- **Extent:** The proportion of the wetland and/or its catchment affected by a given activity (expressed as a percentage).
- **Intensity:** The degree to which wetland characteristics have been altered within the affected area. Intensity of impact is measured on a scale of 0-10, with a score of 0 representing no impact or deviation from natural, and a score of 10 representing complete transformation from natural.
- **Magnitude:** The overall impact of a particular activity or suite of activities on the component of wetland PES being evaluated. This is determined by calculating an area-weighted impact score such that the intensity of impact is scaled by its extent. The magnitude of impact is expressed on a scale of 0-10 by multiplying intensity by extent of impact as follows:
  Magnitude = Extent / 100 x Intensity

For example: If a given activity was affecting 25% of the wetland and its intensity was 4 (on a scale of 0-10), then the magnitude of the impact would be 25/100 x 4 = 1.0. However, if the same activity (intensity of 4) was affecting 75% of the wetland, then the magnitude of impact would be 75/100 x 4 = 3.0.

Once the magnitude-of-impact scores for individual activities and/or impacts have been calculated, these are combined in a structured way to provide a measure of overall impact on a scale of 1-10, which is scaled into six categories as shown and described in **Table 3.1**.

Table 3.1. Descriptions of the impact categories used in WET-Health, together with the applicable range of Impact Scores associated with each category

IMPACT CATEGORY	DESCRIPTION	IMPACT SCORE RANGE
None	No discernible modification or the modification is such that it has no impact on wetland integrity.	0-0.9
Small	Although identifiable, the impact of this modification on wetland integrity is small.	1-1.9
Moderate	The impact of this modification on wetland integrity is clearly identifiable, but limited.	2-3.9
Large	The modification has a clearly detrimental impact on wetland integrity. Approximately 50% of wetland integrity has been lost.	4-5.9
Serious	The modification has a clearly adverse effect on this component of habitat integrity. Well in excess of 50% of the wetland integrity has been lost.	6-7.9
Critical	The modification is present in such a way that the ecosystem processes of this component of wetland health are totally / almost totally destroyed.	8-10

3.4. Derivation of Ecological Categories

The ultimate aim of WET-Health Version 2.0 is to facilitate the derivation of an Ecological Category for each of the four components of wetland PES (introduced in **Section 3.1**) and an overall Ecological Category for each wetland that is being assessed. A common suite of Ecological Categories (or Present State Categories), ranging from A to F, are typically used in PES assessments of inland aquatic ecosystems in South Africa (see **Table 3.2**).

Table 3.2. Descriptions of the Ecological Categories typically used for PES assessments of inland aquatic ecosystems in South Africa, together with the applicable range of Impact Scores and PES Scores for each Category (after Kleynhans, 1996; Macfarlane et al., 2008) [colour-coding according to that of the River EcoStatus Monitoring Programme (REMP) of DWS]

ECOLOGICAL CATEGORY	DESCRIPTION	IMPACT SCORE*	PES SCORE (%)*
A	Unmodified, natural.	0-0.9	90-00
B	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1-1.9	80-89
C	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact	2-3.9	60-79
D	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota and has occurred.	4-5.9	40-59
E	Seriously modified. The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6-7.9	20-39
F	Critically modified. Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	0-19

* The Habitat Integrity methods developed by and for DWS (then DWAF) derive PES Scores that reflect the ecological integrity or intactness of the ecosystem, typically expressed as a percentage, whereas the WET-Health method developed for SANBI by Macfarlane *et al*. (2008) derives "impact scores" (scaled from 0 to 10) that reflect the degree of ecosystem modification

At all levels of assessment and for each of the four modules, the goal is to identify impacts and, based on these impacts, to determine the Ecological Categories provided in **Table 3.2**. It is recommended that the impact scores and associated Ecological Categories are best kept separate for each of the four modules, which helps focus wetland management on relevant activities. At the same time, however, it is recognised that, for certain applications, some users will want a single score and overall Ecological Category for a wetland. The refined tools for WET-Health Version 2 thus derive an integrated single score and associated Ecological Category, in addition to the individual scores and categories for each module.

3.5. Differentiation between HGM types

It is widely held that the hydrological and geomorphological attributes of a wetland, as expressed in the hydro-geomorphic (HGM) type (after Brinson, 1993), are intricately linked to the origins and present-day functioning of the wetland (e.g. Ellery *et al*., 2008, Kotze *et al*., 2008). As such, the differences between the various HGM types should be taken into account when assessing the PES of a wetland (Macfarlane *et al*., 2008). Central to WET-Health (Versions 1 & 2), therefore, is the characterisation of HGM units, which have been defined based on geomorphic setting, water source and pattern of water flow through (and out of) the wetland unit.

In South Africa, the most widely used HGM-based classification system for wetlands and other inland aquatic ecosystems is currently the one developed for SANBI (Ollis *et al*., 2013). The different HGM types, as specified in this wetland classification system, have been catered for in the suite of Wetland PES assessment tools that have been developed. At the same time, it is recognised that the extent to which inferences can be drawn from the HGM type, on its own, will depend strongly on the heterogeneity within the type. If an HGM type includes wetlands which are widely divergent in terms of attributes/processes, then the inferences drawn are likely to be unreliable.

In the refined tools that have been developed, an attempt has been made to account for at least some of the factors that lead to differences in the functional characteristics of certain of the primary HGM types. For example, for assessments at Levels 1B and 2 (explained in **Section 3.6**, below), depressions are distinguished on the basis of their outflow drainage (endorheic versus exorheic), and a distinction is made between channelled valley-bottom wetlands that are dominated by lateral inputs versus those that are dominated by overbank flows from the through-flowing channel. More details about the classification of HGM types in WET-Health Version 2.0 is provided in **Section 4.2**.

Within each module of WET-Health Version 2.0, as in the original version of the tool, the scoring for various aspects has been weighted according to HGM type, in an attempt to account for the differences highlighted above. For example, when integrating the impact scores for the different external areas of influence surrounding a wetland (i.e. the separately delineated portions of the catchment), different relative weightings have been given to each of the external areas of influence for different wetland types. For example, for floodplain wetlands, greater weightings have been assigned to impacts in the further reaches of the catchment and, in particular, to impacts affecting the inflowing streams, compared to the weighting for impacts from the area immediately surrounding the wetland. This is based on the assumption that the functioning of this wetland type is typically driven largely by water and sediment inputs from the inflowing streams that receive runoff from the further reaches of the catchment. For depressions, on the other hand, the highest weighting has been assigned to impacts from the area immediately surrounding the wetland, based on an assumption that the functioning of this wetland type is typically strongly influenced by localised processes within and adjacent to the wetland. Detailed explanations of the weightings that have been used in the tools are provided in the relevant sections of this report.

3.6. Catering for different levels of assessment

In developing WET-Health Version 2.0, it has been recognised that the resolution at which a wetland PES assessment may need to be conducted will vary considerably. At one extreme is the situation where thousands of wetlands need to be assessed in order to produce a national or regional summary of wetland PES for broad-scale planning purposes. At the other extreme is a situation where the PES of a single wetland needs to be assessed in order to identify specific stressors and impacts on the wetland for management and rehabilitation planning.

To cater for application across a range of spatial scales and for different purposes, the suite of tools that have been developed provides the following three levels of assessment:

- *Level 1A (desktop-based, low resolution)*, which is entirely desktop-based and uses only pre-existing landcover data (i.e. no "heads-up" interpretation of aerial imagery is required). In many cases, particularly when applied at a national level, it is not possible to delineate the upslope catchments of each of the individual wetlands. Instead, the landcover types in a GIS buffer around a wetland and within a “pseudo-catchment” selected to represent the true catchment (such as Sub-Quaternary catchments) is used as a coarse proxy of the impacts on the wetland arising from its upslope catchment. Impacts arising from within individual wetlands are inferred from landcover types occurring within desktop-delineated wetlands.

- *Level 1B (desktop-based, high resolution)*, which is largely desktop-based using pre-existing landcover data but makes a few finer distinctions than Level 1A in terms of landcover types and usually requires "heads-up" interpretation of the best available aerial imagery in order to do so. This also allows the pre-defined landcover types to be mapped more accurately. Furthermore, the upslope catchment of each wetland can be individually delineated at this level, and landcover in this area is used as a proxy of the impacts on a wetland arising from its upslope catchment. As for Level 1A, impacts arising from within individual wetlands are inferred from landcover types occurring within the delineated wetlands. In terms of water quality PES, the option is provided to factor in point-source pollution inputs in a Level 1B assessment.

- *Level 2 (rapid field-based assessment)*, is also strongly informed by desktop landcover mapping, but is refined by assessing a range of catchment and wetland-related indicators that are known to affect wetland condition. Impacts arising from the upslope catchment of a wetland are inferred from landcover mapping but are refined based on additional information (e.g. for plantations, the user must indicate whether the trees making up the plantations are eucalypts or pines and/or wattle). Landcover types occurring within the wetland are used as the starting point for assessing human impacts arising from within the wetland but are refined through the assessment of additional indicators as part of a rapid field-based assessment. This involves sub-dividing the wetland into relatively homogenous “disturbance units” (informed initially based on landcover types) and assessing a suite of site-based wetland questions that provide a more direct assessment of change (e.g. the density, depth and orientation of artificial drainage channels, and the texture of the soil in the wetland). Determination of water quality PES in a Level 2 assessment requires the identification and characterisation of point-source pollution inputs, which is not mandatory in Level 1A and 1B assessments.

The numbering of the levels of assessment that have been catered for in WET-Health Version 2.0 has been structured so as to align with the “three-tier framework” of the United States Environmental Protection Agency (USEPA) for wetland monitoring and assessment programmes. According to this well-established framework, Level 1 represents desktop-based assessments, Level 2 represents rapid field-based assessments, and Level 3 represents detailed assessments involving the intensive collection of biological and physico-chemical data at each assessment site (Fennessy *et al*., 2007). The “three-tier framework” of the USEPA has been recommended by Wilkinson *et al*. (2016) as an appropriate framework for the envisaged National Wetland Monitoring Programme (NWMP) in South Africa. As such, it is important to align the levels of assessment in WET-Health Version 2.0 with the “three-tier framework” as far as possible. It is important to note that, although three levels of assessment have been catered for in WET-Health Version 2.0, two of these are desktop-based and thus both fall under “Level 1” of the USEPA’s three-tier framework. No tools have been developed for a detailed Level 3 assessment, as this is not a rapid assessment conducted using generic tools.

When selecting the appropriate level of assessment, it is important to consider the required resolution and number of sites needing to be assessed, as well as the resources available for “heads up” interpretation of aerial imagery, the identification (and characterisation) of point-sources of pollution and the field assessment. Some preliminary guidelines have been developed to assist with this (see **Table 3.3** and additional guidance below).

Table 3.3. Guidelines for selecting the appropriate level of assessment

Factors to consider	Level 1A	Level 1B	Level 2
Resolution of the assessment	Very low	Low	Moderate to high
Number of wetlands typically assessed	Tens to thousands	Up to ~100	<20, and usually 1 to 5
“Heads up” interpretation of aerial imagery	None	Some	Extensive
Identification of point-source pollution inputs	No	Optional	Required
Field verification	None	Limited to a sub-set of the wetlands assessed	Extensive field verification of each wetland assessed
Level of expertise required	Basic GIS mapping experience	Wetland ecologist with basic training	Wetland ecologist with good experience

Given the resolution of the different levels of assessment, it is important that the appropriate tool is selected for different applications. The following broad guidance is provided for a range of typical applications that require wetland PES assessments:

- **Regional assessments**: Level 1A is developed specifically for this level of assessment and can be used to obtain an initial indication of the PES of wetlands at regional and/or national scale.
- **Environmental authorization processes**: Where a wetland assessment is required to inform an environmental authorization process, care must be taken to select the appropriate tool. In instances where only a few wetlands (<5) are being assessed and/or where significant risks to wetlands are identified, a Level 2 assessment should typically be undertaken. In instances where risks are lower, and/or numerous wetlands need to be assessed (e.g. for assessing impacts from linear infrastructure), a Level 1B assessment can be undertaken. Where a Level 1B assessment is undertaken, this must however be refined based on site-level information and expert opinion.
- **Wetland rehabilitation:** Level 2 is designed to build a comprehensive understanding of wetland functioning and is ideally suited to rehabilitation planning. Once the relevant spreadsheet has been populated, scores can also be refined to assess the level of response anticipated under a post-rehabilitation scenario.
- **Wetland offsets:** Level 1B can be effectively applied to help screen potentially suitable offset sites. Detailed offset planning and monitoring should, however, be undertaken using the Level 2 tool.

4. PRECURSORY STEPS IN THE ASSESSMENT PROCESS

Irrespective of the level of assessment, there are a number of precursory steps that need to be followed as part of the assessment process. These precursory steps could be completed in Google Earth or ESRI's online "ArcGIS Earth", but should preferably be done using Geographical Information Systems (GIS) software. In addition to these precursory steps, the user should decide upfront what level of assessment is required for their particular application of the tool/s (see preliminary guidelines for this in **Section 3.6**). For a Level 2 assessment, there are a number of additional precursory steps that need to be undertaken, as explained in **Section 6.1**.

4.1. Mapping of wetlands (and inflowing/out-flowing streams)

Before any of the refined tools for WET-Health Version 2.0 can be applied, the location and extent of wetlands being assessed must be mapped. The accuracy of these delineations would be dependent upon the level of assessment, with more accurate mapping required for more detailed studies, but for all assessments the wetlands must be mapped as polygons with an outer edge and an areal extent (as opposed to being mapped as point features). In some cases, the wetlands would have already been mapped, but in other cases they will need to be mapped from scratch. If wetlands need to be mapped from scratch, the user should refer to the wetland mapping guidelines of Job *et al*. (2018). For Level 1 assessments, which are typically undertaken at a broad spatial scale and involve many wetlands, mapping is typically desktop-based (possibly with some ground-truthing), while a field-based delineation of a wetland is typically required for a Level 2 assessment (following the delineation guidelines of DWAF, 2005).

For Level 1B and Level 2 assessments, the inflowing and out-flowing channels of a wetland must also be mapped (as line features). The 1:50 000 scale drainage line coverages produced by the Chief Directorate: National Geospatial Information (NGI), as part of the topographical map series for the entire country, can be used to aid with this mapping. This additional step is not required for Level 1A assessments.

4.2. Classification of wetlands by HGM type

The wetlands to be assessed should be classified in terms of their primary HGM type, following SANBI's classification system for inland aquatic ecosystems in South Africa (Ollis *et al*., 2013). This is an essential step for all levels of assessment because the assessment process varies slightly between groups of different HGM types (as explained in **Section 3.5**). The primary HGM types are as follows:

- Floodplain wetlands;
- Channelled valley-bottom wetlands;
- Unchannelled valley-bottom wetlands;
- Seeps;
- Depressions; and
- Wetland flats.

More information about the classification of HGM types can be found in Ollis *et al*. (2013).

For Level 1B and Level 2 assessments, depressions and channelled valley-bottom wetlands should be classified further in terms of their inflow and outflow characteristics. This is because the ecological functioning of a wetland is driven, to a large extent, by the degree of connectivity to the drainage network, which can vary substantially from one wetland to another for depressions and channelled valley-bottom wetlands. Wetlands that are subject to water and sediment inputs from inflowing drainage lines are significantly affected by the characteristics of the inflowing drainage lines, especially in terms of hydro-geomorphology and water quality. The PES of such wetlands can also be influenced by landuses from further afield than wetlands that are not connected to the drainage network.

To account for the above-mentioned variability, for depressions, a determination should be made as to whether the wetland is subject to flushing or not (i.e. endorheic versus exorheic in terms of surface and sub-surface outflows) when conducting assessments at Levels 1B and 2. Depressions generally do not have outflows but some do have such outflows. The most visually obvious of these are in the unusual situation where channelised surface outflows can be seen. Sub-surface outflows are difficult to detect, but are assumed to occur if the depression is connected with a regional aquifer or if signs of seepage are visible closely downslope of the depression. Further information about understanding the outflow characteristics of a wetland is provided in **Appendix A**. When conducting a Level 2 assessment, for depressions, a further distinction must be made as to whether or not there are channelled inflows into the wetland.

For channelled valley-bottom wetlands, a determination should be made as to whether the contribution of lateral inputs to the HGM Unit is low or high, relative to the inputs from the channel running through the wetland (see explanation of this in **Appendix A**, which deals with the building of a conceptual model of how water moves into, through and out of a wetland). In the absence of a detailed assessment or a lot of experience, it can be challenging to identify if a channelled valley-bottom wetland is maintained predominantly by lateral inputs. The following key indicators are however typical of this wetland type:

- The valley floor is generally elevated some distance above the water level in the main channel passing through the valley floor such that the channel seldom overtops to flood the valley floor;
- The wettest areas of the HGM unit generally occur along the periphery of the valley floor and typically correspond with lateral seepage from adjoining hillslopes or where first order streams lose confinement when they enter the valley floor.

For assessments at Level 1A, it is typically not possible to classify wetlands in terms of HGM sub-types, as described above. In assessments undertaken at this level, the following assumptions are thus made in terms of wetland HGM types:

- Floodplain wetlands, channelled valley-bottom wetlands, and unchannelled valley-bottoms wetlands are generally strongly influenced by water inputs from inflowing and/or through-flowing channels.
- Seeps, depressions and wetland flats are generally not strongly influenced by channelised water inputs.

The typical range of geomorphic variability associated with different HGM types is briefly described in **Appendix B**. This appendix is included as an aid to assessing the geomorphic integrity (covered in **Section 8**) by assisting in describing the natural reference state(s) of a wetland, and informing decisions around whether to attribute observed deposition/erosion to natural or anthropogenic causes.

4.3. Identification and delineation of "assessment units"

Once all the wetlands for a particular study have been mapped at an appropriate scale and level of accuracy (as explained in **Section 4.1**), and classified in terms of HGM types (as explained in **Section 4.2**), "assessment units" should be identified and mapped. An assessment unit can be an entire HGM Unit, which is generally the case for Level 1A assessments, or it can be a portion of an HGM Unit, depending on the purpose and focus of the assessment that is being undertaken. For example, for an Environmental Impact Assessment (EIA) on a portion of land located adjacent to an extensive valley-bottom wetland that occupies a few kilometres of a valley floor, the portion of wetland that could be affected by a proposed development (which could be only a few hundred metres in length) may be a more appropriate "assessment unit" than the entire wetland. Each assessment unit that is identified must be separately assessed using the refined tools that have been developed, which results in an individual overall PES Score and Ecological Category being generated for each assessment unit.

If an overall, area-weighted PES score is required for a complex wetland made up of more than one HGM Unit (or for an HGM Unit that has been divided into more than one "assessment unit"), the approach and guidelines of WET-Health Version 1 should be used for this purpose. The procedure simply involves the calculation of an area-weighted impact score for each assessment unit based on the relative size of the assessment unit in relation to the relevant HGM Unit (= [proportion of HGM Unit represented by the assessment unit]/100 x [impact score]), and then summing the area-weighted scores across all assessment units within the HGM Unit. This is done separately for each component of wetland PES. If the assessment units are entire HGM Units, then the area-weighted impact scores are based on the relative size of each HGM Unit in relation to the whole wetland area. These calculations would need to be done after applying the refined Wetland PES assessment tools that have been developed because, unlike WET-Health Version 1, the refined tools do not, in and of themselves, cater for the amalgamation of scores for separate assessment units (or separate HGM Units). Adding this functionality to the refined tools would introduce significant and unnecessary complexity, and create confusion for the user.

It is important to note that some aspects of the assessment procedure require consideration of the wetland as a whole and, therefore, the step of mapping the entire wetland (at least on a desktop basis) should not be omitted when smaller assessment units are to be evaluated for a particular application. It is also important not to confuse the "assessment unit" with the "Disturbance Units" that must be identified and delineated when conducting a Level 2 assessment. Disturbance Units represent portions of an assessment unit that are subject to distinct impacts or disturbances, as explained in **Section 6.2**.

4.4. Delineation of "external areas of influence"

In addition to delineating the extent of the wetlands that need to be assessed and classifying the HGM types (and sub-types for more detailed assessments), the catchments of the wetlands or of the pre-selected assessment units must be delineated to apply WET-Health Version 2.0, as was the case for Version 1. Conceptual models have been developed for different wetland types that aim to differentiate between the relative importance of water, sediment and pollution inputs from different parts of the catchment of a wetland (as explained in **Section 3.5**). As such, it is important to map out the different "external areas of influence" within the catchment. For all levels of assessment, these include:

- **200 m wide GIS buffer immediately adjacent to the wetland**: This provides an estimation of the local upslope catchment of a wetland, based on the rationale that there is likely to be a reasonable degree of overlap between the 200 m wide GIS buffer[6] around a wetland and the wetland's local upslope catchment. It is, however, acknowledged that in many wetlands the correspondence between these two respective areas will not be very high. In very small wetlands the 200 m upslope buffer will potentially extend well beyond the wetland's local upslope catchment, but for most other wetlands the 200 m upslope buffer is likely to fall short of the limits of the local upslope catchment. For large wetlands, especially, the local upslope catchment often extends for more than 500 m upslope from the wetland boundary. Under such a scenario, especially for assessments

[6] NOTE: In this report, and in the tools developed for WET-Health Version 2.0, the word "buffer" is typically used to simply represent an area or zone of a particular predetermined width that is delineated adjacent to a wetland or adjacent to the inflowing streams of a wetland. This is the common use of the term in GIS. It is not referring to a recommended buffer zone width for the protection of a wetland, as in the *Buffer Zone Guidelines for Rivers, Wetlands and Estuaries* (Macfarlane & Bredin, 2017a, b), or to the "regulated area" of a wetland used to determine whether Water Use Authorisation is required for an activity in terms of Sections 21(c) and (i) of the National Water Act (Act No. 36 of 1998).

at Level 1B or 2, it may be desirable to specifically map out this area of influence rather than using the 200 m proxy.

- **Broader catchment area**: This includes all portions of the catchment beyond the 200 m wide GIS buffer area immediately adjacent to a wetland.

The 200 m GIS buffer area and the broader catchment of a wetland will generally be delineated in different ways for different levels of assessment (see note in **Box 4.1**).

BOX 4.1: Delineating catchments and GIS buffer areas for different levels of assessment

- For more detailed assessments (at Levels 1B and 2), the true topographical **catchment** of each wetland must be delineated, while for broad-scale assessments (at Level 1A), pseudo-catchments (e.g. Sub-Quaternary catchments) that act as pre-existing proxies or estimations of the true catchments can be used in place of the true topographical catchments.
- The **GIS buffer areas** around the wetlands that are being assessed should be clipped to only include up-slope areas in the case of a detailed assessment (by intersecting the buffers with the topographical catchment boundary), whereas the entire buffer (including down-slope areas) would typically be used in broader-scale assessments.

For Level 2 (and Level 1B) assessments, a 200 m wide GIS buffer should also be delineated along the edges of the inflowing channels of a wetland, up to the catchment boundary. Tributaries that join the main inflowing channels should also be buffered by 200 m, up to the catchment boundary. This is achieved by simply applying a 200 m wide GIS buffer to the 1:50 000-scale rivers coverage for South Africa, or mapping of rivers at a similar resolution. The intention here is to delineate areas close to influent streams that can have a disproportionately high impact on water quality and sediment inputs from the upstream catchment. The **GIS buffers for the inflowing streams** derived in this way should be "clipped" where they intersect with the 200 m wide GIS buffer of the wetland into which the streams flow.

4.5. Calculation of the areal extent of specified landcover types within each wetland and in the external areas of influence

One of the biggest changes to the assessment process and the tools for WET-Health, in moving from Version 1 to Version 2.0, has been the inclusion of the explicit requirement to calculate the areal extent of specified landcover types within the wetlands that are to be assessed, and in the "external areas of influence" making up the catchment of each wetland. This precursory step would typically be carried out by producing a desktop-based map of the specified landcover types within the wetlands and in their surrounding/upslope areas of influence. From such a map, the areal extent (in hectares) of each landcover type within each wetland and its external areas of influence can be calculated, preferably using GIS or an online application such as Google Earth or ESRI's ArcGIS Earth.

The specified landcover types to be used for different levels of assessment are described in **Chapter 5**. The mapping of the relevant landcover types within a particular wetland provides a starting point for the identification of "Disturbance Units" in the case of a Level 2 assessment (as explained further in **Section 6.2**).

4.6. Determination of relevant Quaternary catchment/s

A range of hydrological parameters are available for all of the Quaternary catchments in South Africa (as delineated by what was previously the Department of Water Affairs & Forestry), through the Water Resources of South Africa 2012 (WR2012) study (Bailey & Pitman, 2015). Some of these data are used to inform various aspects of the PES assessments in WET-Health Version 2.0, as was the case in Version 1. This information is simply obtained by determining in which Quaternary catchment each wetland is located[7]. The spreadsheet tools that have been developed for WET-Health Version 2.0 then automatically extract the following data for the selected catchments:

- Mean Annual Runoff (MAR);
- Mean Annual Precipitation (MAP); and
- Mean Annual Evaporation (MAE) or Potential Evapo-transpiration (PET).

The above-mentioned data are presented for all Quaternary catchments in South Africa, in the "Quats_WR2012" worksheet of the spreadsheet tools (hidden by default). The MAR:PET ratio for each Quaternary catchment is used to derive a "hydrological vulnerability factor" for the wetlands in a particular Quaternary catchment (as explained in **Chapter 7: Hydrology module**).

4.7. Determination of broad hydro-geological type setting (and evaluation of change in water level and water quality of regional aquifer)

One of the major additions to WET-Health Version 2.0, which was not included in WET-Health Version 1 (Macfarlane *et al*., 2008) or in the Wetland-IHI (DWAF, 2007), is consideration of the implications of a connection to an underlying regional aquifer on the PES of a wetland. This was a short-coming of all the previously available tools for the rapid assessment of wetland PES identified by Ollis & Malan (2014). A conceptual model has been formulated to deal with this aspect in WET-Health Version 2.0, which requires the identification of the broad hydro-geological type setting of the wetlands that are to be assessed (as explained in **Appendix A**). In particular, for all levels of assessment, a determination must be made as to whether each wetland that is to be assessed is located on a **coastal plain** or in a **Karst landscape**[8]. This is captured in the "Wetland Attributes" worksheet of the relevant spreadsheet tool, using the drop-down list provided for the hydro-geological type setting in the tools that have been developed. The available options in the drop-down list are "Coastal Plain", "Karst landscape", and "Other" (i.e. other hydro-geological type setting).

If a wetland falls within a Coastal Plain or Karst landscape setting, then by default it is assumed that the wetland would be well connected with the regional aquifer under natural conditions. Although this probably represents a reasonable approximation of many wetlands in these two settings, it is recognized that this assumption would hold very poorly for those wetlands which are perched above the regional aquifer. Therefore, if evidence is available of a perched situation (see guidance in **Appendix A**), the default assumption can be overridden in a Level 1B and Level 2 assessment. For other Hydrogeological type settings, it is assumed by default that the wetland is not connected with the regional aquifer, and that the wetland's hydrological inputs are confined to its topographically defined catchment. This is likely to hold for most wetlands outside of Coastal plains and Karst landscapes. Again however, if evidence is available of a connection (see guidance in **Appendix A**), then the default assumption of no connection can be overridden in a Level 1B and Level 2 assessment. No overriding of the default assumptions based on the selected hydro-geological type setting is possible in the case of a Level 1A assessment, but for these assessments the assumed degree of connectivity to a regional aquifer is simply used to "flag" those wetlands for which the results of the assessment are likely to be questionable and thus of very low confidence.

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[7] A GIS map of the Quaternary catchments in South Africa is included with the electronic data sources provided with this report (see list in **Appendix D**).

[8] A GIS map showing the location of these hydro-geological type settings, at a coarse national scale, is included with the electronic data sources provided with this report (see list in **Appendix D**).

In the case of Level 1B and Level 2 assessments, the assessor should also attempt to establish whether there has been a lowering (or raising) of the water level of the regional aquifer, and whether there has been a decline in the water quality of the regional aquifer. These evaluations, which are not catered for in a Level 1A assessment, should be based on existing desktop information in a Level 1B assessment. Drop-down lists are provided for these factors in the "Wetland Attributes" worksheet of the spreadsheet tools for Level 1B and Level 2 assessments. For situations with too much uncertainty, especially on the basis of existing desktop-based information, the option of "Unknown" is provided for in the drop-down lists. If this answer is selected, the spreadsheet tool will assume a moderate ("middle of the road") scenario. The intention is for this option to only be used in Level 1B assessments, whereas in a Level 2 assessment the assessor should obtain some information about the water level and water quality of the regional aquifer if it is highly likely that there is a connection between the regional aquifer and the wetland being assessed. To obtain the required information at a reasonable level of confidence may well require the input of, and possibly data collection by, a groundwater specialist or hydropedologist.

More detailed information and guidance for assessing changes in the water levels and water quality of a regional aquifer are provided in **Hydro Step 1B-1** and **WQ Step 1A**, as included in the chapters on the Hydrology (**Chapter 7**) and Water Quality (**Chapter 9**) modules, respectively.

5. DESKTOP-BASED "LEVEL 1" ASSESSMENTS

Two levels of desktop-based assessment are provided in WET-Health Version 2.0, namely:

- "Level 1A" for regional- to national-scale assessments based on national landcover data (see **Section 5.1**); and
- "Level 1B" for local- to regional-scale assessments based on more refined landcover classes than those used in a Level 1A assessment (see **Section 5.2**).

Both of these tools represent a modification of the method developed by Kotze (2016a, b) for the rapid assessment of wetland condition by non-specialists, using landcover types based on the National Land Cover 2014 (NLC-2014) dataset to which default impact intensity scores have been assigned as the starting point. The same approach is followed in both Level 1A and 1B, whereby the relative extents of the predefined landcover types are estimated both within the wetlands that need to be assessed and in the catchments of the wetlands. This information is then used to derive modelled impact scores (and Ecological Categories) for the four components of wetland condition, based on the default impact intensity scores for the predefined landcover types, taking the HGM type into account. In the case of a Level 1B assessment, the option is also provided of taking point-source pollution inputs into account for water quality PES, where these are known and/or important.

Technical guidance for the application of Level 1 assessments using GIS is provided in **Appendix C**.

5.1. Regional- to national-scale assessments based on national landcover data (Level 1A)

Application of the tool, at this level, simply requires the user to estimate the extent of each of a predefined list of broad landcover categories within the following three “areas of influence”:

1) within the wetlands that need to be assessed;
2) within a 200 m wide GIS buffer area around the wetlands; and
3) within the pseudo-catchments selected as a proxy for the true topographical catchments of the wetlands (e.g. relevant Sub-Quaternary Catchments or a relatively wide GIS buffer area of 500 m or more in width).

This is typically undertaken in GIS using a systematic mapping approach (as explained in **Appendix C**), once the precursory steps in the assessment process (as described in **Chapter 4**) have been completed. The results from this exercise are entered into the spreadsheet tool that has been developed for Level 1A assessments and the PES results are automatically generated for all the wetlands (as explained below). No further steps are required for a Level 1A assessment.

The landcover classes from NLC-2014 were grouped into a number of broad landcover categories and additional national spatial datasets were used to sub-divide some of the NLC-2014 classes, to produce a total of 19 predefined broad landcover categories for Level 1A assessments (see **Table 5.1**). It is important to note that, for the purposes of wetland PES assessment, all landcover types which are considered to be indigenous vegetation (e.g. indigenous forest, shrubland fynbos) have been grouped together in a single type called "Natural / Minimally impacted". Excluding this type, and that of “Open Water – Natural”, all other landcover types in the list are characterised by particular human impacts. For example, “Commercial annual crops (irrigated)” is generally characterised by the complete clearance of the indigenous vegetation and the addition of fertilizers. The original groupings were driven by the water quality module (in that landcover classes considered to have a similar impact on wetland water quality were grouped together), with additional refinements added to facilitate improved desktop-based assessment of hydrology, geomorphology and vegetation.

As well as combining some landcover classes in terms of their likely impact on wetland condition, other classes were split using additional datasets (as indicated by orange text in **Table 5.1**). The additional datasets and the way in which they were used were as follows:

- The "artificial wetlands" layer from the National Freshwater Ecosystems Priority Areas (NFEPA) project (Nel *et al.,* 2011) and a "water splits" layer generated by the Department of Environmental Affairs were used to separate artificial and natural open waterbodies;
- The latest "field crop boundaries" layer from the Department of Agriculture, Forestry & Fisheries (DAFF) was used to distinguish between irrigated versus non-irrigated cultivated commercial fields;
- Data from the Mine Water Atlas (WRC, 2016) were used to separate high and medium risk mining areas from those that are of low contamination risk[9]; and
- A layer of "abandoned lands" generated by SANBI for the NBA-2018 project was used to separate semi-natural from natural areas.

Table 5.1. List of predefined landcover categories for "Level 1A" assessments and the NLC-2014 classes that can be used to represent each landcover category (orange text indicates additional national spatial layers that have been used to derive the predefined landcover category)

Level 1A Landcover Categories	NLC 2014 Classes (and additional layers used to derive predefined Categories)
Open Water – Natural	(1) Water seasonal; (2) Water permanent; MINUS artificial waterbodies (DEA/NFEPA layer)
Open Water – Artificial	(1) Water seasonal; (2) Water permanent; ONLY artificial waterbodies (DEA/NFEPA layer)
Natural / Minimally impacted	(3) Wetlands; (4) Indigenous Forest; (5) Thicket / Dense bush; (6) Woodland / Open bush; (7) Grassland; (8) Shrubland fynbos; (9) Low shrubland; (41) Bare none vegetated...minus SANBI "abandoned lands" layer
Semi-natural / Abandoned lands	SANBI "abandoned lands" layer
Orchards and vineyards	(16-18) Cultivated orchards; (19-21) Cultivated vines
Sugar cane	Cultivated cane pivot (26-27); (28-31) Cultivated cane commercial/emerging
Commercial annual crops (irrigated)	(13-15) Cultivated comm pivots; (10-12) Cultivated comm fields ONLY with irrigation (DoA layer)
Commercial annual crops (non-irrigated)	(10-12) Cultivated comm fields MINUS irrigated areas (DoA layer); (22) Cultivated permanent pineapple
Subsistence Agriculture	(23-25) Cultivated subsistence
Plantations and dense alien vegetation	(32-34) Plantations / Woodlots
Mining – Low Risk	(35-36) Mines bare/semi-bare; (37-38) Mines water; (39) Mine buildings...MINUS "Medium" and "High" Mining Risk areas (derived from Mine Water Atlas data)
Mining – Medium Risk	(35-36) Mines bare/semi-bare; (37-38) Mines water; (39) Mine buildings...ONLY "Medium" Mining Risk areas (derived from Mine Water Atlas data)
Mining – High Risk	(35-36) Mines bare/semi-bare; (37-38) Mines water; (39) Mine buildings...ONLY "High" Mining Risk areas (derived from Mine Water Atlas data)
Eroded areas	(40) Erosion (donga)
Urban Industrial/Commercial	(42) Urban commercial; (43) Urban industrial
Urban Informal	(44-47) Urban informal
Urban Residential – high density	(48-51) Urban residential; (61-64) Urban township; (69-72) Urban built-up
Urban Residential – low density	(53-56) Urban smallholding; (65-68) Urban village
Urban Open Space	(52) Urban school and sports ground; (57-60) Urban sports and golf

[9]The "Mineral Risk" and "Mining Activity Risk" scores for "Mineral Provinces" from the Mine Water Atlas were combined to derive a "Mining Risk" layer distinguishing between mining areas with high and moderate contamination risk (quarrying for stone and sand, which are types of mining with a low contamination risk, were not considered in the Mine Water Atlas). This layer was then intersected with the NLC-2014 coverage to separate out mining areas with high, medium and low contamination risk.

The NBA-2018 team assisted by producing a GIS data layer (in raster format) of the predefined broad landcover categories for the whole country (as listed in **Table 5.1**, above), which can be used to apply a "Level 1A" assessment in a semi-automated manner with GIS (as explained in **Appendix C)**. This data source (included in **Appendix D** as part of a list of electronic data sources provided with this report, for use in application of WET-Health Version 2.0) would typically be used in GIS to produce a map such as that shown in **Figure 5.1**. The “extent of landcover type” data that are required for input into the spreadsheet tool for a Level 1A assessment would be derived from a map like this.

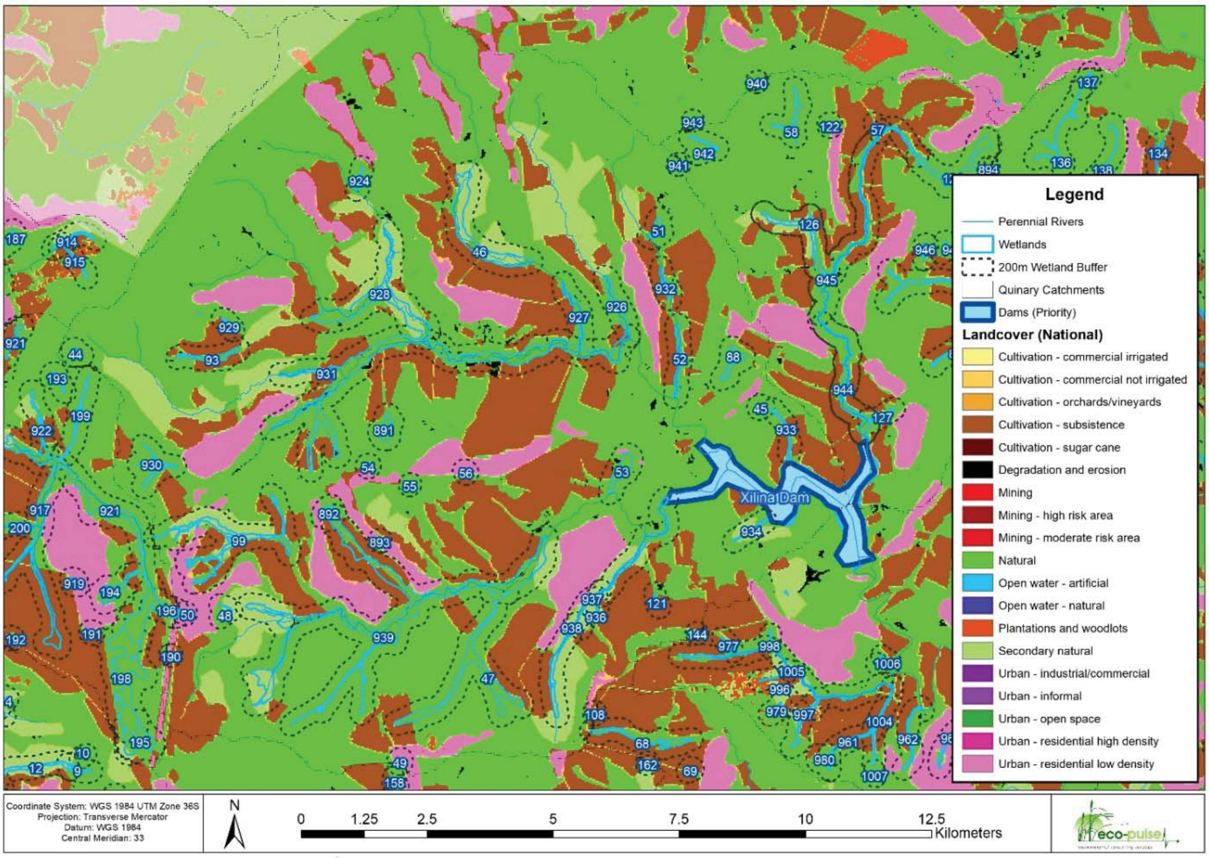

Figure 5.1. Example of a map produced in GIS to show the extent of the predefined landcover categories for a Level 1A assessment (see colour-coded legend) that occur within the wetlands to be assessed (light blue outlines), within the 200 m GIS buffer area around the wetlands (dashed black outlines), and within the Quinary catchments in the study area (light grey outlines).

Once the extent (in hectares) of each of the predefined broad landcover categories (as listed in **Table 5.1**) have been estimated within the specified areas, these values must be entered into the relevant spreadsheet tool that has been developed for Level 1A assessments. The spreadsheet tool, which allows for the entry of data for up to 2000 wetlands, then automatically derives an impact score, PES score and Ecological Category for the various components of wetland PES, based on the following approach:

- Impact intensity scores (ranging from 1 to 10) have been assigned to each landcover category for the following factors relating to the wetland itself, the buffer of the wetland and the (pseudo-)catchment (as presented in **Tables 5.2 and 5.3**)[10]:

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[10] In the case of the water quality intensity scores for the various land-cover categories, these were derived from a normalised sum of the intensity scores assigned to individual water quality parameters, namely: nutrients (with N and P, considered separately), COD/BOD, TDS/conductivity, TSS/turbidity, heavy metals, and other toxics.

– For **within-wetland** landcover (**Table 5.2**), the factors for which impact intensity scores have been assigned are changes in hydrology ([Wet-Hydro]), geomorphological processes ([Wet-Geo_Pr]), geomorphological structure ([Wet-Geo_St]), water quality ([Wet-WQ]), and vegetation cover ([Wet-Veg]).
– For landcover in the **external areas of influence** (i.e. the GIS buffer around the wetland and the broader catchment or pseudo-catchment) (**Table 5.3**), the hydrological factors are changes in MAR ([EXT-MAR]), seasonality ([EXT-Seas]) and flood-peaks ([EXT-Peak]), while change in sediment supply ([EXT-Sed]) is the only factor for geomorphology, and the final factor is the overall change in water quality resulting from landuses outside of the wetland ([EXT-WQ]).

Table 5.2. Default impact intensity scores assigned to the specified landcover categories for the various within-wetland factors that are taken into consideration in a Level 1A assessment

		Hydrology	Geomorphology		Water Quality	Vegetation
		Wet_Hydro	**Wet_Geo_Pr**	**Wet_Geo_St**	**Wet_WQ**	**Wet_Veg**
Open Water – Natural	WATER_NAT	0	0	0	0	0
Open Water – Artificial	DAM	7	4	4	0	10
Natural / Minimally impacted	NATURAL	0	0	0	0.4	1
Semi-natural	SEMI_NAT	4	2	1	0.8	6
Orchards and vineyards	ORCH_VINE	7	5	2	6.1	10
Sugar cane	SUGARCANE	8	6	2	6.4	10
Commercial annual crops (irrigated)	CROP_IRRIG	7.5	6	2	6.9	10
Commercial annual crops (non-irrigated)	CROP_NOIRR	7	6	2	6.5	10
Subsistence crops	CROP_SUBS	7	4	2	3.6	10
Plantations and dense infestations of invasive alien plants	PLANT_INV	7	1	1	1.2	10
Mining - Low contamination risk	MINING_L	9	9	10	2.1	9
Mining - Moderate contamination risk	MINING_M	10	10	10	8.4	10
Mining - High contamination risk	MINING_H	10	10	10	10	10
Eroded areas (& heavily degraded land)	ERODED	7	7	8	2.2	9
Urban Industrial/Commercial	INDUS_COMM	10	10	10	8.2	10
Urban Informal	INFORMAL	7	4	8	7.6	9
Urban Residential – high density	RESIDENT_H	10	8	8	5	10
Urban Residential – low density	RESIDENT_L	6	6	5	4	6
Urban Open Space	OPENSPACE	3	4	1	4.2	9

Table 5.3. Default impact intensity scores assigned to the specified landcover categories for the various factors relating to the external areas of influence that are taken into consideration in a Level 1A assessment

		Hydrology			Geomorph	Water Quality
		MAR	**Seas**	**Peak**	**Sed**	**WQ**
Open Water – Natural	WATER_NAT	0	0	0	0	0
Open Water – Artificial	DAM	-8	3	-9	-8	0
Natural / Minimally impacted	NATURAL	0	0	0	0.5	0.3
Semi-natural	SEMI_NAT	0	0	1.5	2	0.6
Orchards and vineyards	ORCH_VINE	-5	4	2	4	4.1
Sugar cane	SUGARCANE	-4	1	2	6	4.3
Commercial annual crops (irrigated)	CROP_IRRIG	-5	4	3	8	4.6
Commercial annual crops (non-irrigated)	CROP_NOIRR	-2	1	3	7	4.3
Subsistence crops	CROP_SUBS	-2	1	3	6	2.4
Plantations and dense infestations of invasive alien plants	PLANT_INV	-6.5	0	0	4	0.6
Mining - Low contamination risk	MINING_L	-1	1	4	9	1.4
Mining - Moderate contamination risk	MINING_M	-4	2	5	9	5.6
Mining - High contamination risk	MINING_H	-5	2	5	9	6.7
Eroded areas (& heavily degraded land)	ERODED	2	0	5	9	1.5
Urban Industrial/Commercial	INDUS_COMM	2	1	9	4	5.5
Urban Informal	INFORMAL	2	1	7	5	5.1
Urban Residential – high density	RESIDENT_H	2	2	7	3	3.3
Urban Residential – low density	RESIDENT_L	2	1	5	2	2.7
Urban Open Space	OPENSPACE	-1	1	3	2	2.8

Rationale for scores in Tables 5.2 and 5.3

The impact intensity scores that are used for the various landcover categories in a Level 1A assessment have been derived from the intensity scores assigned to the refined landcover categories in a Level 1B assessment. The rationale underlying the default impact scores for a Level 1B assessment, for both within-wetland landuses and landuses in the external areas of influence, is provided in **Section 5.3**.

- The impact intensity scores are multiplied by the proportional extent of each landcover category in each "area of influence", to generate magnitude-of-impact scores for each wetland [WET-mag], the buffer of the wetland [BUFF-mag], and the remaining broader catchment or pseudo-catchment [CATCH-mag]. In the case of the scores for MAR (i.e. [BUFF-mag-MAR] and [CATCH-mag-MAR]), these are also multiplied by a "hydrological vulnerability factor" (as explained in **Hydro Step 1A**). Minor variations to this approach were introduced to address some under-scoring issues that were identified during testing, in particular:
  - The impact of dams located in the catchment of a wetland on the hydrology of the wetland, which tends to be disproportionate to the cumulative surface area that dams occupy in the catchment because the impact is more closely related to the cumulative *volume* of the dams (which is unknown in a Level 1A assessment). Dams with a relatively small surface area can still hold a significant volume of water (if they are deep) and thus have a significant impact on runoff, seasonality and floodpeaks. In an attempt to address this, in a simplistic way for Level 1A assessments, the proportional extent of the catchment occupied by dams is multiplied by a factor before multiplying by the relevant impact intensity score. The multiplication factor is x3 for EXT-MAR, x2 for EXT-Seas, and x5 for EXT-Peak. This results in the maximum possible magnitude-of-impact scores for EXT-MAR, EXT-Seas and EXT-Peak relating to dams being reached at a cumulative coverage of 33%, 50% and 20%, respectively, by dams in the GIS buffer or remaining catchment of a wetland.

– The impact of medium- and high-risk mining landuses on the water quality of the wetland, typically consisting of coal and ore mining, which also tends to be disproportionate to the cumulative surface area that these landuses occupy in the catchment, largely because of Acid Mine Drainage and other subsurface impacts extending the impact well beyond the “surface footprint” of the landuse. As in the case of the impact of dams in the catchment on wetland hydrology, this issue is simplistically addressed for medium- and high-risk mining landuses by applying a multiplier to the proportional extent of these landuses within the various areas of influence before multiplying by the impact intensity score. This results in the maximum magnitude-of-impact score being reached with less than 100% surface area coverage by these landcover categories. The multiplication factors used here are x5 for medium- and high-risk mining activities within wetlands, and x3 for these landuse types in the external areas of influence (i.e. the wetland buffer and broader catchment). More details about this are provided in the chapter dealing with the Water Quality module, under **WQ Step 1B** (especially in **Table 9.3** and **Figure 9.4**).

- The magnitude-of-impact scores for the wetland buffer (i.e. [BUFF-mag-MAR], [BUFF-mag-Seas], etc.) and the remaining catchment (i.e. [CATCH-mag-MAR], [CATCH-mag-Seas], etc.), derived as explained above, are multiplied by the relevant HGM-specific weightings (as presented in **Table 5.4**). This results in the derivation of an overall magnitude-of-impact score for the external areas of influence in relation to change in water quantity [EXT-MAR], change in seasonality of flows [EXT-Seas], change in peak flows to the wetland [EXT-Peak], change in the delivery of sediment to the wetland [EXT-Sed], and change in water quality from the external areas of influence [EXT-WQ].

Table 5.4. HGM-specific weightings used to combine the magnitude-of-impact scores for landuses in the external areas of influence in a Level 1A assessment

HGM type	RELATIVE WEIGHTINGS	
	CATCH	BUFF
FP	0.8	0.2
CVB	0.5	0.5
UVB	0.5	0.5
SEEP	0.2	0.8
DEP	0.2	0.8
FLAT	0.2	0.8

FP = floodplain wetland; CVB = channelled valley-bottom wetland;
UVB = unchannelled valley-bottom wetland; DEP = depression

Rationale for scores in Table 5.4

The use of HGM-specific weightings in the integration of scores for the different external areas of influence is one of the ways in which WET-Health Version 2.0 attempts to address inherent differences in the functional characteristics of different HGM types (as explained in **Section 3.5**). The weightings for a Level 1A assessment were derived from the weightings that were formulated for a Level 1B assessment (see **Table 5.9** and accompanying rationale in **Section 5.2**), with some generalisation and simplification required due to no HGM sub-types being catered for in a Level 1A assessment (specifically for CVB and DEP wetland types). The relative extent of the contributing areas is not used for any of the HGM types, as it is in the case of a Level 1B assessment, because a pseudo-catchment is typically used in a Level 1A assessment (which tends to be bigger than the true catchment for most wetlands) and following this approach leads to results that are not representative of the true situation. Similarly, for FP, CVB and UVB wetlands, the weighting of the catchment (relative to the wetland buffer) has been made less for Level 1A assessments than in the case of a Level 1B assessment to ensure that the less accurate catchment score does not override the overall result. For example, the catchment of a FP wetland is attributed a weighting of 0.8 in a Level 1A assessment, versus a weighing of 0.9 in a Level 1B assessment.

- The overall Hydrology Impact Score is derived by generating a "within-wetland water distribution and retention score" from [Wet-mag-Hydro] and combining this with a "catchment alteration score", using a cumulative summing algorithm that constrains the total to a maximum of 10 (explained in **Box 5.1**). The "catchment alteration score" is the maximum of [EXT-MAR], [EXT-Seas], and [Catch-Peak] multiplied by a HGM-specific adjustment factor that attempts to account for the assumed vulnerability of the relevant HGM type to both increased and reduced floodpeaks respectively (see **Table 5.5**).

Table 5.5. HGM-specific adjustment factors used to adjust the floodpeaks score for the catchment (EXT_Peak) in a Level 1A assessment

HGM type	Adjustment factor	
	(EXT_Peak) >= 0	(EXT_Peak) < 0
FP	0.3	0.9
CVB	0.4	0.6
UVB	0.5	0.4
SEEP	0.7	0.2
DEP	0.5	0.3
FLAT	0.5	0.3

FP = floodplain wetland; CVB = channelled valley-bottom wetland;
UVB = unchannelled valley-bottom wetland; DEP = depression

Rationale for scores in Table 5.5

The adjustment factors in this table are an attempt to account for the assumed differences in the vulnerability of different HGM types to an overall increase or decrease in floodpeaks from the catchment, which are applied when evaluating the impact of the change in floodpeaks on the hydrological integrity of the wetland. Floodplain wetlands are assumed to be the most vulnerable to reduced floodpeaks ([EXT_Peak]<0) because they are generally strongly dependent on flood events to provide key hydrological inflows, and therefore have the highest adjustment factor for reduced floodpeaks (0.9). In contrast, seeps are assumed to be least dependent on flood events because they are generally maintained by sustained sub-surface flows, and therefore have the lowest adjustment factor for reduced floodpeaks (0.2), followed by depressions and flats (with an adjustment factor of 0.3). The vulnerability of CVB wetlands to reduced floodpeaks depends on the degree to which they are sustained by inputs from the through-flowing stream, versus lateral inputs, but this distinction is not made in a Level 1A assessment. The adjustment score for this HGM type (0.6) is, therefore, intermediate between that for FP wetlands and that for depressions and flats in terms of vulnerability to reduced floodpeaks. UVB wetlands are typically less dependent on flood events than CVB wetlands, but more dependent than depressions and flats. This HGM type is thus assigned an adjustment score for reduced floodpeaks (0.4) that is slightly than that assigned to depressions and flats. The adjustment factors for increased floodpeaks ([EXT_Peak]>=0) follow the opposite pattern to that for reduced floodpeaks, with higher scores assigned to those HGM types that are assumed to be inherently less dependent on flood events.

- The overall Geomorphology Impact Score is the average of the scores for “geomorphic structure” [WET-mag-Geo_St] and “overall change in geomorphic processes”. The combined score for “overall change in geomorphic processes” is derived from adding the scores for [EXT-Sed] and [WET-mag-Geo_Pr], using the same cumulative summing algorithm that is used to derive the overall Hydrology Impact Score (as explained in **Box 5.1**).

- The overall Water Quality Impact Score is derived by taking the maximum of the scores for external water quality impacts [EXT-WQ] and within-wetland water quality impacts [Wet-mag-WQ].

- The Vegetation Impact Score is simply derived from [Wet-Veg] because there is no catchment score to factor in, unlike the situation for the other components.

- The overall Impact Scores for Hydrology, Geomorphology, Water Quality and Vegetation are converted to PES Scores by subtracting the Impact Score from 10 and expressing the result as a percentage. These PES % scores are then used to determine the relevant Ecological Category, based on the ranges of scores for each Category presented in **Table 3.2**.

Box 5.1: Explanation of the cumulative summing algorithm used to integrate certain scores in WET-Health Version 2.0

When combining certain scores in WET-Health Version 2.0 (such as the "within wetland score" and "catchment alteration score" for Hydrology), which must be constrained to a maximum allowable value, the following formula is sometimes used:

[COMBINED SCORE] = [Score1] + (10 – [Score1]) * [Score2]/10

where [Score1] and [Score2] are being combined, with a maximum allowable value of 10

For example, if [Score1] was 6 and [Score2] was 5, the combined score would be 8.0, calculated as follows:

[COMBINED SCORE] = 6 + (10-6)*5/10 = 6 + (4*0.5) = 6 + 2 = 8

The formula can be applied iteratively to combine more than two scores. This algorithm ensures that combined impact scores never exceed the maximum allowable score (generally a value of 10), and can be described conceptually as a way of drawing down "a full glass" of integrity, with each successive impact drawing down only what remains in the glass from the previous impact/s.

The use of this algorithm is often preferable to, and somewhat of a compromise between, the following three alternative options for combining scores:

- Taking the maximum score, which results in the lower scores not having any influence over the overall score. For the example above (with input scores of 6 and 5), the combined score would be 6.0 using this approach.
- Taking an average or mean of the input values, which tends to "dilute" the effect of scores that are much higher than the other input scores (this is not an issue if there is a small range of variation between the input scores). For the example above, the combined score would be 5.5 using an average.
- Simply adding the input scores together (i.e. taking their sum), which can potentially result in the combined score exceeding the maximum allowable value. For the example above, the combined score would be 11.0 using this approach, which is greater than the maximum allowable impact score of 10.

It is important to note that, while the cumulative summing algorithm is often preferable to the above-mentioned alternatives, this is not always the case. One of the problems with the algorithm is that, if multiple scores are integrated using this approach, the combined score will "creep" closer and closer to the maximum allowable value as input scores are added. This is often not desirable and, in these cases, a maximum or average score may be more appropriate and preferable.

The tool that has been developed for a Level 1A assessment automatically derives an Integrated Wetland PES Score and associated Ecological Category by combining the scores for the four modules of wetland PES (i.e. Hydrology, Geomorphology, Water quality and Vegetation). This is done by using the formulae explained in **Section 11.2**. The individual scores and Ecological Categories for each of the constituent "modules" are not lost by this integration of results, however, and users of WET-Health Version 2.0 are encouraged to always present and refer to the scores for the individual components when conducting an assessment. This is facilitated by the inclusion of all the results in the summary worksheet for the Level 1A tool (see example of output for five hypothetical wetlands in **Figure 5.2**) and in the tools for Level 1B and Level 2 assessments).

In addition to presenting the PES results, as described above, the tool that has been developed for Level 1A assessments also determines the "hectare equivalents" represented by each wetland. This is simply derived by multiplying the PES score (as a percentage) for each wetland by the total extent of the wetland.

Finally, another output provided in the summary worksheet for a Level 1A assessment is an automatically generated confidence rating for the PES results that have been derived for each wetland. This is a very coarse confidence rating, simply based on the hydrogeological setting of each wetland. Those wetlands located on a "Coastal plain" or in a "Karst landscape" are assigned a rating of "Very low confidence: evaluation of groundwater connectivity and quality required". This is based on the assumption that wetlands in these settings have a high likelihood of being connected to (and thus significantly influenced by) an underlying regional aquifer, which the Level 1A assessment does not take into account in generating the results. It thus acts as a "flag" to highlight the wetlands for which the results generated by the Level 1A tool have a relatively high probability of being inaccurate. All other wetlands are assigned a rating of "Low confidence: landcover-based desktop assessment", highlighting the fact that a Level 1A assessment, by its nature, will always be of low confidence. If greater confidence is required, the assessor must conduct a Level 1B or a Level 2 assessment.

PES Summary

Wetland_ID	Wetland area (Ha)	HYDROLOGY			GEOMORPHOLOGY			WATER QUALITY			VEGETATION			OVERALL CONDITION			HECTARE EQUIVALENTS (based on Overall PES)	CONFIDENCE
		Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Impact Score	PES Score (%)	Ecological Category	Combined Impact Score	Overall PES Score (%)	Combined Ecological Category		
Wetland_ID	WET_AREA	IMPACT_HYD	PES_HYDRO	EC_HYDRO	IMPACT_GEO	PES_GEO	EC_GEO	IMPACT_WQ	PES_WQ	EC_WQ	IMPACT_VEG	PES_VEG	EC_VEG	IMPACT_ALL	PES_ALL	EC_ALL	HA_EQUIV	
WET-1	1.8	4.2	58.2	D	2.6	74.1	C	3.5	65.3	C	4.3	57.1	D	3.7	63.1	C	1.1	Very low confidence: evaluation of groundwater connectivity and quality required
WET-2	1.0	3.8	61.5	C	1.3	87.1	B	1.4	86.2	B	5.5	45.0	D	3.1	69.0	C	0.7	Very low confidence: evaluation of groundwater connectivity and quality required
WET-3	2.5	3.2	68.0	C	2.3	77.0	C	2.5	75.3	C	3.8	62.0	C	3.0	70.3	C	1.8	Low confidence: landcover-based desktop assessment
WET-4	2.5	5.9	40.8	D	3.2	67.8	C	1.1	89.2	B	6.2	38.0	E	4.3	57.0	D	1.4	Low confidence: landcover-based desktop assessment
WET-5	4.0	6.1	39.2	E	4.5	54.8	D	3.0	69.8	C	7.5	25.0	E	5.5	44.5	D	1.8	Low confidence: landcover-based desktop assessment

Figure 5.2. Example of the summary that is automatically generated in the tool for a Level 1A assessment

5.2. Local- to regional-scale assessments based on refined landcover classes (Level 1B)

The Level 1B assessment is also largely desktop-based, using landcover mapping as a basis for the assessment, but is undertaken for a single assessment unit at a time.

The assessment is based largely on the same procedure that is followed for a Level 1A assessment (explained in **Section 5.1**, above), but integrates a number of changes to improve the accuracy of the assessment. Once the precursory steps have been completed (as outlined in **Chapter 4**), relevant wetland attributes including the HGM type and Quaternary catchment are captured in the tool provided. Where the wetland is associated with a regional aquifer, supplementary information including the degree to which the wetland is connected to the underlying regional aquifer and the change in the water level and water quality of the regional aquifer[11] must also be recorded.

For a Level 1B assessment, a refined list of landcover categories has been developed (see **Table 5.6**). This list includes a total of 26 landcover categories for all potential areas of influence (versus 19 for Level 1A assessments). Three of the refined landcover categories are only applicable within wetlands, while two of the categories ("water supply dam" and "semi-natural") are split into two options for within-wetland landcover.

Field-based verification of the landcover mapping for a Level 1B assessment is recommended in order to increase the degree of confidence in the results that are produced. In addition, one of the fundamental differences between a Level 1A and a Level 1B (and Level 2) assessment, in terms of landcover mapping, is that the true catchment of the wetland is mapped, instead of a "pseudo-catchment". Furthermore, the catchment area beyond the 200 m wide GIS buffer immediately adjacent to the wetland is sub-divided into two external areas of influence (versus one for Level 1A assessments), namely the GIS buffer area adjacent to the inflowing streams[12] and the broader remaining catchment. The wetland buffer is also refined in a Level 1B assessment by excluding the portion of the GIS buffer located down-slope of the wetland, where landuse is unlikely to have an influence on wetland condition.

[11] As explained in **Section 4.7**, the option is given of selecting "Unknown" for the degree to which the water level and water quality of the regional aquifer has been changed, for those situations where insufficient existing information is available to make these evaluations with a reasonable level of confidence.

[12] Note that where wetlands or riparian areas have been mapped upstream of the assessment unit, these must be included as part of the 200 m wide GIS buffer applied to influent streams for assessment purposes. As such, buffers should be applied to streamlines (extended centrally through any unchannelled valley bottom wetlands) rather than to polygons of watercourses in the upstream catchment. Intact wetland and riparian areas should then be mapped as part of the "Natural / Minimally impacted" landcover class.

Table 5.6. List of refined landcover categories for "Level 1B" assessments, showing the categories that are applicable to the catchment separately to those applicable within the wetland

Level 1A Landcover Categories	Level 1B / 2 Refined Landcover Categories	
	Catchment	Wetland
Open Water – Natural	Open Water – Natural	Open Water – Natural
Open Water – Artificial	Water supply dam	Deep flooding from impoundments
		Shallow flooding from impoundments
	Aquaculture dams/ponds	Aquaculture dams/ponds
Natural / Minimally impacted	Natural / Minimally impacted	Natural / Minimally impacted
Semi-natural / Abandoned lands	Semi-natural	Semi-natural (undrained)
		Semi-natural (drained)
	Moderately degraded land	Moderately degraded land
Orchards and vineyards	Orchards and vineyards	Orchards and vineyards
Sugar cane	Sugar cane	Sugar cane
Commercial annual crops (irrigated)	Commercial annual crops (irrigated)	Commercial annual crops (irrigated)
Commercial annual crops (non-irrigated)	Commercial annual crops (non-irrigated)	Commercial annual crops (non-irrigated)
Subsistence Agriculture	Subsistence crops	Subsistence crops
Plantations and dense alien vegetation	Tree plantations	Tree plantations
	Dense infestations of invasive alien plants	Dense infestations of invasive alien plants
Mining	Quarrying (sand, stone, diamonds)	Quarrying (sand, stone, diamonds)
	Coal mining	Coal mining
	Ore mining	Ore mining
Eroded areas	Eroded areas (& heavily degraded lands)	Eroded areas (& heavily degraded lands)
Urban Industrial/Commercial	Urban Industrial/Commercial	Urban Industrial/Commercial
Urban Informal	Urban Informal	Urban Informal
Urban Residential – high density	Urban Residential – high density	Urban Residential – high density
Urban Residential – low density	Urban Residential – low density	Urban Residential – low density
Urban Open Space	Urban Open Space	Urban Open Space
[Various]	Livestock feedlots (cattle and pigs)	Livestock feedlots (cattle and pigs)
	Chicken farms	Chicken farms
	Planted pastures (irrigated)	Planted pastures (irrigated)
		Infilling (incl. infrastructure)
		Sediment deposits
		Artificially wetter areas (e.g. seepage below dams)

Application of the tool that has been developed for a Level 1B assessment, as is the case for a Level 1A assessment, then requires the user to estimate the extent of each of the predefined list of landcover categories within the wetland and relevant "external areas of influence" in the wetland's catchment. In the case of a Level 1B assessment, however, the refined list of landcover types is used (as presented in **Table 5.6**) and there are four areas of influence that must be separately accounted for (instead of three), as follows:

1) within the wetland that needs to be assessed;
2) within a 200 m wide GIS buffer area around the wetland;
3) within a 200 m wide GIS buffer area around the streams flowing into the wetland (if present); and

4) within the remainder of the true topographical catchment of the wetlands (once the inflowing stream buffers have been clipped out).

This is, again, typically undertaken in GIS by specifically mapping out the extent of each landcover type.

As in the case of Level 1A, default impact intensity scores have been assigned to the refined list of landcover categories for Level 1B assessments, with separate sets of intensity scores for landuses within a wetland (**Table 5.7**) and in the external areas of influence (**Table 5.8**), taking the same factors into account as in a Level 1A assessment.

Table 5.7. Default impact intensity scores assigned to the specified landcover categories for the various within-wetland factors that are taken into consideration in a Level 1B assessment

Level 1B Landcover Categories	Default Intensity Scores				
	Wetlands				
	Hydrology	Geomorphology		Water Quality	Vegetation
	Wet_Hydro	Wet_Geo_Pr	Wet_Geo_St	Wet-WQ	Wet_Veg
Open Water – Natural	0	0	0	0	0.0
Deep flooding from impoundments	7	4	4	0	10.0
Shallow flooding from impoundments	3	3	2	0	5.0
Aquaculture dams/ponds	7	4	4	7.8	10.0
Natural / Minimally impacted	0	0	0	0.4	1.0
Semi-natural (undrained)	1	1.5	0	0.6	4.0
Semi-natural (drained)	5	4	2	0.9	7.0
Moderately degraded land	3	3	3	1.6	6.0
Orchards and vineyards	7	5	2	6.1	10.0
Sugar cane	8	6	2	6.4	10.0
Commercial annual crops (irrigated)	7.5	6	2	6.9	10.0
Commercial annual crops (non-irrigated)	7	6	2	6.5	10.0
Subsistence crops	7	4	2	3.6	10.0
Tree plantations	8	2	2	1.2	10.0
Dense infestations of invasive alien plants	6	2	2	0.5	9.0
Quarrying (sand, stone, diamonds)	9	9	10	2.1	9.0
Coal mining	10	10	10	8.4	10.0
Ore mining	10	10	10	10	10.0
Eroded areas (& heavily degraded lands)	7	7	8	2.2	8.0
Urban Industrial/Commercial	10	10	10	8.2	10.0
Urban Informal	7	4	8	7.6	9.0
Urban Residential – high density	10	8	8	5	10.0
Urban Residential – low density	6	6	5	4	6.0
Urban Open Space	3	4	1	4.2	9.0
Livestock feedlots (cattle and pigs)	8	4	5	7.2	10.0
Chicken farms	8	8	5	6.6	10.0
Planted pastures (irrigated)	6	3	1	3.4	10.0
Infilling (incl. infrastructure)	10	10	10	1	10.0
Sediment deposits	4	5	5	2.6	5.0
Artificially wetter areas (e.g. seepage below dams)	5	7	1	0.8	5.0

Table 5.8. Default impact intensity scores assigned to the specified landcover categories for the various factors relating to the external areas of influence that are taken into consideration in a Level 1B assessment

Level 1B Landcover Categories	Default Intensity Scores				
	External areas of influence				
	Water Inputs			Sediment inputs	Water Quality
	EXT_MAR	EXT_Seas	EXT_Peak	EXT_Sed	EXT_WQ
Open Water – Natural	0	0	0	0	0.0
Water supply dam	-8	3	-9	-8	0.0
Aquaculture dams/ponds	-8	3	-9	3	5.2
Natural / Minimally impacted	0	0	0.5	0.5	0.3
Semi-natural	0	0	1.5	2	0.6
Moderately degraded land	1	1	3	5	1.1
Orchards and vineyards	-5	4	2	4	4.1
Sugar cane	-4	1	2	6	4.3
Commercial annual crops (irrigated)	-5	4	3	8	4.6
Commercial annual crops (non-irrigated)	-2	1	3	7	4.3
Subsistence crops	-2	1	3	6	2.4
Tree plantations	-7.5	0	2	5	0.8
Dense infestations of invasive alien plants	-5.5	0	0	3	0.3
Quarrying (sand, stone, diamonds)	-1	1	4	9	1.4
Coal mining	-4	2	5	9	5.6
Ore mining	-5	2	5	9	6.7
Eroded areas (& heavily degraded lands)	2	0	5	9	1.5
Urban Industrial/Commercial	2	1	9	4	5.5
Urban Informal	2	1	7	5	5.1
Urban Residential – high density	2	2	7	3	3.3
Urban Residential – low density	2	1	5	2	2.7
Urban Open Space	-1	1	3	2	2.8
Livestock feedlots (cattle and pigs)	1	1	4	9	4.8
Chicken farms	-2	2	2	3	4.4
Planted pastures (irrigated)	-4	3	2	2	2.3

Rational underlying the default impact intensity scores assigned in Tables 5.7 & 5.8

The rationale underlying the default impact scores for a Level 1B assessment, for both within-wetland landuses and landuses in the external areas of influence, is provided in **Section 5.3**.

The "tweaks" that are applied in the approach to deriving magnitude-of-impact scores for the impact of dams in the catchment on wetland hydrology in a Level 1A assessment (as explained in **Section 5.1**) are also applied for changes in MAR and seasonality in a Level 1B assessment, but not for changes in floodpeaks. Instead, the magnitude-of-impact score for floodpeaks [EXT-Peak] is derived from an estimate of the cumulative volume of water stored in dams in the catchment of a wetland in relation to the total MAR of the catchment (as explained below). The "tweaks" that are applied to the impact of medium- and high-risk mining landuses on the water quality of the wetland in a Level 1A assessment are also applied in a Level 1B assessment, but in this case with specific reference to coal and ore mining.

Dams located in the catchment of a wetland tend to affect the delivery of floodpeaks (and sediments) to the wetland to a greater degree than that suggested by the proportional extent of the catchment occupied by their cumulative surface area, as explained in **Section 5.1**. To factor this into a Level 1B assessment, instead of simplistically applying a multiplier as in the case of a Level 1A assessment, the magnitude-of-impact score for changes to floodpeaks [EXT-Peak] and sediment inputs [EXT-Sed] related to dams is derived from an estimate of the collective volume of the dams in the catchment of a wetland in relation to the MAR of the catchment (as explained in **Hydro Step 1C-2**). These calculations are accommodated in the "Default Dam Ratings" worksheet of the spreadsheet tools developed for Level 1B and Level 2 assessments. The final magnitude-of-impact scores for [EXT-Peak] and [EXT-Sed] in relation to dams that are used in a Level 1B (and a Level 2) assessment, as based on the estimated cumulative volume of storage in the catchment, are presented in **Table 5.9**.

Table 5.9. Default magnitude-of-impact scores for changes in floodpeaks (EXT-Peak) and sediment inputs (EXT-Sed), as used in a Level 1B (and Level 2) assessment for dams in the catchment of a wetland

	Default Magnitude-of-impact Scores				
Cumulative size of upstream dams	Small (<20% MAR)	Modest (20-35% MAR)	Medium (36-60% MAR)	High (60-120% MAR)	Very High (>120% MAR)
Water Inputs (EXT-Peak)	-0.5	-1	-2.5	-4	-5
Sediment Inputs (EXT-Sed)	-1	-2	-3	-4	-5

Rationale for scores in Table 5.9

The greater the total storage capacity of dams in the catchment of a wetland is, in relation to the Mean Annual Runoff (MAR) from the catchment, the greater the impact will be on changes to the natural floodpeaks and sediment inputs delivered to the wetland. For small to medium cumulative storage capacity, the impact on sediment inputs would presumably be more significant than the impact on water inputs because sediments will continue to settle in the dams even when they are full and overtopping. This is why the absolute scores for [EXT-Sed] are 0.5 to 1 less than the absolute scores for [EXT-Peak] under small, modest and medium levels of cumulative storage capacity of upstream dams. These differences would be less noticeable for high levels of cumulative storage capacity, where the total storage is approaching or exceeding the MAR of the catchment. As such, the scores here are the same for [EXT-Peak] and [EXT-Sed].

None of the scores are greater than 5 out of a maximum possible value of 10. This is because, even with high levels of cumulative capacity in dams that exceeds the MAR of the catchment, there would still generally be a significant amount of runoff from portions of the wetland catchment that are located outside of the localised catchment areas of the dams.

As in the case of a Level 1A assessment, the magnitude-of-impact scores for the external areas of influence are also multiplied by HGM-specific weightings in a Level 1B assessment, at least for changes to water inputs [EXT-MAR], changes to sediment inputs [EXT-Sed] and changes in water quality as a result of runoff from external areas of influence [EXT-WQ]. For a Level 1B assessment, however, there is an additional area of influence to consider (namely, the inflowing stream buffers), and there are additional HGM sub-types that must be taken into account for certain HGM types (as shown in the relevant table of HGM-specific weightings presented in **Table 5.10**).

Table 5.10. HGM-specific weightings used to combine the magnitude-of-impact scores for changes in water inputs (EXT-MAR) and changes in sediment inputs and water quality from external sources (EXT-Sed & EXT-WQ) in relation to landuses in the external areas of influence in a Level 1B assessment

HGM type (refined)	FP	CVB-lat	CVB-chan	UVB	SEEP	DEP-exo	DEP-endo	FLAT
EXT-MAR:								
Wetland buffer weighting	10	70	N/A	N/A	N/A	N/A	N/A	N/A
Broader catchment weighting	90	30	Calculation based on the relative extent of contributing areas					
Inflowing stream buffer weighting								
EXT-Sed & EXT-WQ:								
Wetland buffer weighting	10	70	30	30	80	80	80	80
Broader catchment weighting	22.5	7.5	17.5	17.5	20	20	20	20
Inflowing stream buffer weighting	67.5	22.5	52.5	52.5				

FP = floodplain wetland; CVB-lat = channelled valley-bottom wetland laterally maintained (i.e. with substantial lateral inputs); CVB-chan = channelled valley-bottom wetland not laterally maintained; UVB = unchannelled valley-bottom wetland; DEP-exo = exorheic depression (i.e. with flushing); DEP-endo = endorheic depression (i.e. without flushing)

Rationale for scores in Table 5.10

In the case of FP wetlands, most of the water (and sediment and pollution) inputs are presumed to originate from the catchment of the wetland, as opposed to lateral inputs from the immediate wetland buffer, based on the conceptual model for this type of wetland where overbank flooding from the through-flowing channel/s is considered to be one of the key drivers of wetland function. As such, the catchment is given a weighting of 90%, versus a weighting of 10% for the immediate wetland buffer, in the case of this HGM type (for EXT-MAR, EXT-Sed and EXT-WQ).

For CVB-lat wetlands, on the other hand, most water (and sediment and pollution) inputs would be from the immediate wetland buffer, due to the domination of lateral inputs into this type of wetland by definition. Inputs from the broader catchment (including inflowing stream buffers) still play a significant role, however. Here, therefore, the buffer is given a weighting of 70%, versus a weighting of 30% to the remaining catchment outside of the immediate wetland buffer.

In terms of water inputs (EXT-MAR), none of the other HGM types (i.e. CVB-chan, UVB, SEEP, DEP-exo, DEP-endo, and FLAT) are considered to be dominated, in particular, by lateral inputs from the immediate wetland buffer or by inputs from the catchment area outside of the wetland buffer. No HGM-specific weightings are thus applied in this case when combining the scores for the different external areas of influence. Instead, the scores are simply combined on the basis of the relative extent of the contributing areas, with the external area of influence with the greater extent being afforded a higher weighting.

For the derivation of integrated scores for sediment and pollution inputs from the external areas of influence (EXT-Sed & EXT-WQ), however, HGM-specific weightings have been assigned. This is because most research suggests that sediment and pollution runoff tends to be attenuated to significantly lower levels over relative short distances, with inputs from the distant reaches of the catchment typically contributing significantly less than inputs from the immediate buffer of the wetland and the buffers of the inflowing streams (as explained, with references, in the Water Quality chapter of this report). In the case of CVB-chan and UVB wetlands, it is presumed that the biggest contribution of sediment and pollution inputs is from the buffers of the inflowing streams because these HGM types typically occur in a valley floor position and are fed by a network of streams emanating in the up-slope catchment area. The catchment, as a whole, is thus given an overall weighting of 70% for these HGM types, with three-quarters of this (52.5%) attributed to the inflowing stream buffers (versus the remaining broader catchment). In the case of FP and CVB-lat wetlands, when deriving scores for EXT-Sed and EXT-WQ, three-quarters of the allocation for the remainder of the catchment outside of the wetland buffer is also apportioned to the inflowing stream buffers, for the same reason.

In the case of SEEP, DEP-exo, DEP-endo and FLAT wetland types, there are typically no major inflowing streams that originate from the distant parts of the catchment, and most sediment and pollution inputs originate from immediate wetland buffer. A weighting of 80% has thus been assigned to the wetland buffer for all these HGM types, and the 20% apportioned to the broader catchment (outside of the wetland buffer) is not split between the inflowing stream buffers and the remaining catchment.

No HGM-specific weightings are applied when combining the scores from the different external areas of influence to derive overall magnitude-of-impact scores for change in the seasonality of water inputs [EXT-Seas] and changes to floodpeaks [EXT-Peak] in a Level 1B assessment. As in the case of the [EXT-MAR] scores for all HGM types except FP and CVB-lat (discussed above), the overall [EXT-Seas] and [EXT-Peak] scores are derived by combining the respective scores for the wetland buffer ([BUFF-mag-Seas] and [BUFF-mag-Peak]) and the remaining catchment ([CATCH-mag-Seas] and [CATCH-mag-Peak]) according to the proportional extent of these areas of influence in relation to one another. This is because changes in the seasonality of water inputs and floodpeaks are not really affected by the type of wetland under consideration.

Allowance has been made for point-source pollution inputs into inflowing streams or directly into a wetland to be taken into account (in an optional extra worksheet), where relevant, in the derivation of an overall Water Quality Impact Score. This option was brought into the Level 1B assessment, having previously only being considered in a Level 2 assessment, after a number of test cases highlighted the overriding impact that point source discharges can have on the water quality of a wetland. In a Level 1B assessment, the assessor is simply required to select the type of effluent that is being discharged (with three optional types for discharges into inflowing streams, and seven optional types for discharges directly into a wetland), and to select the relevant category for the distance upstream of the wetland (in the case of a point-source discharge into an inflowing stream) and/or the proportion of the wetland affected (for a point-source discharge entering directly into a wetland). A maximum of two point-source discharges into inflowing streams and two point-source discharges directly into a wetland is catered for in the tool that has been developed for a Level 1B assessment (versus up to five in each case for a Level 2 assessment). An explanation is provided of the point-source discharge categories that are available for selection and the way in which an impact score is derived in the Water Quality module (**Chapter 9**).

The overall Impact Scores for Hydrology, Geomorphology, Water Quality and Vegetation are derived in a similar way for a Level 1B assessment as they are in a Level 1A assessment (explained in **Section 5.1**). Differences in the approach include the following:

- The magnitude-of-impact score for the lowering of the regional aquifer is added to the magnitude-of-impact score for the change in surface water inputs from the topographical catchment, to derive an overall Impact Score for the change in water inputs to the wetland from external areas of influence. Before adding these scores together, they are each multiplied by a factor representing the proportional contribution from the regional aquifer and the topographical catchment, respectively, which is based on the score for the degree of connectivity to the regional aquifer.
- The magnitude-of-impact score for the water quality of the regional aquifer is added to the magnitude-of-impact score for the change in water quality as a result of inputs from the topographical catchment, to derive an overall Impact Score for the change in wetland water quality from external water inputs. Before adding these scores together, they are each multiplied by a factor representing the proportional contribution from the regional aquifer and the topographical catchment, respectively, which is based on the score for the degree of connectivity to the regional aquifer.
- There is an additional external area of influence (i.e. buffers of inflowing streams) for Hydrology, Geomorphology and Water Quality, which is factored into the calculation of overall impact scores for the external areas in these modules.
- The HGM-specific adjustment factors used to adjust the magnitude-of-impact score for change in floodpeaks, to account for differences in the vulnerability of different HGM types to increased or decreased floodpeaks, make provision for the additional HGM sub-types that are considered in a Level 1B assessment (see **Table 5.11**).

- Modifiers have been factored into the derivation of a final Impact Score for Water Quality to account for increased pollution concentrations in a wetland associated with endorheic drainage and reduced water inputs (as explained in the Water Quality module, under **WQ Step 3B**).

Table 5.11. HGM-specific adjustment factors used to adjust the floodpeaks score for the catchment (EXT_Peak) in a Level 1B assessment

HGM type (refined)	FP	CVB-lat	CVB-chan	UVB	SEEP	DEP-exo	DEP-endo	FLAT
Floodpeaks adjustment factor:								
EXT-Peak >=0	0.3	0.7	0.4	0.5	0.7	0.5	0.5	0.5
EXT-Peak <0	0.9	0.4	0.7	0.4	0.2	0.3	0.3	0.3

FP = floodplain wetland; CVB-lat = channelled valley-bottom wetland laterally maintained (i.e. with substantial lateral inputs); CVB-chan = channelled valley-bottom wetland not laterally maintained; UVB = unchannelled valley-bottom wetland; DEP-exo = exorheic depression (i.e. with flushing); DEP-endo = endorheic depression (i.e. without flushing)

Rationale for scores in Table 5.11

The adjustment factors in this table are similar to those for a Level 1A assessment (see rationale for scores in **Table 5.5**), taking into account the additional HGM types that are considered in a Level 1B assessment. The main difference is for channelled valley-bottom wetlands, which are split into those dominated by lateral inputs (CVB-lat) and those dominated by inputs from a through-flowing channel connected to the broader catchment (CVB-chan). Due to the inherent dependence of CVB-chan wetlands on flood events, this wetland type was assigned a relatively high adjustment score (0.7) for their vulnerability to reduced floodpeaks and a relatively low adjustment score (0.4) for vulnerability to increased floodpeaks. The adjustment scores for CVB-lat wetlands, which are dominated by lateral inputs by definition, are the other way around – relatively high (0.7) for vulnerability to increased floodpeaks and relatively low (0.4) for vulnerability to reduced floodpeaks.

As in the case of a Level 1A assessment, the overall Impact Scores for Hydrology, Geomorphology, Water Quality and Vegetation derived in a Level 1B assessment are automatically converted to PES Scores, by subtracting the Impact Score from 10 and expressing the result as a percentage. These PES % scores are then used to determine the relevant Ecological Category, based on the ranges of scores for each Category presented in **Table 3.2**.

In the tool for a Level 1B assessment, an opportunity is provided for users to refine certain of the automatically generated impact scores based on further field indicators and expert opinion (as explained further in **Section 11.1**). Such changes must be appropriately justified in the “Review” worksheet by providing a clear rationale (together with a confidence rating) for any refinements that are made to the automatically-derived scores. An opportunity is also provided in the “Review” worksheet to rate the "Trajectory of Change" for each component of wetland PES, so as to present a more complete picture of “wetland health” (see general guidelines for assessing the anticipated trajectory of change in **Section 12.1**).

The outcomes of the assessment are presented in a final summary page (see example in **Figure 5.3**). This includes an overview of the unadjusted and final (adjusted) scores for each component of wetland PES. An Integrated Wetland PES Score and associated Ecological Category, derived by combining the scores for the four modules of wetland PES using the formulae explained in **Section 11.2**, is also presented. The summary worksheet, as in the case of the tool for a Level 1A assessment, also shows the “hectare equivalents” represented by each wetland, which is derived by multiplying the PES score (as a percentage) by the total extent of the wetland. Finally, the summary worksheet for a Level 1B assessment includes an automatically generated confidence rating for the PES results that have been derived for an individual wetland (as explained below).

	Wetland PES Summary			
Wetland name	Hypothetical example			
Assessment Unit	AU#1			
HGM type	Depression without flushing			
Wetland area (Ha)	3.5 Ha			
Unadjusted (modelled) Scores				
PES Assessment	Hydrology	Geomorphology	Water Quality	Vegetation
Impact Score	6.5	4.2	6.5	6.6
PES Score (%)	35%	58%	35%	34%
Ecological Category	E	D	E	E
Combined Impact Score	6.1			
Combined PES Score (%)	39%			
Combined Ecological Category	E			
Hectare Equivalents	1.4 Ha			
Confidence (modelled results)	Low to Moderate: Desktop assessment based mostly on refined landcover mapping			
Final (adjusted) Scores				
PES Assessment	Hydrology	Geomorphology	Water Quality	Vegetation
Impact Score	5.8	4.6	5.4	6.0
PES Score (%)	42%	54%	46%	40%
Ecological Category	D	D	D	E
Trajectory of change	↓	→	↓	↓↓
Confidence (revised results)	Medium	Low	Low	High
Combined Impact Score	5.5			
Combined PES Score (%)	45%			
Combined Ecological Category	D			
Hectare Equivalents	1.6 Ha			

Figure 5.3. Example of the summary that is automatically generated in the tool for a Level 1B assessment

If the hydro-geological type setting of a wetland is selected as "Coastal plain" or "Karst landscape", and "Unknown" is recorded for 'Connectivity of wetland to a regional aquifer', 'Change in groundwater levels in the regional aquifer' or 'Water quality of regional aquifer' in the Wetland Attributes worksheet, then a wetland is assigned a rating of "Very Low: High probability of connection to regional aquifer but missing information on the degree of connectivity, the lowering of the water table, and/or groundwater quality". If "Unknown" is recorded for any of these variables but the hydro-geological type setting is selected as "Other", then the assigned rating is "Low: Relatively low probability of connection to regional aquifer but missing information on the degree of connectivity, the lowering of the water table, and/or groundwater quality". For all scenarios where the required information has been recorded for 'Connectivity of wetland to a regional aquifer', 'Change in groundwater levels in the regional aquifer' and 'Water quality of regional aquifer' in the Wetland Attributes worksheet, a confidence rating of "Low to Moderate: Desktop assessment based on refined landcover mapping" is assigned to the results of the assessment.

5.3. Rationale for default impact intensity scores assigned to predefined landcover categories

[A] Within-wetland landuses

(Rationale underlying the default impact intensity scores assigned in Table 5.7)

Hydrology Impact Intensity Scores (landuses in the wetland)

- The majority of South African wetlands are very shallowly flooded, many of them for relatively short periods. Therefore **deep flooding from impoundments** (including **aquaculture dams/ponds**) represents a greater departure from the natural condition and increases water retention in the wetland to a greater degree than **shallow flooding from impoundments**, and the hydrology impact score is therefore relatively high.
- The hydrological impact of **semi-natural, undrained** wetland is taken as only slight, given that drainage furrows, impoundments and other human influences on water distribution and retention are absent, and the vegetation structure and cover is generally similar to the natural vegetation (although vegetation composition may have changed greatly).
- The hydrological impact of **semi-natural, drained** wetland is taken as significantly higher than semi-natural, undrained given that drainage furrows are present. However, the impact is taken as lower than all of the cultivated landcover types, given the fact that in semi-natural areas the drainage furrows are generally not maintained, as is the case in cultivated wetland, and therefore the furrows tend to operate less efficiently in altering the retention of water in the wetland.
- **Moderately degraded land** is typically subject to prolonged intensive use by livestock. These areas lack drainage furrows, impoundments and other human influences on water distribution and retention. However, rills and minor gully erosion are often present, which influences water distribution and retention to some extent.
- For the various forms of <u>cultivation</u> (including **orchards and vineyards**, **sugar cane**, **commercial annual crops**, and **subsistence crops**), the primary physical characteristic impacting upon the hydrology of the wetland is the level of artificial drainage typically associated with the landcover. The potentially profound impact of artificial drainage on wetlands has been widely demonstrated, e.g. by Skaggs (1980), Mitsch and Gosselink (1993) and Dunn and Mackay (1996). The hydrology impact scores also take into account whether the crop is irrigated, which is taken to increase the impact. **Planted pastures (irrigated)** typically have lower levels of artificial drainage than the various forms of cultivation, but they are generally irrigated in the dry season and thus typically impact on the hydrology of a wetland to a slightly less degree than the various types of cultivation.
- For **tree plantations** and invasive alien trees (**dense infestations of invasive alien plants**), the hydrology impact scores were informed by the extensive studies (e.g. Scott and Lesch, 1997; Scott *et al.,* 1998; Gush *et al.,* 2002; Scott, 2005) examining the water use of different tree types in relation to the natural vegetation. These studies confirm, for example, that tree plantations and invasive alien trees generally use more water than the natural vegetation, and in addition eucalyptus trees are greater water users than wattle and pine trees.
- **Quarries** and mines (e.g. **coal mining** or **ore mining**) represent extreme transformation of the landscape and often result in the complete removal of the wetland (Mitsch *et al.,* 1983). Therefore, they are scored very high in terms of hydrological impacts.
- **Eroded areas and heavily degraded lands** are generally characterised by reduced vegetation cover and major erosion gullies, which act to reduce water retention in the wetland, generally to a greater degree than in moderately degraded lands.

- Infilled areas (including roads) generally occur with a sufficient depth of fill to completely eliminate wetland conditions, resulting in major environmental impacts (Mitsch and Gosselink, 1993). Therefore **infilling** is scored very high in terms of hydrological impacts.
- **Urban Industrial/Commercial** and **Urban Residential** – **high density** landuses in wetlands are taken to have similarly high hydrological impacts, resulting from infilling and/or a high level of artificial drainage and the hardened, impermeable surfaces associated with infrastructure. However, informal settlements (**Urban Informal**) are scored somewhat lower, given that artificial drainage and/or infilling generally occurs to a much lesser extent, but hardened, impermeable surfaces are still extensive. **Urban Residential** – **low density** is scored somewhat lower still, given the lower extent of hardened, impermeable surfaces in this landcover type. **Urban Open Spaces** in wetlands typically have minor landscaping or other human influences on water distribution and retention, but to a much lesser degree than in commercial or residential landcover types.
- Recent **sediment deposits** (e.g. as a result of sediment washing into the wetland from upslope eroding lands) vary in terms of their depth and level of impact, but typically would not be so deep as to greatly alter water distribution and retention in the wetland.
- **Livestock feedlots** and **chicken farms** in wetlands would typically have infilling and/or a high level of artificial drainage, and the hardened, impermeable surfaces associated with these landcover types. These landuses are, therefore, considered to have high hydrological impacts.
- **Artificially wetter areas** such as seepage below dam walls typically continues throughout the year, often altering the seasonality in a wetland, and hence the hydrological condition of the wetland.

Geomorphology Impact Intensity Scores (landuses in the wetland)

For the purposes of the geomorphology assessment, landuses in the wetland were rated both in terms of anticipated impacts to geomorphic processes (*Wet_Geo_Pr*) and geomorphic structure (*Wet_Geo_St*). Scores for geomorphic processes were based principally on anticipated changes of landuse activities on water (and associated sediment) distribution and retention patterns. Scores for geomorphic structure, on the other hand, were based on the degree to which landuse activities are likely to alter the geomorphic structure of the wetland through a range of processes including (i) excavation and removal of sediment, (ii) sediment loss through erosion, (iii) stream channel modification, and (iv) artificial wetland infilling or impoundment by dams and/or enhanced deposition.

- Artificial inundation typically enhances rates of sediment accumulation which changes geomorphic structure over time. Moderate impact scores were therefore allocated with such landuses, with deeply inundated areas (**deep flooding from impoundments**, including **aquaculture dams/ponds**) scoring higher than **shallow flooding from impoundments**, which may be flushed of sediment during flood events.
- The level of artificial drainage, and channel modification were key aspects used to inform the scoring of **semi-natural** areas, **moderately degraded land** and <u>agricultural landuses</u>. Drainage is typical in areas used for **sugarcane** and **commercial annual crops**, whilst levels are typically somewhat lower in **orchards and vineyards** and, even more so, in wetland areas used for **subsistence crops**. **Planted pastures** are highly variable, but typically do not require the same level of drainage as other agricultural landuses. Whilst drainage has some impact on geomorphic structure, the main impact is on geomorphic *processes*, which includes a reduction in depositional processes and increases in soil loss. As such, the impact scores for geomorphic processes were rated higher than for structure.
- **Tree plantations** and **dense infestations of invasive alien plants** are rarely associated with much soil disturbance and, whilst they may have some impact on surface roughness, are regarded as generally having a low impact on wetland geomorphology.

- Landuses such as **quarrying** and **(coal and ore) mining** as well as **eroded areas** scored high since they are associated with excavation and/or loss of sediment, which affects both the structure and processes of sediment retention and distribution in the wetland.
- The presence of urban landuses in wetlands is typically associated with **infilling**, which totally transforms the geomorphic landscape, whilst practices such as drainage, stream channel modification and deposition are typical in any untransformed urban areas. As such, intensive urban landuses (e.g. **Urban Industrial/Commercial, Urban Informal, Urban Residential – high density**) scored high, but with some down weighting for lower intensity landuses (e.g. **Urban Residential – low density**). The default impact intensity scores assigned to **Urban Open Space** were significantly lower, being more similar to subsistence cropping in terms of impacts on geomorphic process and structure.
- **Chicken farms** require dry conditions and were also scored high due to the anticipated levels of drainage and infilling to make wetland areas suitable for such landuse. **Livestock feedlots**, on the other hand, do not typically require any infilling but are usually drained so this landuse type was assigned the same score as chicken farms for its impact geomorphic structure and half the score for impact on geomorphic processes.
- **Sediment deposits** alter the geomorphic structure but may also alter the pattern of sediment distribution and retention in the wetland. Identification of such features at a desktop level suggests considerable deposits and was therefore rated quite high.
- Dams tend to trap sediment, often leading to a considerable reduction in sediment inputs downstream. As such, **artificially wetter areas**, such as that typical below earthen dam walls was allocated a high impact score for geomorphic processes. Unless accompanied by drainage or incision, impacts on geomorphic structure is generally limited.

Water Quality Impact Intensity Scores (landuses in the wetland)

For the assessment of landuse-related impacts on wetland water quality, default impact intensity scores were derived by considering the potential impact of each of the specified landcover types on a suite of pre-selected water quality parameters (as explained in more detail in **Chapter 9**). These parameters were nutrient (Nitrogen and Phosphorus) concentrations, Biological and Chemical Oxygen Demand (BOD/COD), the concentration of Total Dissolved Salts (TDS), Total Suspended Sediments (TSS), heavy metals and other toxics. Preliminary impact intensity scores (ranging from 0-10) were assigned to each of the parameters for each of the specified landcover categories (these parameter-specific scores are presented in **Table 9.2** of **Chapter 9**). The intention was for the parameter-specific intensity scores to provide quantified estimates of the presumed propensity of a particular landcover type to alter each water quality parameter from the natural reference range. References that were consulted to inform the assignment of parameter-specific "intensity scores" for the different landcover types included, *inter alia*, USEPA (2001), Malan & Day (2012), Malan *et al*. (2013), (DWA, 2013), and Macfarlane & Bredin (2017a) and relevant appendices. The individual parameter-specific intensity scores were summed for each landcover category, and these scores were then normalised so that the category with the highest summed score is assigned a value of 10 (as shown in **Table 9.2**). These normalised overall scores for each landcover type (presented in **Table 5.7**) were then taken as the default Water Quality Impact Intensity scores for within-wetland landuses. Further explanation of the rationale behind the relative difference between the scores for the various landuse types is provided below.

- The very high impacts on water quality that are generally associated with mining are well documented (e.g. Mitsch *et al.,* 1983; Ashton *et al*., 2001; Heath *et al.,* 2009; Barclay *et al.,* 2011). **Ore mining** has the highest impact intensity score (rated at the maximum of 10) because these mining operations tend to cause major issues in relation to all the water quality parameters that were considered, with gold mining being particularly problematic due to the use of relatively large quantities of cyanide and other toxic compounds in the refining process (Ashton *et al*., 2001). **Coal**

mining does not typically involve the use of as many toxic compounds as gold or other ore mining operations, but it is as detrimental (if not worse) as ore mining in terms of most other water quality parameters, including the potential for the ubiquitous problem of Acid Mine Drainage. As such, it has also been given a high default intensity score (close to 8.5). **Quarrying**, on the other hand, mostly results in sedimentation and elevated TSS levels so it has a very low impact intensity score (just over 2).

- After ore and coal mining, **Urban Industrial/Commercial** areas were rated as having the next-highest landuse-related impact on water quality (with a score >8). This is due to the prevalence of the runoff of a wide range of pollutants (including heavy metals and other toxic compounds such as hydrocarbons, elevated nutrients and somewhat elevated TDS levels) from the impervious surfaces in areas dominated by these landuse types (e.g. see Schoonover and Lockaby, 2006; Carey *et al*., 2011), especially from industrial areas. Less intensive urban landuses (i.e. **Urban Residential – low & high density** and **Urban Open Space**) were given much lower scores (4-5), while **Urban Informal** was given a relatively high score (7.6), only slightly lower than Urban Industrial/Commercial, due to the prevalence of high nutrient levels and BOD/COD related to the contamination of stormwater runoff from informal settlements with untreated sewage and other organic contaminants.
- Relatively high impact intensity scores (between 7 and 8) were also assigned to **aquaculture dams/ponds** and **livestock feedlots**. This is largely due to the high nutrient levels and sedimentation associated with these landuse types, typically leading to elevated BOD/COD and TSS. Several studies (e.g. Buck *et al.,* 2004) have demonstrated the effect of high densities of livestock on water quality in receiving waters. **Chicken farms** were given a slightly lower score (between 6.5 and 7) because, whilst they are also associated with elevated nutrient and BOD/COD levels (and relatively high levels of non-metal toxins related largely to un-ionised ammonia), these facilities typical have low levels of sedimentation.
- The greater the level of artificial drainage of <u>cultivated areas</u>, the greater will be the potential for leaching from these areas given that artificial drainage channels may act as a major conduit of nitrogen and phosphates from the soil of agricultural lands to receiving waters (Randall and Goss, 2001; Nguyen and Sukias, 2002). This, in turn, impacts negatively on the aquatic habitats within (and downstream of) the wetland.

  Irrigation also contributes to the likelihood of leaching of nutrients from cultivated lands to receiving waters when compared with an equivalent non-irrigated crop (Görgens *et al.,* 2012).

  The greater the level of fertilizer or biocide application to cultivated areas, the greater the likelihood of their leaching from these areas (Thorburn *et al.,* 2013). By virtue of the fact that certain crops generally receive more fertilizer and biocides, it can be assumed that these crops have greater potential to impact on water quality.

  In annual crops, the growth of plants (and therefore uptake of nutrients) is interrupted when one crop is harvested and the next has yet to develop (Randall and Goss, 2001). This provides greater opportunities for loss of nutrients from the soil than in perennial crops, where uptake of nutrients is sustained (Randall and Goss, 2001). This, in turn, impacts negatively on the aquatic habitats within (and downstream of) the wetland.

  It has been well demonstrated that the greater the level of tillage, the greater the exposure of soil to erosion, and therefore the lower the potential of a wetland to store sediment, given that each time the soil is tilled its structure is disrupted and plant roots contributing to the strength of the soil are destroyed. The reduced storage of sediment in turn reduces the natural storage of phosphorus, given that phosphorus tends to be strongly bound to soil particles (Pierzynski *et al.,* 2005).

  All the above-mentioned factors were taken into account in assigning parameter-specific scores to and deriving integrated impact intensity scores for the <u>cultivation-related landuse types</u>. This resulted in similar overall default impact intensity scores (ranging between 6 and 7) for the commercial agriculture categories (i.e. **orchards and vineyards**, **sugar cane**, and **commercial annual crops** – **irrigated and non-irrigated**), with significantly lower scores (close to 3.5) for **subsistence crops** and **planted pastures (irrigated)**.

- **Sediment deposits**, **eroded areas (and heavily degraded land)**, **moderately degraded land** and **infilling** are all characterised by varying degrees of sedimentation and resulting increases in the TSS of adjacent aquatic ecosystems, but very few other water quality impacts of significance. The overall impact intensity scores for these landuse types are accordingly low, varying between 1 and approximately 2.5.
- The main water quality impact associated with **tree plantations** and **dense infestations of invasive alien plants** is sedimentation (from increased erosion), resulting in increased turbidity/TSS in the water column. There is also often a slight increase in the levels of nutrients and solutes, which are typically adsorbed onto the sediment particles and become released into the water column when the sediments are mobilised. In the case of nitrogen-fixing invasive alien plants such as the *Acacia* species, their presence (especially in dense infestations) can result in slightly elevated nutrient levels in adjacent aquatic ecosystems (e.g. see review by Chamier *et al*., 2012). Despite these water quality concerns, the overall impact intensity scores for tree plantations and, particularly, dense infestations of alien invasive plants were relatively low (close to 0.5 and 1, respectively) because there are typically very few other water quality issues associated with these landuse types.
- The water quality impacts associated with **natural / minimally impacted** areas, **semi-natural** areas and **artificially wetter areas** are negligible, with all these landuse types having impact intensity scores <1.

Vegetation Impact Intensity Scores (landuses in the wetland)

- Landcover types where vegetation is replaced completely (e.g. by infrastructure, deep flooding by dams or cultivation) resulting in there being no vegetation at all, have been assigned the highest possible vegetation impact score (i.e. 10). This is taken to include **deep flooding from impoundments**, **aquaculture dams/ponds**, **orchards and vineyards**, **sugarcane, commercial annual crops**, **subsistence crops**, **tree plantations, coal and ore mining**, **urban industrial/commercial landuses**, **high-density urban residential areas**, **livestock feedlots**, **chicken farms**, **planted pastures**, **and areas subjected to infilling (including infrastructure)**.
- Landcover types where there is typically near-complete replacement of vegetation but a very small amount of vegetation may still be present have been assigned vegetation impact scores of 9.0. This includes **dense infestations of invasive alien plants**, **quarries**, **eroded areas (and heavily degraded lands)**, **informal urban areas**, and **urban open space**.
- Typically, **semi-natural areas** were cultivated or otherwise disturbed in the past and vegetation has recovered to some degree. Where such areas are drained (and therefore the hydrology greatly altered), the potential for recovery of the native vegetation is more limited than in undrained areas, given the key influence of hydrology over wetland vegetation composition. Therefore **semi-natural drained** areas have been assigned a higher impact intensity score than **semi-natural undrained** in terms of the impact on vegetation.
- **Moderately degraded land** is typically subject to prolonged intensive use by livestock, which results in vegetation compositional changes, but given the lower intensity of impact this tends to be less than in **heavily degraded land**, where vegetation composition is generally highly altered. The readiness with which the natural vegetation in a wetland recovers after removal of the vegetation (e.g. for cultivation) varies considerably. However, as a general rule, it appears that areas which are permanently wet and tending to naturally support a few tall-growing species

recover far more readily than the temporary to seasonal wetland areas supporting shorter and more diverse vegetation (Walters *et al.,* 2006).

- The more sustained wetness in **artificially wetter areas** such as seepage below dam walls impacts on the vegetation by generally favouring tall-growing competitive plants such as bulrushes (*Typha*) even in situations where nutrient levels are not elevated (Boers and Zelder, 2008).
- The impact of anthropogenically-caused **sediment deposits** in a wetland on the wetland vegetation are likely to vary greatly deepening on the sensitivity of the vegetation and depth of the deposit, but typically some of the native vegetation persists, and impacts on the vegetation are therefore taken as intermediate.

[B] Landuses in external areas of influence

(Rationale underlying the default impact intensity scores assigned in Table 5.8)

Impact Intensity Scores for Water Inputs (landuses in the catchment of the wetland)

- The effect of upstream dams in reducing runoff available to downstream aquatic ecosystems/wetlands has been well demonstrated (Mantel *et al*., 2010). Dams also act to dampen floodpeaks, particularly where their level generally remains below full supply level, which applies to the majority of South African dams. Furthermore, dams potentially alter the seasonality of inflows to downstream ecosystems, especially with respect to early wet season flows, which enter dams when they are at their lowest and therefore most “primed” to capture flows. These impacts apply to **water supply dams** and **aquaculture dams/ponds**.
- The effect that **dense infestations of invasive alien plants** and different **plantation** trees (e.g. eucalypts vs. pines) have in reducing runoff is also well demonstrated (see Rationale for Hydrology Impact Intensity Scores in relation to landuses in the wetland). Although stormflows are decreased within plantation blocks once the trees have grown reasonably large, this effect is countered by the fact that tree plantations characteristically include a network of roads between the plantation blocks, which act to some extent as a drainage network increasing the collection and delivery of stormflows. Thus, on balance floodpeaks are increased slightly from areas with tree plantations.
- Much of the current **semi-natural** vegetation was cultivated in the past, and this historical disturbance of the soil is assumed to impact slightly on infiltration, and therefore on floodpeaks.
- **Moderately degraded land** is typically subject to reduced basal cover and reduced infiltration (Tainton, 1999). These changes, in turn, result in increased peak discharges/quickflows and reduced inputs of sustained sub-surface water to the downstream wetland. In **highly degraded land and eroded areas** these impacts are further increased.
- For all <u>irrigated cultivated land</u> (including **sugarcane** and **irrigated planted pastures**) in the wetland’s catchment, it is assumed that the irrigation water is withdrawn from the wetland’s catchment rather than being derived from another catchment. Thus, this irrigation exposes the water in the wetland’s catchment to increased atmospheric loss, thereby reducing mean annual runoff from the wetland’s catchment. Orchards and vineyards, which characteristically occur in the winter rainfall area of South Africa, are subject to extended irrigation during the dry summer season. In addition, irrigation of commercial croplands generally occurs extensively in the dry season. Thus, **orchards and vineyards** and **irrigated commercial annual crops** generally result in increased dry season water inputs to downslope areas as a result of irrigation return flows, thereby having a moderate impact on seasonality of inflows to a wetland. The hydrological impacts of **non-irrigated commercial crops** and **subsistence agriculture** are typically a lot less severe.

- **Urban industrial/commercial** and **high-density urban residential** areas all have a high extent of impermeable surfaces. The greater the extent of impermeable surfaces, the lower the infiltration of storm-waters and therefore the greater the surface runoff and flood peaks. Thus, these landcover types have a high impact in increasing floodpeaks. The hydrological impacts of **urban informal areas** and **low-density urban residential areas** in the catchment of a wetland are typically less severe. Proportionately, **livestock feedlots** and **chicken farms** have a somewhat lower extent of hardened surfaces than urban areas, and therefore have a somewhat lesser impact on increasing floodpeaks. However, in **urban open spaces** hardened surfaces are generally much more limited but nonetheless generally present.
- **Mines** and **quarries** represent extreme transformation of the hillslopes and soils within a catchment, with important implications for water inputs to a wetland. Although the effect of hardened surfaces may to some extent be countered by the effect of detention ponds and excavated depressions in the mining operational area, the net effect is generally taken to increase floodpeaks.

Impact Intensity Scores for Sediment Inputs (landuses in the catchment of the wetland)

- The effect of dams in trapping sediment has been well demonstrated (e.g. Kondolf, 1997) and, as such, **water supply dams** and **aquaculture dams/ponds** are scored high in terms of their impact on sediment supply.
- **Semi-natural areas** tend to have similar vegetation cover to natural vegetation but slightly increased surface flows, which are assumed to result in only a slight increase in sediment supply. **Moderately degraded land** is typically subject to somewhat reduced basal cover and increased surface runoff, often with some rill and minor gully erosion present, resulting in somewhat increased sediment supply. **Highly degraded land and eroded areas**, characterised by major gully erosion, are key sediment sources and are therefore rated highly in terms of increased sediment inputs.
- **Commercial annual crops** are generally subject to some of the highest levels of tillage, thereby exposing this landcover to some of the highest levels of soil loss, and thus scoring relatively high in terms of increased sediment supply. **Sugarcane** and **subsistence crops** are subject to somewhat less tillage and exposure of the soil, with correspondingly lower scores for increased sediment supply. **Orchards and vineyards** tend to have still lower levels of tillage and in many cases soils may remain permanently covered in vegetation or mulch, and therefore they score correspondingly lower. Of all of the cultivated landcover types, **planted pastures** is assumed to have the lowest level of disturbance and highest vegetation cover, and therefore it scores lowest with respect to increased sediment supply.
- For much of their growth cycle, **tree plantations** tend to have a high litter cover on the soils protecting against increased sediment loss. However, following harvesting and associated disturbance of the soil surface, extensive areas are exposed which can result in pulses of increasing sediment yield. **Dense infestations of invasive alien plants** are not subject to the periodic disturbances of tree plantations, and therefore score lower in terms of increased sediment supply. However, they tend to be less effective than the indigenous vegetation in controlling sediment loss, often due to a reduction in basal cover.
- **Mines** and **quarries** represent an extreme form of disturbance, thus scoring very high in terms of increased sediment supply.
- **Urban areas** include a mix of areas covered in hardened surfaces where sediment supply is reduced, as well as localised areas such as eroding drainage lines and construction sites where it may be greatly increased. On balance, a low to moderate increase in sediment supply to a wetland is assumed for most of the urban landuse types in the catchment.

- Because of the very high concentration of trampling animals, **livestock feedlots** are assumed to have a high increase in sediment supply, while **chicken farms** are less likely to elevate sediment inputs.

Impact Intensity Scores for Water Quality (landuses in the catchment of the wetland)

The presence of a particular landuse within a wetland typically represents the worst-case scenario in terms of the potential impact of that landuse on wetland water quality, whereas runoff from the same landuse located in the surrounding areas outside of the wetland would generally have less impact on the water quality of the wetland. In recognition of this, the default Water Quality Impact Intensity Scores for landuse types in the external areas of influence (i.e. the catchment of the wetland) were derived by simply dividing the within-wetland scores by a common factor of 1.5 (as explained further in **Chapter 9**). As such, the same rationale that was given above for the default Impact Intensity Scores relating to landuses within a wetland is also applicable to the impact of landuses in the external areas of influence on the water quality of a wetland, especially in terms of the relative impact of the different landuse types on wetland water quality.

5.4. Flexibility in the application of Level 1A and 1B assessments

One of the key findings that emerged from the engagement with stakeholders and testing of draft versions of the tools for Level 1A and 1B assessments was that some flexibility needs to be catered for in the way in which the tools are applied. An attempt has been made to accommodate this, by structuring the tools so that they represent a consistent framework for assessment that is not too rigidly prescriptive. Some of the flexibility that has been catered for in the tools for Level 1 assessments includes the following options:

- In a Level 1A assessment, the assessor has freedom to choose how best to delineate "pseudo-catchments" for the purposes of the assessment being undertaken. For example, Quaternary or sub-Quaternary (SQ4) catchments can be used to represent catchments, or smaller units such as a buffer area of 600 m around the wetlands can be used. Pseudo-catchments could also be delineated in different ways for different HGM types, such as SQ4 catchments for floodplain and valley-bottom wetlands versus a 600 m buffer for the other HGM types (different width buffers could even be used for different HGM types). Another more technically demanding option, which may be necessary for certain applications, would be to use modelled catchments for each wetland derived from a DEM using GIS.
- Alternative landcover maps can be used in a Level 1A assessment, in place of the default landcover map that has been produced from the publicly available NLC-2014 dataset. For example, finer-scale provincial landcover maps may be available for the area of interest. It is important to bear in mind that any alternative landcover maps that are used would first have to be re-classified into the 19 landcover categories that are considered in a Level 1A assessment.
- For a Level 1A assessment, some of the landcover categories, as delineated on the basis of the default landcover map derived from NLC-2014, could be changed to a more appropriate category in certain areas if there is some knowledge of the area that suggests this may be necessary. For example, in a particular region, the portions of the catchment mapped as "Natural / Minimally impacted" on the basis of the default landcover map for Level 1A assessments may be more reflective of "Semi-natural", which would justify changing the categorisation of the landcover type in this case. Another less extreme option, along the same lines, that could be implemented would be to gauge the proportion of the catchment that has been misrepresented by a particular landcover type (e.g. "Natural") and then apportion that percentage of coverage to a more appropriate landcover type (e.g. Semi-natural"). This would not replace one landcover type with another, but may require the addition of an extra landcover type that was not captured by the original mapping based on the default map for Level 1A assessments.

- In both Level 1A and Level 1B assessments, the width of the GIS buffer adjacent to the wetland and/or the inflowing streams can be changed from the default width of 200 m, provided sufficient justification is given. For example, in a very flat landscape dominated by small depression wetlands, a narrower GIS buffer of 100 m could be applied.
- The default impact intensity scores for the various landcover types can be altered if there is well-motivated justification for doing so. For example, in a particular study area the portions of the catchment consisting of reasonably heavily degraded land (categorised as "Eroded areas & heavily degraded land" in a Level 1B assessment) may be less eroded than the typical scenario for this landcover type but more eroded than the typical "moderately degraded land". An adjustment of the [EXT-Sed] impact intensity score may well be justifiable in this scenario, such as a reduction of the intensity score from the default value of 9 to a value that is intermediate between the default and the score of 5 for "moderately degraded land".
- The HGM-specific weightings / multipliers could be adjusted, if there is very good justification to do so. This option should only be considered in situations where the assessor has the necessary expertise to change these weightings because they are one of the cornerstones for the assessment framework that has been developed for WET-Health Version 2.0.

It is very important that, if any of these (or other) variations on the standard approach are implemented in the completion of a wetland PES assessment using the tools for WET-Health Version 2.0, a written explanation should accompany the results, providing the rationale for the adaptations.

A NOTE ABOUT THE LIMITATIONS OF THE TOOLS FOR LEVEL 1 ASSESSMENTS

It is very important to note that, while flexibility has been catered for in the application of Level 1A and 1B assessments, the tools that have been developed for Level 1 assessments still require further development to enable the user to apply variations to the standard approach in a more user-friendly way. Besides the need for an improved user interface for these desktop-based tools that more effectively incorporates adaptations in a transparent and semi-automated manner, there is also a need for more testing of the tools at this level of assessment. Although a significant amount of testing of the Level 1 tools was conducted as part of the current project, the time and budget available was not adequate to test the multitude of scenarios and contexts within which such desktop-based tools could be applied. As such, it is strongly recommended that further testing and refinement of the Level 1 tools is undertaken in a follow-up project and, in the meantime, that users of these tools take cognisance of the limitations alluded to here.

6. FIELD-BASED "LEVEL 2" ASSESSMENTS

While there is a clear need for tools to cater for broad-scale, desktop-based wetland PES assessment methods along the lines of the "Level 1" tools presented in the previous section, there will always be the need for rapid but robust field-based wetland PES assessment methods. With this in mind, an attempt has been made to produce a rapid but broad/inclusive wetland PES assessment tool that can be applied at "Level 2", building on the tools that are applied at "Level 1".

The "Level 2" assessment tool has been developed as a series of separate modules that have been brought together in an integrated assessment. Information for each module is presented in **Sections 7 to 10** of this document. First, the additional precursory steps that must be completed when embarking on a Level 2 assessment are explained (in **Section 6.1**), followed by an explanation of the fundamental step of identifying and delineating “Disturbance Units” for a "Level 2" assessment (in **Section 6.2**). An overview of the Level 2 assessment process and accompanying spreadsheet tool is provided in **Section 6.3**.

6.1. Additional precursory steps for a Level 2 assessment

In going from a Level 1 to a Level 2 assessment, it should be noted that there is a substantial increase in the amount of effort and expertise required to undertake the assessment. Whereas application of the Level 1 assessment requires a relatively basic understanding of wetlands, the application of Level 2 requires a much greater understanding of wetlands and the factors affecting their formation and functioning. As such, a Level 2 assessment should be completed only by a wetland ecologist with appropriate training and experience in wetland assessments.

Part of the extra effort required for a Level 2 assessment relates to the additional precursory steps, described below, which should be completed before embarking on the assessment.

Step 1: Field verification of the HGM type

As described in **Section 4.2**, the HGM type of the wetland would have already been identified, usually through desktop means, as one of the over-arching precursory steps for WET-Health Version 2. Informed by field observations, the HGM type should now be reviewed and revised if necessary. When doing so, it is important to note that HGM type should be based on the natural reference conditions. This is particularly relevant for valley-bottom wetlands, which often become incised as a result of anthropogenic impacts. Where there is any doubt as to what the HGM type should be or if channel incision is expected, assessors are strongly encouraged to obtain and review historic aerial photography for the wetland being assessed. This is available from National Geo-spatial Information (NGI), as far back as the 1930s and 1940s across large regions of South Africa. For those wetlands comprising more than one HGM unit, it is important to emphasise that from this point on each HGM unit (and its catchment) are assessed individually as separate "assessment units" (as explained in **Section 4.3**).

Step 2: Describe additional indicators relevant to an understanding of natural reference conditions

Defining the natural reference state is critical to any assessment of Present Ecological State. As such, it is important that a range of characteristics that broadly describe the perceived reference state of the wetland (in addition to HGM type) are documented prior to initiating the assessment. These include:

- ***Channel characteristics (if present):*** Briefly describe natural channel characteristics (size, sinuosity, dis-continuity) and dynamics (stability).
- ***Natural wetness regimes:*** Provide a broad description of natural wetness regimes which would be present in the HGM unit based on the options provided. It is recognised that if the level of

anthropogenic modification of the wetland is high then this will need to be inferred from indicators of the historical hydrology or with reference to a comparable intact wetland. It is also recognised that, in most cases, inadequate time/resources are available to map the zones and instead the assessor is required simply to identify which of the following four classes best describes the natural reference condition of the wetland: (1) dominated by temporarily saturated soils; (2) mix of seasonal and temporarily saturated soils; (3) dominated by seasonally saturated soils; and (4) dominated by permanently saturated soils.
- ***Broad vegetation attributes:*** Describe which vegetation cover types (e.g. swamp forest, herbaceous grasses, herbaceous sedges/rushes) would be present in the HGM unit under natural reference conditions and which one of these would dominate in terms of spatial extent. Also note suspected natural exposure to fires and grazing/trampling by indigenous herbivores.

Step 3: Determine the longitudinal slope of the HGM unit

The longitudinal slope of a HGM unit has bearing on the hydrological and geomorphological vulnerability of the HGM unit to impacts. This must be estimated based on available information. This may include the use of contour data available from a topographical map, more detailed contour data or by coarsely estimating slope in Google Earth Pro. To calculate longitudinal slope, simply estimate the change in elevation from the top to the bottom of the wetland, divide this value by the length of the wetland and convert into a percentage. For further guidance, refer to the guidelines in Box 6 of the user manual for classification of inland wetlands in South Africa (Ollis *et al*., 2013).

Step 4: Define the dominant form of sediment accumulation in the wetland

Three types of sediment can accumulate within and/or leave a wetland and include:

- Clastic sediment (mineral particles that are a product of rock weathering in the catchment);
- Organic sediment (organic material); and
- Chemical sedimentation (precipitates of silica or calcium/magnesium carbonates).

Processes of chemical sedimentation in wetlands are arguably least well understood, and is particularly difficult to quantify without geochemical laboratory analysis, and whilst recognising that chemical sedimentation may be an important process, particularly in depressions (See **Box 6.1**), changes in the rates of chemical sedimentation are difficult to assess in practice. As such, this form of sediment accumulation is not specifically considered as part of this module, which is restricted to an assessment of changes in clastic and organic sedimentation processes.

Whilst either clastic or organic sediment accumulation can be easily identified as the dominant process in most wetlands, there are some instances where dominant sediment processes vary across the wetland. This may be the case for example in large floodplain wetlands where clastic accumulation is the dominant process over much of the wetland but with localised organic accumulation occurring in distal backswamp areas that are largely isolated from clastic sediment inputs.

In other wetlands, such as many Palmiet wetlands in the Eastern and Western Cape, both clastic and organic matter accumulation may be evident in the wetland. An example is the Tierkloof wetland, where peat layers alternate with layers of clastic sediment that are transported from the catchment during high flow conditions (Bekker, 2016). In such scenarios, the user is required to make a call regarding the dominant form of sediment accumulation process (noting the "time window" for this assessment), which is then used to inform the method used to evaluate changes in geomorphic processes.

Deposition of waterborne clastic sediments takes place in wetlands in areas where there is a reduction in the ability of a stream to carry its sediment load. It may take place preferentially at the head of a wetland where the inflowing stream loses confinement or reduces its gradient, or it may take place along its length where tributary streams enter the wetland and supply additional sediment (Ellery *et al.,* 2008). Natural geomorphic processes of erosion and deposition are maintained in these systems by the balance of sediment inputs and outputs. In most wetlands, there may be a net accumulation of clastic sediment, provided an elevated base level reduces longitudinal slope and therefore creates accommodation space in which sediment deposition is enhanced (Ellery *et al*., 2008*)*. Wetlands driven by clastic accumulation can be identified in the field by assessing soil characteristics which are predominantly minerogenic in nature.

Maintenance and accumulation of organic sediment, on the other hand, is not dependent on inputs of alluvial sediment from the catchment but on sustained water inputs and/or inundation that promotes persistent anaerobic conditions and resultant organic matter accumulation. Indeed, peat formation is a response to an abundant supply of sediment-free water. Unlike processes associated with clastic or chemical sedimentation, peat formation passively accumulates in stable landscape settings and requires permanently saturated conditions to form.

For the purposes of this assessment, wetlands containing soils with high to very high organic matter contents are assessed based on organic sediment accumulation processes. As such, wetlands must be allocated into one of the following classes:

- **Organic**: Topsoils with an average organic carbon content of at least 10% throughout a vertical distance of 200 mm (after Soil Classification Working Group, 1991).
- **Clastic** (mineral): Non-organic soil (with an average organic carbon content of less than 10% throughout a vertical distance of 200 mm) consisting primarily of rock and/or mineral particles smaller than 2 mm in diameter. Mineral soils include sandy soil, silt (mud), clayey soil and loamy soil.

To identify such wetlands, firstly, refer to the peatland database to check if peat has been recorded on the site. Peat is defined as organic soil material with a particularly high organic matter content which, depending on the definition of peat, usually has > 30% organic material (dry mass), is located in stable landscapes and requires permanently saturated conditions to form. Secondly, (and more importantly) observe soil samples in the field. The presence of peat, Champagne soil form, or high organic soil can generally be determined in the field based on observation of soil morphology and 'feel' of the soil sample in the hand.

Box 6.1: A note on sediment dynamics in depression wetlands

Tooth & McCarthy (2007) in their text on wetlands in drylands provide some very useful insights into both the origins and sedimentation processes associated with selected depressions:

- Sedimentation in pans may include a clastic component, with fine-grained sediments (sand, silt, clay) being derived from episodic river inflows or aeolian processes, but often is dominantly chemical, with evaporites (e.g. carbonates, sulphates, chlorides) accumulating on and within near-surface sediments as water bodies desiccate after inundation events (Shaw and Thomas, 1997).
- Over time, clastic and chemical sedimentation may result in the accumulation of thick deposits in the pan floors but this is commonly counteracted by aeolian deflation in the intervals between inundation events, which serves to maintain or deepen the depression.
- Deflated sand, clay pellets or gypsum may accumulate around the base of plants growing on the pan floor as lee or nebkha dunes, or around the pan margins as parabolic or lunette dunes (Goudie and Thomas, 1985, 1986; Goudie and Wells, 1995; Shaw and Thomas, 1997).

6.2. Identifying Disturbance Units within the HGM Unit

A key step in a Level 2 assessment involves the division of the assessment unit into Disturbance Units, as explained below.

6.2.1. What are Disturbance Units and how should they be identified?

A Disturbance Unit refers to an area within a wetland/HGM unit that has been subject to similar type/s and level/s of human impact. The landcover types in the wetland, which are mapped as part of the desktop component of the assessment, provide the first step in identifying Disturbance Units. In some landcover categories (e.g. Urban Industrial/Commercial), the type and level of human impact are generally similar across the landcover unit and, therefore, they would constitute a single Disturbance Unit. However, other landcover categories (in particular the natural and semi-natural vegetation categories) tend to be more heterogeneous in terms of type and level of human impact, and they will often need to be sub-divided into separate Disturbance Units.

In the example in **Figure 6.1** (below), it can be seen that one of the landcover categories in the HGM Unit ("Dense infestation of alien plants") remains as a single Disturbance Unit. The "Commercial annual crops" category, on the other hand, is divided into two Disturbance Units, the first with no artificial drainage and the second with a high levels of artificial drainage. Similarly, the "Natural vegetation" category is divided into two Disturbance Units, the first with a very limited occurrence of invasive alien plants and the second with a high occurrence of scattered invasive alien plants.

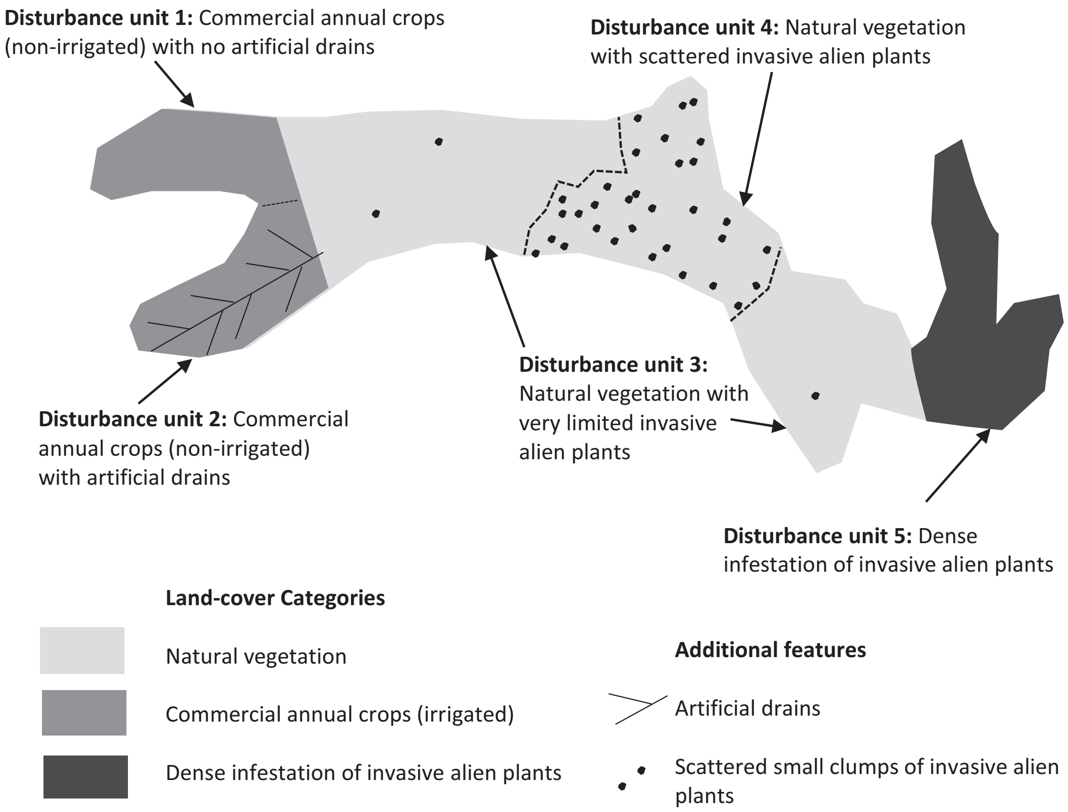

Figure 6.1. A hypothetical HGM Unit comprising three different landcover types and five Disturbance Units

For each of the landcover categories included in the tool, **Table 6.1** (below) provides specific guidance in terms of key features to consider when deciding whether to keep the category as a single Disturbance Unit or to divide the landcover category into separate Disturbance Units.

Table 6.1. Key features to consider when distinguishing Disturbance Units in different landcover categories

Refined Landcover Categories (Level 1B)	Factors to consider when distinguishing different disturbance types within the landcover category
Open Water – Natural	No differentiation required for natural features.
Water supply dam	A key feature to consider in distinguishing Disturbance Units is whether emergent plants are absent owing to the flooding by the dam being too deep or whether flooding is shallow enough to allow emergent plants to persist. As such, the back end of the dam may be separated out as a separate disturbance unit.
Aquaculture dam/pond	
Natural (Minimally impacted)	Key features to consider in identifying Disturbance Units within these categories are abundance of invasive alien plants and ruderal/pioneer plants*. Other potential factors to consider include level of artificial drainage, channel incision or erosion, where such features are present.
Semi-natural (undrained)	
Semi-natural (drained)	
Orchards and vineyards	Intensive agricultural landcover categories tend to be fairly uniform in terms of intensity of impacts and therefore will usually not need to be sub-divided into Disturbance Units (i.e. they will each comprise a single Disturbance Unit). However, in some cases sub-division will be necessary, usually where the landcover type includes areas with widely differing levels of artificial drainage. Another possible factor to consider is the level of tillage, e.g. areas under minimum tillage distinguished as a separate Disturbance Unit from areas under conventional tillage.
Sugar cane	
Commercial annual crops (irrigated)	
Commercial annual crops (non-irrigated)	
Subsistence Agriculture	
Tree plantations	A key feature to consider in distinguishing Disturbance Units is tree type. Most commonly eucalypt trees (which have particularly high water use) are distinguished from wattle and pine trees. In some cases it may be necessary to distinguish disturbance types based on other factors, e.g. where there are widely differing levels of artificial drainage, erosion or channel incision within the landcover category.
Dense infestations of invasive alien plants	
Quarrying (sand, stone, diamonds)	These respective landcover categories tend to be fairly uniform in terms of intensity of impacts within the category, and therefore will usually not need to be sub-divided into disturbance units.
Coal mining	
Ore mining	
Eroded areas	Where erosion comprises a narrow gully, such features are typically mapped as part of a broader disturbance unit rather than being mapped as a separate feature. There are, however, instances where portions of a wetland have been impacted by more widespread erosion. A key aspect to consider in distinguishing Disturbance Units is whether the eroded areas are still predominantly bare or they have become revegetated. It may also be necessary to distinguish areas with natural erosion from areas with human-caused erosion as separate disturbance units.
Urban Industrial/Commercial	Intensity of impacts are generally uniform within the category and therefore sub-division into Disturbance Units is generally not required.
Urban Informal	
Urban Residential – high density	
Urban Residential – low density	These landcover categories are often uniform in term of intensity of impacts within the category and therefore there is usually no need for sub-division into Disturbance Units. In most cases natural or semi-natural vegetation is absent. However, sometimes a portion of Urban Residential contains some scattered patches of natural and/or semi natural areas too small to map as separate Disturbance Units, and therefore this portion may need to be distinguished as a separate Disturbance Unit from a portion in the same category lacking such scattered patches.
Urban Open Space	
Livestock feedlots (cattle and pigs)	Intensity of impacts are generally uniform and therefore sub-division into Disturbance Units is generally not required.
Chicken farms	
Planted pastures	Key features to consider in distinguishing Disturbance Units is whether the pastures are annual or perennial and the level of artificial drainage.
Infilling (incl. infrastructure)	Intensity of impacts is generally uniform and therefore sub-division into Disturbance Units is generally not required. However, a substantial difference in the depth of infilling may justify distinguishing a deeply infilled portion from a shallowly infilled portion as two separate Disturbance Units.
Sediment deposits	See above
Areas where water supply has become more sustained	A key feature to consider in distinguishing Disturbance Units would be the source of the increased water supply, e.g. from irrigation return flows, or seepage downslope of dams or embankments.

* Areas of natural and semi-natural vegetation vary considerably in terms of the level of abundance of invasive alien plants. While not having a continuous cover of invasive alien plants and therefore not qualifying as the landcover category "Dense infestations of invasive alien plants", the collective cover of invasive alien plants may nonetheless be moderate to high, e.g. distributed as many small clumps or individual plants scattered throughout the natural/semi-natural vegetation. If, for example, the lower portion of an area of natural vegetation has a high abundance of scattered invasive alien plants and the upper portion a low abundance of invasive alien plants, then these two portions would generally be identified as two separate Disturbance Units within the landcover type. Similarly, different Disturbance Units may be identified within natural or semi-natural vegetation based on the abundance of ruderal/pioneer species. Typically, cultivated lands which have been recently abandoned have a higher abundance ruderal/pioneer species than lands which have had a longer time to recover.

6.2.2. What is an appropriate number of Disturbance Units?

When identifying the appropriate number of Disturbance Units, it is important to strike a balance between representing the heterogeneity within an HGM Unit while at the same time keeping the number of assessment units to a minimum. A maximum of 15 Disturbance Units per HGM Unit is suggested, but in very large and/or heterogeneous HGM Unit, more than this may be required. Another suggested rule of thumb is that Disturbance Units should generally cover more than 3% of the spatial extent of the HGM Unit. However, it is recognised that if a high-resolution assessment is required, it may be necessary to consider Disturbance Units where the relative spatial extent is less than this.

6.3. Overview of Level 2 assessment process and spreadsheet tool

In order to make the spreadsheet tool for a Level 2 assessment as streamlined as possible, the Level 1B assessment is used as the starting point of the Level 2 assessment because this helps with the identification of preliminary Disturbance Units. A list of catchment-related questions and a list of wetland-related questions are provided in the spreadsheet tool, which an assessor user must answer in addition to estimating the proportions of different landcover categories within the specified "areas of influence" (as shown in the diagram in **Figure 6.2**). This represents quite a significant change from the structure of the spreadsheet tool for a Level 2 assessment in WET-Health Version 1 (Macfarlane *et al*., 2008), where each module had its own set of questions to be answered (with substantial repetition of questions between modules). The module-specific worksheets in the revised spreadsheet tool now serve as "auto-populated" look-up tables where the detailed results for each module can be checked.

The spreadsheet tool for a Level 2 assessment also includes a "Review tab", where the overall results can be reviewed and refined (with justification) if necessary, as well as a worksheet providing a summary of the final results (as shown in **Figure 6.2**). It should be noted that further guidance for completing the spreadsheet tool for a Level 2 assessment is provided in an introductory "INSTRUCTIONS" worksheet.

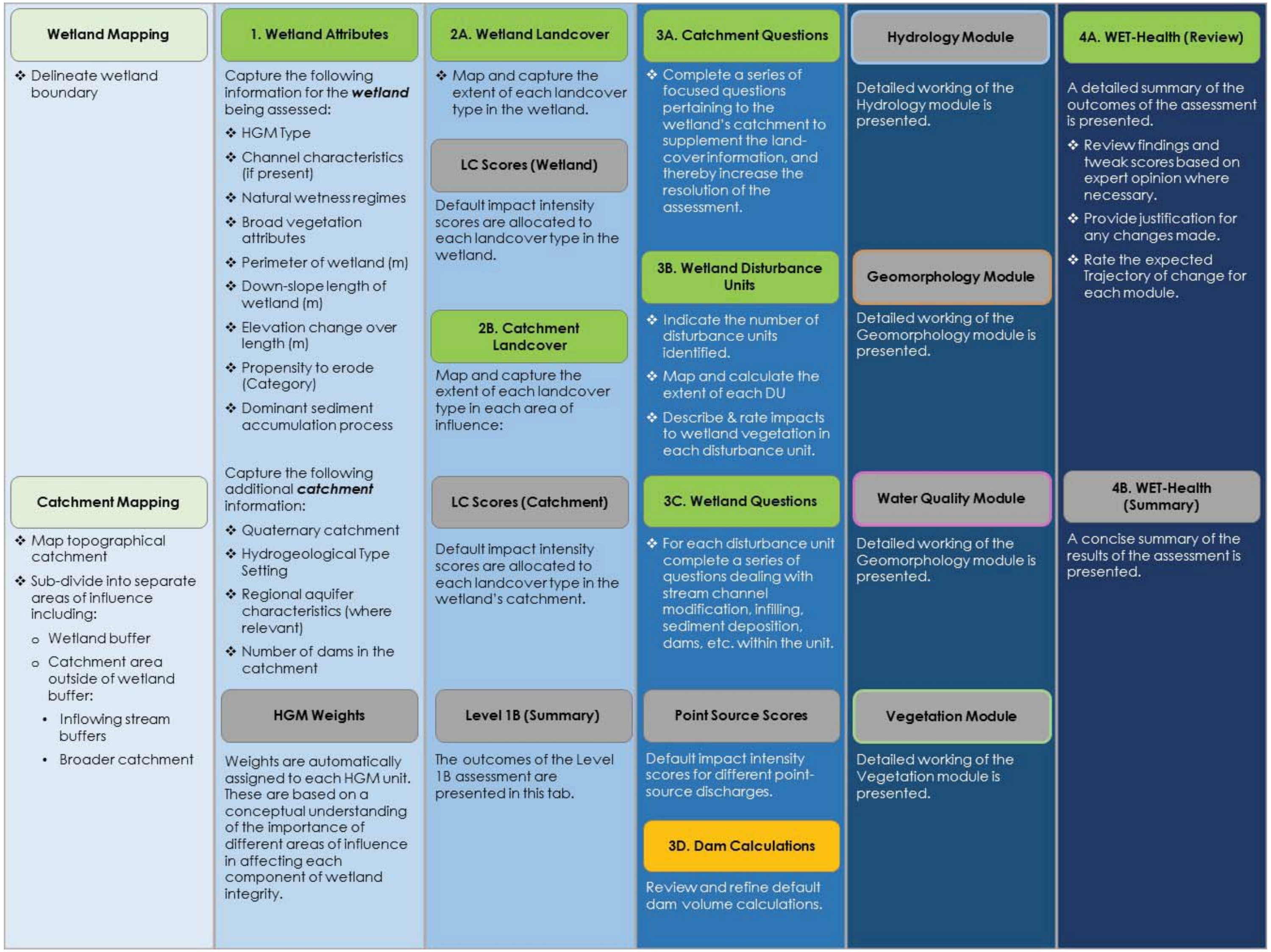

Figure 6.2. Overview of the process to be followed in conducting a Level 2 assessment using WET-Health Version 2, showing the aspects that are dealt with in the worksheets that have been included as separate tabs in the relevant spreadsheet tool

7. HYDROLOGY MODULE

7.1. Introduction

For the purpose of this assessment, hydrology refers to the movement of both surface and sub-surface water into, through and out of a wetland. Hydrology is the defining feature of wetlands and therefore forms a key component of the assessment of wetland health. The hydrologic conditions affect many important wetland processes, including the development of anaerobic conditions in the soil (waterlogging), availability of nutrients and other solutes, and sediment fluxes. These factors strongly influence which fauna and flora will inhabit a wetland, and this in turn has a feedback effect on hydrologic conditions, e.g. through transpiration by plants (Mitsch and Gosselink, 1993). Clearly therefore, the consequences of altering the hydrologic conditions in a wetland may be enormous in terms of overall wetland structure and the biophysical process taking place in a wetland.

7.1.1. Conceptual Framework

The hydrology of a wetland can be altered through (i) human modifications to the catchment which change the quantity and pattern of water inputs to the wetland and (ii) human modifications taking place within the wetland itself which alter the distribution and retention patterns of water within that wetland (**Figure 7.1**).

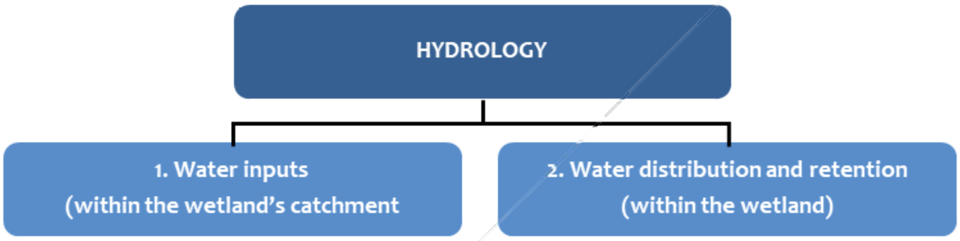

Figure 7.1. The primary components included in an evaluation of hydrological impacts that may affect a wetland

To simplify the evaluation of the hydrology of a wetland, separate assessments are undertaken for the two components shown in **Figure 7.1**, namely Water inputs and Water distribution and retention, which are then integrated into an overall health score.

7.1.2. Overview of the steps to be followed in the hydrology assessment process

An overview of the steps involved in the hydrology assessment process are outlined in **Figure 7.2** below, whilst a schematic indicating how the different components of the method fit together is included in **Figure 7.3**.

Precursory steps:

- Mapping of wetlands and inflowing/out-flowing streams
- Classification of wetlands by HGM type
- Delineation of catchments and buffer areas ("external areas of influence")
- Calculate the extent of landcover classes in the wetland and external areas of influence
- Delineation of disturbance units

↓

Step 1: Assess impacts of changes in quantity and pattern of water inputs to the unit from its upstream catchment

- Step 1A: Assess vulnerability of the wetland to altered inputs based on local climate
- Step 1B: Assess impact of landuse activities that reduce the inflow quantity to the wetland
- Step 1C: Assess the intensity of impact of factors potentially altering floodpeaks delivered to the wetland & in turn reducing sustained sub-surface inputs
- Step 1D: Assess the intensity of impact of factors potentially altering floodpeaks delivered to the wetland & in turn reducing sub-surface inputs
- Step 1E: Assess the combined magnitude of impact of altered input quantity & pattern

↓

Step 2: Assess the degree to which natural water distribution and retention patterns within the wetland have been altered as a result of on-site activities

- Step 2A: Assess magnitude of impact of stream channel modification and altered floodpeaks (from Step 2C) in affecting lateral connectivity
- Step 2B: Assess the impact of drains and erosion gullies
- Step 2C: Assess the impact of anthropogenic deposition, infilling and excavation (including dams)
- Step 2D: Assess the impact of altered surface roughness
- Step 2E: Assess the impact of direct water losses
- Step 2F: Determine the combined magnitude of impacts of on-site activities

↓

Step 3: Derivation of a PES Score and Ecological Category for Hydrology

- Step 3A: Combining scores for external change in water inputs and within-wetland activities to derive an Integrated Hydrology Impact Score
- Step 3B: Derivation of a Final Hydrology Impact Score, PES Score and Ecological Category

↓

Step 4: Assess the anticipated Trajectory of Change for the wetland's hydrological state

Figure 7.2. An outline of the steps involved in the hydrology module

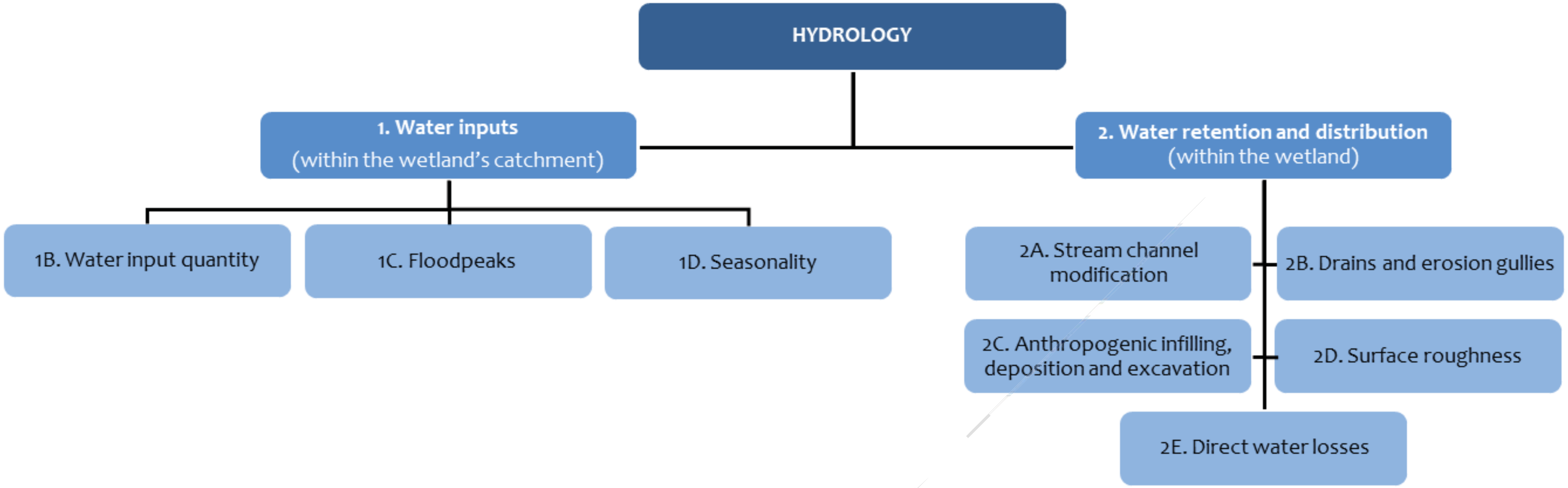

Figure 7.3. Schematic illustrating the overall structure of the hydrology module

7.2. The Hydrology Assessment Process

Hydro Step 1: Assess changes in the quantity and pattern of water inputs to the wetland

Changes in water inputs include changes in the quantity and pattern of water received by the wetland. For the purposes of this assessment, pattern encompasses floodpeaks and seasonality (**Figure 7.4**). A change in any of these aspects can significantly alter the hydrological state of a wetland. This assessment therefore serves to assess changes to both of these aspects and then integrates these results in order to provide an overall indication of the level of variation in water inputs from natural reference conditions. The quantity of water entering a wetland may either be increased or decreased depending on landuse in the catchment. Given the high demand for water in South Africa, which in global terms has low rainfall, decreased inflows are far more widespread than increased inputs, except in urban areas where discharges (e.g. from sewage treatment plants, or storm run-off from hardened catchments) often increase inflows to wetlands.

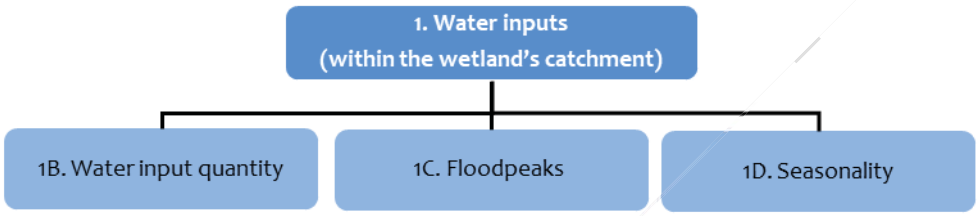

Figure 7.4. The components evaluated as part of an assessment of impacts on water inputs to a wetland

The evaluation in Step 1 is undertaken at the scale of the wetland's catchment and therefore reflects impacts from altered catchment characteristics. The key focus of the evaluation is to understand the changes to water inputs that result from catchment changes and to evaluate what effect these changes are likely to have on wetland health. Not all wetlands are affected equally by changes in quantity, seasonality and floodpeaks. Some types of wetlands (e.g. floodplains) may be particularly sensitive to reduced floodpeaks, while other wetlands are more sensitive to reduced overall quantity of inputs. Thus, to assess the effect of altered inputs it is necessary not only to determine how the water inputs have been altered, but to also determine the impact of these alterations on the ecological state of the wetland, taking into account the particular features of the wetland, notably its HGM type and local climate.

It is also potentially important to know where in the catchment the impacts arise. For the purpose of a Level 1B and 2 assessment (insert section number), inputs from the wetland's topographically defined catchment are divided into (i) the local upslope catchment which supplies water to the wetland from its adjacent hillslopes via diffuse lateral surface and sub-surface inputs and sometimes also via small (first order) tributaries; and (ii) the upstream catchment which feeds the wetland longitudinally via the main stream/s entering the wetland (as elaborated upon in **Appendix A**). The relative contributions of (i) and (ii) vary depending on the particular circumstances at the site. For the purposes of this assessment, the refined HGM type of the site (as described in **Section 4.2**) is used as the basis for deciding the relative importance or the two sources of water. Impacts from these two respective parts of the catchment are assessed separately and then weighted according to refined HGM type. For example, if the wetland is a floodplain (which are generally maintained by inflows from the upstream catchment) then impacts on floodpeaks from the upstream catchment carry a predefined weighing of 90% of the score compared with 10% for the local upslope catchment.

Hydro Step 1A: Assess the vulnerability of the wetland to altered water inputs based on local climate

Prior to evaluating impacts of anthropogenic activities on water inputs, it is important to recognise that wetlands differ in their inherent vulnerability to changes in water inputs. The hydrology of South African wetlands and the factors affecting the vulnerability of individual wetlands to reduced inflows are still poorly understood and are in need of further investigation. However, wetlands with a higher ratio of Mean Annual Precipitation (MAP) to Potential Evapotranspiration (PET) are generally assumed to be less vulnerable to reduced inflow such changes than where the MAP to PET ratio is lower.

Over most of South Africa, the MAP is lower than the PET, and there is a general trend of decreasing MAP and increasing PET from east to west across the country. An example of a wetland in the east is Mfabeni wetland, adjacent to Lake St Lucia, where MAP is 958 mm and PET is 1400 mm, giving a MAP to PET ratio of 0.68, and an example in the west is the Soutpan wetland, north of Upington, where MAP is 148 mm and PET is 2750 mm, giving a MAP to PET ratio of 0.05. The lower the MAP:PET ratio, the smaller will be the contribution of direct precipitation falling onto the wetland and the more dependent the hydrology of the wetland will be on inflows from its upstream catchment, and therefore the more vulnerable it will be to reduced inflows. This ratio is used in **Table 7.1** to score the contribution of climate to the impact of flow-reducing activities in the wetland's catchment. When applying WET-Health, identify in which quaternary catchment the wetland falls, and the spreadsheet tool then automatically extracts MAP and PET for that catchment.

Table 7.1. Hydrological vulnerability factor based on the MAP:PET ratio

MAP to PET ratio	>0.65	0.50-0.65	0.36-0.49	0.20-0.35	<0.20
Vulnerability factor	0.80	0.85	0.90	0.95	1.00

Note: The vulnerability factor is used later (e.g. in Table 7.2) as a multiplier in the calculation of impact intensity of landuses in the catchment that reduce flow (e.g. tree plantations).

Hydro Step 1B: Assess changes to the quantity of water inputs to the wetland

Given the low MAP to PET ratio characterizing most of South Africa, direct precipitation alone is insufficient to sustain wetlands, and therefore wetlands are reliant on inflows (Ellery *et al*., 2008). These inflows may be from one or more different sources, which include: (i) groundwater inputs from a regional aquifer; (ii) water inputs from the topographically defined catchment, including the hillslopes of the local upslope catchment and the more distant upstream catchment. The impact that changes in any of these water sources has on the hydrological character of the wetland depends on the degree of alteration and the relative importance of the respective water input sources in sustaining a given wetland. This assessment therefore involves a structured process to assist the assessor in diagnosing important water input sources and then evaluating the impact that such changes have had on the overall quantity of water inputs supplied to the wetland.

Hydro Step 1B-1: Accounting for impacts associated with the lowering (or raising) of the regional aquifer

The first step required when undertaking the level 1B and Level 2 assessments, is to identify whether the hydrological supply area is likely to: (1) correspond with the topographically defined catchment or (2) be linked with a regional aquifer, which would be supplied from well beyond the wetland's topographically defined catchment. This is done by identifying into which of the 11 hydrogeological type settings described in **Appendix A** the wetland falls. For nine of these settings, wetlands are assumed to generally not be linked with the regional aquifer (see **Appendix A**). For these settings the hydrological supply area corresponds with the topographically-defined catchment, and the assessment can simply be based on the landcover within the topographically-defined catchment. However, the remaining two of these settings, namely Coastal plains and Karst landscapes, have a high incidence of wetlands which are connected to the regional aquifer and are therefore likely to be supplied from far beyond their topographically-defined catchments. If a wetland falls within either of these two type settings then describing the landuse in the wetland's topographically-defined catchment will be inadequate to determine the extent to which human activities have altered hydrological inflows. The assessment must therefore be informed by an understanding of changes to the regional aquifer as well as those associated with the topographically-defined catchment.

For wetlands located in Coastal plains and Karst landscapes, an assessment of the altered contribution from the regional water table is assessed at Level 2 by evaluating the degree to which the regional water table has been lowered (thereby reducing inputs) or elevated (thereby increasing inputs) (**Table 7.2**). This is preceded by firstly estimating the reliance of the wetland on the regional aquifer relative to the topographically-defined catchment (**Table 7.2**). The impact to wetland hydrology is then calculated by adjusting the score to account for the natural vulnerability of the wetland resulting from the climate (**Table 7.1**).

For a Level 1B assessment, the option is available of selecting "unknown" for the degree to which the regional aquifer has been altered. In this case, the tool automatically assigns a score of -3 (representing "moderate lowering of the water table in the regional aquifer") to the wetland. The option is also given of recording the degree of connectivity as "unknown", in which case the hydrogeological type setting is then used to pre-assign a score (0 for "Other" and 0.8 for Coastal plain or Karst setting).

Table 7.2. Estimating the change in contribution of water inputs from a regional aquifer for wetlands in coastal plain and karst landscapes

Indicator	**0**	**0.2**	**0.6**	**0.8**		**Score**
A1. Connectivity of wetland to a regional aquifer	No connection (generally because perched well above the regional aquifer)	Connected to the regional aquifer, but other sources appear to be dominant	Connected to both the regional aquifer and other sources, but neither appear to be dominant	Connected to the regional aquifer, which appears to be the dominant water input source		
Indicator	**0**	**-3**	**-7**	-10		Score
A2. Change in groundwater levels in the regional aquifer Note: only score this indicator if A1 >0.	No or negligible evidence of any lowering of the water table in the regional aquifer	Moderate lowering of the water table in the regional aquifer which moderately reduces its contact with the rooting zone in the wetland	Severe lowering of the water table but it still occasionally makes contact with the rooting zone in the wetland and therefore does not lead to a complete loss of wetland hydrological conditions	Critical lowering of the water table such that it no longer makes contact with the rooting zone even in a wet year, and this leads to a complete loss of wetland hydrological conditions		
		1	3	5		
		Minor elevation of the water table in the regional aquifer which slightly increases its contact with the rooting zone in the wetland	Moderate elevation of the water table in the regional aquifer which moderately increases its contact with the rooting zone in the wetland	Severe elevation of the water table such that contact with the rooting zone in the wetland is significantly increased		
Change in contribution from regional aquifer: A1 x A2 x Vulnerability factor (from Table 7.1)						

Rationale for Table 7.2

<u>A1. Connectivity of wetland to a regional aquifer</u>

Connectivity of a wetland to the regional aquifer refers to the situation under natural reference conditions. , For Coastal plains and Karst landscapes connectivity is generally high. Nevertheless, within these settings the degree to which individual wetlands are linked to the regional aquifer is variable, and is affected by local topography and soil conditions. Of particular relevance here, are the soil characteristics of the catchment and the degree to which the wetland may be perched above the regional aquifer. Where soils are very course (e.g. coastal sandy aquifers), with rapid infiltration throughout the soil profile, water falling in the topographically-defined catchment will simply contribute towards the level of the regional water table, and as such, there is a very high reliance on the regional aquifer. Where soils are less permeable, some surface and subsurface runoff may be directed downslope, thereby contributing directly to water inputs into the wetland. This effect is amplified in instances where wetlands are underlain by an aquiclude (a layer impervious to water) which may retain water inputs, thereby mitigating the effect of a change in the regional water table. For wetlands in coastal plains and Karst landscapes connected to the drainage network (i.e. valley bottom wetlands and floodplains), water inputs may be strongly reliant on upstream catchment inputs rather than the regional aquifer. For further information see **Appendix A**, Table 3.3.

A2. Change in groundwater levels of the regional aquifer

Groundwater levels in regional aquifers may be either raised or lowered through anthropogenic activities. In terms of impacts on the wetland's hydrological state, lowering is rated more severely given the potential that this has to cause the complete loss of wetland conditions. Furthermore, given that South Africa is a water-scarce country, lowering of the regional water table is considerably more prevalent than raising. For wetlands located in Coastal plains and Karst landscapes, the extent to which the regional aquifer has been altered needs to be determined as far as possible. It is beyond the scope of WET-Health to provide detailed guidance for carrying out this determination. However, it is suggested that assessors conduct the assessment based on the following sources of information: (1) recent reports giving the results of regional aquifer survey/s, (2) records from any nearby boreholes and/or (3) from someone with good local groundwater knowledge. Based on the above sources of information, the intensity of impact resulting from the effect of human activities on the regional aquifer should be assessed.

Hydro Step 1B-2: Assess the degree to which water inputs from the wetland's topographical catchment have been altered

Having assessed, in Step 1B-1, the impacts associated with the regional aquifer, in this next step (Hydro Step 1B-2) impacts from the topographically-defined catchment are assessed. Water inflows from the topographically-defined catchment refer to both surface and sub-surface water entering a wetland from its upslope/upstream catchment. As described in **Section 7.2**, the catchment is sub-divided into (i) the local upslope catchment which refers to the hillslopes adjacent to the wetland which supply the wetland by predominantly diffuse surface and sub-surface inputs and is represented by the proxy of a 200 m upslope buffer around the wetland: see **Section 4.4.2** that is used to assess changes in lateral inputs and (ii) the upstream catchment which refers to the remaining area of the catchment, which feeds the wetland via the stream/s which enter the wetland. Landuse activities taking place in the wetland itself are therefore excluded from this assessment and water losses associated with on-site activities are explicitly addressed in **Hydro Step 2**.

For Level 1B and 2 the extent to which water inputs from the catchment have been modified is determined based on the pre-assigned intensity scores for the respective landcovers and their relative extents in the wetland's buffer and upstream catchment. For example, cultivated subsistence crops are assigned an intensity score of -3 given the moderate transpiration rates and irrigation levels typically associated with subsistence crops and tree plantations are assigned -7 as a result of the high transpiration levels typically associated with the tree plantations.

Hydro Step 1B-2a. Accounting for changes in water inputs from the upstream catchment

1. Refining the desktop landcover based assessment for the upstream catchment using additional indicators

At Level 2, assessment of altered inflow quantity and patterns is based on landcover, but the intensity of impact for the upstream catchment is refined somewhat for some of the landcover types based on additional catchment-related information which is generally not available in the desktop assessment. The following information relating to landcover based impacts, which is reflected in adjustment factors, is accounted for at Level 2:

- For tree plantations, it is identified whether the trees are eucalypts or whether wattles or pines, with eucalypts scoring highest given their higher rates of water use (Gush *et al*., 2002). If the plantations are eucalypts then the generic plantation impact intensity score from Level 1B is increased by 0.5, if the plantations are mixed then the adjustment is 0, and if pines or wattles then the score is decreased by 0.5.

- For invasive alien plants, it is identified whether they are trees or shrubs, with shrubs assumed to generally have lower water use owing to their lower leaf area. If the invasive alien plants are trees then the generic invasive alien plant intensity score from Level 1B is increased by 0.5, if mixed then the adjustment is 0, and if shrubs then the score is decreased by 0.5.

2. Refining the desktop assessment for the upstream catchment to account for transfers and point-source abstractions or inputs

Additional impacts associated with point-source abstractions or inputs that are not accounted for in the landcover assessment but which can further alter water inputs into the wetland are covered in **Table 7.3**.

Table 7.3. Estimating the intensity of impact of point source impacts (water transfers and abstractions) on inflow quantities to the wetland from its upstream catchment

Indicator	-2	-4	-6	-8	-10	Score
A1. Abstractions / transfers not used for irrigation in the catchment	Small reduction in flows (e.g. 15% reduction in flows)	Moderate reduction in flows (e.g. 30% reduction in flows)	Large reduction in flows (e.g. 50% reduction in flows)	Serious reduction in flows (e.g. 70% reduction in flows)	Critical reduction in flows (e.g. >70% reduction in flows)	
A2. Degree to which water inputs are intercepted and diverted	Small reduction in flows (e.g. 15% reduction in flows)	Moderate reduction in flows (e.g. 30% reduction in flows)	Large reduction in flows (e.g. 50% reduction in flows)	Serious reduction in flows (e.g. 70% reduction in flows)	Critical reduction in flows (e.g. >70% reduction in flows)	
Indicator	**+2**	**+4**	+6	+8	+10	Score
A3. Increase in water inputs from transfers / point-source discharges.	Additional contributions are small (e.g. 15% increase in flows)	Additional inputs are moderate (e.g. 30% increase in flows)	Additional inputs are large (e.g. 50% increase in flows)	Additional inputs are serious (e.g. 70% increase in flows)	Additional flows are critical (e.g. >70% increase in flows)	
Change in water inputs: [A1 + A2 + A3]						

Note: the % reduction/increase in flows given in Table 7.3 are intended as examples rather than prescriptive thresholds.

Rationale for Table 7.3

<u>A1. Abstractions / transfers not used for irrigation in the catchment:</u>

The impacts of irrigation have already been estimated through the landcover assessment, which includes landcover types associated with irrigation, and are based on the assumption that water is abstracted from the same catchment. Abstraction from the wetland's catchment may also take place for purposes other than irrigation, e.g. for domestic purposes. The magnitude score for these abstractions is assessed based on the perceived reduction in water inputs. If the approximate annual abstraction is known then this can be compared with the MAR from the wetland's catchment, calculated based on the MAR for the quaternary (obtained from the Level 1B/2 spreadsheet tool, in the "Quat Catchments" Tab) reduced proportionately by the proportion of the quaternary occupied by the wetland's catchment. This comparison therefore allows an approximate percentage decrease in water inputs to be determined. For example, if the annual abstractions was 200 million litres, MAR for the quaternary was 2000 million litres and the wetland's catchment occupied 25% of the quaternary (giving an MAR for the wetland's catchment of 500 million litres) then water inputs to the wetland would be reduced to 300 million litres, i.e. a 40% reduction considering the MAR of 500 million litres.

A2. Degree to which water inputs are intercepted and diverted:

In some wetlands, inflows which would have naturally entered a wetland may be diverted by a furrow and/or berm so as to bypass the wetland and continue on downstream of the wetland. As for other abstractions, the magnitude score for such diversions is assessed based on the perceived reduction in water inputs.

A3. Increase in water inputs from transfers / point-source discharges.

Increased inputs of water from outside the wetland's topographically defined catchment also need to be accounted for in the assessment. This includes formal inter-basin transfer schemes (typically only relevant to wetlands on main stem rivers) and more localised transfer mechanisms or point source discharges in small catchments. Within areas supplied by domestic water, irrigation of gardens and discharges linked with French drains and the like may result in moderate increases in water inputs. This has already been accounted for in the catchment landcover assessment with minor increases in water inputs attributed to urban landuses (Intensity scores = 1 to 2).

The discharge of water from waste-water treatment works can substantially alter water inputs and needs to be specifically considered in this assessment (especially since it frequently represents water imported from another, distant catchment). If the approximate annual discharge from the treatment works is known then this can be compared with the MAR from the wetland's catchment, which is calculated based on the MAR for the quaternary reduced proportionately by the proportion of the quaternary occupied by the wetland's catchment, as described for B1, above. For example, if the annual discharge was 100 million litres, MAR for the quaternary was 2000 million litres and the wetland's catchment occupied 25% of the quaternary (giving an MAR for the wetland's catchment of 500 million litres) then water inputs to the wetland would be increased to 600 million litres, i.e. a 20% increase. This comparison therefore allows an approximate percentage increase in water inputs to be determined.

There are also instances where water sourced from a different catchment is used for irrigation purposes in the wetland's catchment. In such situations, the intensity score for irrigated crops/orchards (which assumes that the water is obtained from the wetland's catchment) may need to be manually over-ridden and any increase in water inputs in the catchment would need to be accounted for.

3. Calculating the overall change in water inputs from the upstream catchment

This is simply calculated by summing the magnitude of impact scores based on landcover changes (A) and transfers and point-source abstractions or inputs (B).

Hydro Step 1B-2b. Accounting for changes in lateral inputs

It is also important to consider the importance of lateral inputs relative to inputs from the upstream catchment in maintaining the hydrological characteristics of the wetland. This is accounted for in this assessment by specifically assessing impacts from landuse activities in the buffer of the wetland. Ideally, one should specifically consider all lateral inputs by considering landcover types occurring alongside the wetland and up to the edge of the topographically defined catchment. For ease of assessment, an indication of changes to lateral water inputs is based on landcover types within 200 m of the wetland, which is the requirement for the water quality module.

The same approach is followed for both the Level 1B & Level 2 assessments and is simply calculated based on the default intensity scores and the relative extent of different landcover classes in the buffer zone. At Level 2, the intensity of impact on lateral inputs is refined somewhat for tree plantations and invasive alien infestations, as described earlier for the upstream catchment.

It is important to emphasize that, as in the case of the upstream catchment, the assessment of impacts on lateral inputs is very coarse. In particular, it does not take into account the hydropedological characteristics (which refer to characteristics influencing soil-water interactions) of the hillslopes which provide the lateral inputs. These characteristics influence the depth and rate at which these hillslope flows occur, thereby influencing the impacts of specific landuses. For a more refined assessment, refer to the very relevant guidelines of Job and le Roux (2019).

Hydro Step 1B-2c. Assessing the overall change in water inputs from the catchment

Once changes to the quantity of water inputs from the upstream catchment (**Hydro Step 1B-2a**) and lateral inputs (**Hydro Step 1B-2b**) have been assessed, an integrated score is calculated that reflects an overall change in the contribution of water inputs from the topographically defined catchment (**Table 7.4**). In this step, account needs to be taken of the relative importance of lateral inputs vs. upstream catchment inputs for the specific wetland under assessment. This is done using the pre-assigned weighting of scores for upstream and lateral inputs based on the HGM type of the wetland, as explained in **Table 7.4**, below. Account also needs to be taken for the inherent vulnerability of the wetland to changes in water inputs before also accounting for potential contributions from the regional aquifer. Thus, the overall contribution is also adjusted based on any inputs from the regional aquifer, as explained in **Table 7.4**.

Table 7.4. Calculating the overall change in water input contributions from the topographically defined catchment

<table>
<tr><th colspan="5">A. Accounting for the relative importance of water inputs from the upstream catchment relative to lateral inputs</th></tr>
<tr><th>Indicator</th><th>0.3</th><th>0.7</th><th>0.9</th><th>Score</th></tr>
<tr><td>A1. Importance of water inputs from the upstream catchment relative to lateral inputs</td><td>Low:
Channelled valley bottom laterally maintained (i.e. with substantial lateral inputs); flats and depressions not fed by a channel</td><td>High: Channelled valley bottom not laterally maintained; Depressions fed by channel and unchannelled valley bottoms
All other HGM Types with an upstream catchment</td><td>Very High:
Floodplains</td><td></td></tr>
<tr><td colspan="5">B. Overall change in water inputs from the topographically defined catchment:
[Upstream catchment score x A1 + Lateral inputs score x (1-A1)] x Vulnerability factor (from Table 7.1)</td></tr>
<tr><td colspan="5">C. Adjusted overall change in contribution from the topographically defined catchment based on connectivity to the regional aquifer:
B x (1-Connectivity of wetland to regional aquifer)</td></tr>
</table>

Rationale for Table 7.4

A. Accounting for the relative importance of water inputs from the upstream catchment relative to lateral inputs

There is considerable variability in the contributions of water inputs from the upstream catchment relative to lateral sources between and, to some extent, within HGM types. Channelled valley bottoms that are laterally maintained, flats and depressions not fed by a channel are all highly dependent on lateral inputs. Thus, for all of these types, a low weighting of 0.3 is applied in terms of importance of upstream relative to lateral inputs. Floodplains on the other hand, are typically maintained largely by water inputs from the upstream catchment rather than from lateral inputs. Thus for floodplains a high weighting of 0.9 is applied. All other types which have an upstream catchment are generally more reliant on water inputs from the upstream catchment than laterally, with an associated weighting of 0.7.

B. Assessing the overall change in water inputs from the topographically-defined catchment

This is simply calculated based on the individual impact scores and weightings allocated to different input contributions based on HGM type, as described above. Take an example where the Upstream catchment score was -2 and the Lateral inflow score was -6 (i.e. a greater reduction of flows laterally than upstream). If, in this example, the wetland was a floodplain then the overall score would be (-2 X 0.9) + (-6 X (1-0.9)) = -2.4. However, if the wetland was a laterally maintained valley bottom then it would (-2 X 0.3) + (6 X (1-0.3)) = -4.8,

C. Adjusted overall change in contribution from the topographically defined catchment based on connectivity to the regional aquifer:

Where the wetland also receives water inputs from the regional aquifer, the score must also be adjusted to cater for additional contributions from the regional aquifer. This is simply done by multiplying the score for the catchment by the proportional contribution, which is assessed relative to the level of connectivity with the regional aquifer (Table 7.2 - A1).

Hydro Step 1B-3: Assessing the overall change in the quantity of water inputs to the wetland

Once changes to water inputs have been assessed, this needs to be integrated into an overall score that reflects the anticipated impact on the hydrological integrity of the wetland. Where the wetland is not fed by a regional aquifer (1B-1), the assessment is simply based on the alteration score calculated for the topographically defined catchment (1B-2). Where the wetland is also fed by the regional aquifer, the overall impact score is calculated by summing the changes in water input contributions from both input sources (**Table 7.5**).

Table 7.5. Calculating the overall change in water input contributions

1B-1. Altered contribution from regional aquifer	A
1B-2. Altered contribution from topographical catchment	B
Overall change in water inputs: A + B	

Inadequacies in the assessment of changes in the quantity of water inputs to the wetland from its catchment

It must be emphasized that using landuse impacts to estimate the alteration of inflow provides only a very coarse-level indication of reduced water inputs to a wetland. Additional information about the catchment may be available (e.g. the type and depth of the soil) which could be incorporated to enhance the rapid assessment conducted in this step. If resources and data are available, consider modelling the water inputs (e.g. with the ACRU or SCS models) as an alternative to the rapid assessment approach used here. Although modelling requires more resources and time, it can provide a more accurate assessment.

Note also that examining flow reductions over the whole year may mask more subtle seasonal impacts (e.g. abstraction may be concentrated in the early growing season or during low flow periods). The low resolution of the WET-Health assessment mitigates against such fine-level distinctions, but if you as the assessor have an understanding of these factors then an adjustment to the assessment may be made provided that any justification is well-documented.

Hydro Step 1C: Assess changes to flood peaks

Whilst changes in the overall quantity of water inputs into the wetland is critical to a wetland's hydrological functioning, changes in the pattern of water inputs is another key aspect that needs to be considered. Where catchment activities (e.g. extensive hardened surfaces) result in decreased infiltration and increased flood peaks, there is typically a corresponding reduction in base flows. These are the flows that are sustained between rainfall events, and which may be critical to maintaining the natural saturation levels in the wetland. The focus of this assessment is therefore on evaluating the degree to which flood peaks have changed in order to obtain an indication of changes in base flow contributions.

Altered floodpeaks can also affect the incidence of bank overspill in wetlands with a channel, thereby affecting the frequency and extent of inundation. An assessment of changes in flood peaks is therefore also used to obtain an indication of changes in water distribution and retention patterns (**Hydro Step 2A**). Furthermore, the assessment is used to infer changes in sediment distribution and retention patterns as part of the geomorphology module (**Geo Step 1A-2a**).

Hydro Step 1C-1: Estimating changes in floodpeaks based on catchment landcover

For Level 1B assessments, the extent to which floodpeaks have been increased is determined based on the pre-assigned intensity scores for the respective landcovers and their relative extents. For example, natural vegetation is assigned a score of 0 as floodpeaks are assumed not to be altered by this landcover and urban industrial/commercial a score of +9 owing to the extensive hardened surfaces typically associated with this landcover, which prevents infiltration and greatly increases floodpeaks. Thus if a wetland's upstream topographical catchment comprised 60% natural and 40% urban industrial/commercial then the magnitude of impact would be (0 X 60/100) + (9 X 40/100) = 3.6. Note that no differentiation is made between lateral inputs (from the wetland's buffer) and inputs from the upstream catchment when assessing impacts of landuses on flood peaks.

Hydro Step 1C-2: Accounting for the impact of dams

Dams in the wetland's catchment can reduce flood peaks and also need to be accommodated in this assessment. The impact of dams is disproportionate to the area that dams occupy in the catchment and even a relatively small dam may have a significant impact on floodpeaks. To accommodate this, the impact of dams on flood peaks is simply multiplied by 3 for the Level 1A assessment. For the level 1B and 2 assessments, the collective volume (capacity) of the dams in a wetland's catchment is calculated using the formula of Maaren and Moolman (1985) developed to represent a generic area: volume relationship

$$Sv = (A/7.2)^{1.2987012987013}$$

Where:

Sv = storage volume (m^3)
A = surface area (m^2), and

It is recognized that this provides a very coarse estimate of dam volume, which is nonetheless commensurate with the very coarse estimate of MAR for the catchment. If a more accurate estimate of the collective volume of dams in the wetland's catchment is required then this can be calculated on a dam-by-dam basis using the above formula. It can also be calculated using the formula given in Table 2.3 of Macfarlane *et al*. (2009) which is included in the Dam Calculations Tab of the spreadsheet, and which requires additional information on each individual dam, including the maximum dam depth.

Next, the collective volume of dams is expressed as a % of the MAR which is calculated based on the MAR estimate for the catchment and the areal extent of the wetland's topographical catchment. For a Level 1B assessment this provides the primary basis for assessing the intensity of impact, which is done automatically based on the classes given in line 5 of **Table 7.6**. For a Level 2 assessment this impact intensity score is refined, based on a consideration of additional factors, e.g. the level of abstraction from the dams (line 6-8 of **Table 7.6**).

Hydro Step 1C-3. Assessing the degree to which flow diversion structures affect floodpeaks

In some circumstances, water may be diverted away from a wetland, thereby reducing water inputs and associated flood peaks. In the urban context, this is typically associated with stormwater drains whilst in a rural context, this may be linked with irrigation canals or transfer schemes or as a result of a specifically constructed furrow or berm designed to divert flood flows around the wetland rather than allowing them to flow through.

Table 7.6. Accounting for activities that alter the magnitude and/or frequency of floodpeaks received by the wetland

A. Estimating changes in floodpeaks based on catchment landcover (Excludes dams)						
A1. Landcover changes: Calculated based on catchment landcover assessment (Section 5.2)						
B. Assessing the impact of dams on floodpeaks						
Level of reduction	**0**	**-2**	**-5**	**-8**	**-10**	**Score**
B1. Collective volume of dams in the wetland's catchment in relation to mean annual runoff (MAR)	<20%	20-35%	36-60%	60-120%	>120%	
B2. Interception by dams of the streams entering the wetland	<5% of the stream network is intercepted	~25% of the stream network is intercepted	~50% of the stream network is intercepted	~75% of the stream network is intercepted	Most stream input is intercepted before entering the wetland	
B3. Level of abstraction from the dams	Low	Moderately low	Intermediate	Moderately high	High	
B4. Specific allowance for natural floods within the operating rules of the dam *	Good allowance made		Moderate allowance		Negligible allowance	
C. Final Impact Score for dams						
Collective dam volume <120%: -B1/10 x (2B2+B3)/3						
Collective dam volume >120%: -B1/10 x [(2B2 x -B4/10) +B3]/3						
D. Degree to which flood waters are intercepted and diverted around the wetland						
D1. Degree of interception and diversion	Small reduction in flood inputs (e.g. 15% reduction in flood flows)	Moderate reduction in flood inputs (e.g. 30% reduction in flood flows)	Large reduction in flood inputs (e.g. 50% reduction in flood flows)	Serious reduction in flood inputs (e.g. 70% reduction in flood flows)	Critical reduction in flood inputs (e.g. >70% reduction in flood flows)	
Overall change in floodpeaks = A1 + C + D						

*This is only applicable where the collective volume of dams is >120% of MAR.

Rationale for Table 7.6

A. Estimating changes in floodpeaks based on catchment landcover (Excludes dams)

The impact of landuse activities in the upstream catchment on floodpeaks is simply estimated by using the overall impact score for floodpeaks derived from the extent of the various landcover categories in the catchment multiplied by the relevant default intensity scores for floodpeaks, as per the Level 1B assessment (Section 5.2).

B. Assessing the impact of dams of floodpeaks

<u>B1. Collective volume of dams in the wetland's catchment in relation to mean annual runoff (MAR)</u>

The greater the collective volume of dams in relation to the MAR from the wetland's catchment, the greater the potential flood storage, in particular where dams remain at low levels for much of the year. For example, the storage capacity of the Pongolopoort Dam immediately upstream of the Pongolo Floodplain, is 224% of the MAR, which is exceedingly high. In simple terms, therefore, if the dam was emptied, it would take more than two years to refill it under average conditions, even if no water was released. Thus, the potential impact of the impoundment on downstream flows is considerable.

B2. Interception by dams of the streams entering the wetland

The location of dams relative to the wetland determines the potential of dams to intercept and reduce water inputs. The impact of dams will be most severe where dams are located directly upstream of the wetland on the main trunk stream and intercept all water inputs. Impacts decline when dams only intercept flows from a small proportion of the catchment or are located some distance upstream of the wetland.

B3. Level of abstraction from the dams

The greater the level of water abstraction from the dams, the greater is the likelihood that dams will be well below their capacity when potential flood events arrive, thereby greatly dampening floods downstream, unless specific mechanisms for release are being followed (see below).

B4. Specific allowance for natural floods within the operating rules of the dam

This indicator is only included in the assessments where dams account for >120% MAR. Large dams in particular have the potential to eliminate natural flooding downstream of the dam unless specific allowance is made for natural floods within the operating rules of the dam so as to simulate natural flooding. In this regard, it is important to note that some dams do not have the structural capacity for releasing sufficiently large floods to simulate natural flooding.

C. Final impact score for dams

A final magnitude of impact score is calculated by jointly considering the indicators assessed. This score is set initially by the level of interception of catchment inflows and then adjusted based on factors that can affect the degree to which water flood peaks are attenuated. Note here that the collective volume of dams is weighted twice that for the level of abstraction since it is regarded as having a more important influence on flood peaks.

D. Degree to which flood water are intercepted and diverted around the wetland

Flood waters which would have naturally entered a wetland may be diverted so as to bypass the wetland and continue on downstream of the wetland. The magnitude score for such diversions is assessed based on the perceived reduction in flood flows. It is important to note that the % reduction descriptions are given as examples rather than prescriptive thresholds.

Hydro Step 1C-4: Obtaining an overall indication of change in floodpeaks and the impact of this change

For the purposes of this assessment, the scores for the catchment, and upstream diversions and dam assessments are summed to obtain an indication of the overall change to flood peaks entering the wetland (**Table 7.6**) and this overall score should be interpreted in the light of the class descriptions given in **Table 7.7**. It is however important to note that this is a very crude assessment of changes in flood peaks and there are additional factors that may potentially increase or decrease floodpeaks. Gullies, roads and artificial drainage channels, effectively “extend” the drainage network and serve to speed up the delivery of stormflows to the wetland therefore increasing flood peaks. The implementation of measures to specifically mitigate changes in stormwater runoff may also reduce the impact of catchment-activities. This includes implementation of measures such as Sustainable Urban Drainage Systems (SUDS) that are designed to help reduce the impact of urban landscapes on natural flood levels. Thus whilst an estimate of change in floodpeaks is obtained from this assessment, motivated adjustments can be made if necessary.

Table 7.7. Guideline for interpreting the level of alteration of the natural pattern of floods delivered to the wetland

Final impact score (from Table 7.6)	Alteration classes	Description
>6	Large increase	Floodpeaks have been substantially increased, resulting in a marked reduction of sub-surface water inputs.
4 to 6	Moderate increase	Floodpeaks have been moderately increased, often resulting in a noticeable reduction of sub-surface water inputs
1.6 to 3.9	Small increase	Discernible but small increase in floodpeaks that may not necessarily have resulted in the discernible reduction of sub-surface water inputs.
-1.5 to 1.5	No effect	No discernible effect on floodpeaks.
-1.6 to -3.9	Small decrease	Discernible but small reduction in floodpeaks.
-4 to -6	Moderate decrease	Floodpeaks have moderately decreased.
<-6	Large decrease	Floodpeaks greatly reduced, such that in the case of a floodplain, no further flooding out of the main channel across the wetland takes place unless during major floods (i.e. >1 in 20 year flood events).

Having scored the overall change to flood peaks entering the wetland, the impact of this on the hydrological integrity of the wetland is determined based on the assumed vulnerability of the HGM type to both increased and reduced floodpeaks respectively. This is accounted for by pre-assigned HGM-specific adjustment factors (see **Table 5.5** for Level 1A assessments, and **Table 5.11** for Level 1B and Level 2 assessments), which are multiplied by the overall change score. For example, floodplains are assumed to be the most vulnerable to reduced floodpeaks because they are generally strongly dependent on flood events to provide key hydrological inflows, and therefore have the highest adjustment factor (0.9). In contrast, seeps are assumed to be least dependent because they are generally maintained by sustained sub-surface flows, and therefore have the lowest adjustment factor (0.2).

Hydro Step 1D: Assess any change in seasonality of inflows

The seasonality of inflows refers to the pattern of flows across the seasons within a year, and the focus of Step 1D is to determine the degree to which human impacts have modified this pattern. It may be that overall quantity of inflows to the wetland (assessed in **Hydro Step 1B**) has not been altered but how these inflows are "partitioned" across the seasons has been altered substantially. Common situations where the seasonality of inflows may be altered include inter-basin transfers and wastewater discharges. Streams which are highly regulated to supply irrigation water in the dry season and wetlands receiving dry-season irrigation return flows may also greatly alter seasonality.

Hydro Step 1D-1: Estimating changes in seasonality based on catchment landcover

For Level 1 and 2 assessments, the extent to which inflow seasonality has been altered by landuses in the catchment is determined based on the pre-assigned intensity scores for the respective landcovers and their relative extents. For example, orchards and vineyards are assigned a score of 4 given their typically high irrigation levels, usually in the dry season and natural vegetation is assigned a score of 0. Thus if a wetland's upstream catchment comprised 20% orchards and vineyards and 80% natural vegetation then the magnitude of impact would be (4 X 20/100) + (0 X 80/100) = 1.2.

Hydro Step 1D-2: Accounting for transfers and point-source discharges

At level 2, assessment of altered inflow seasonality is adjusted to account for point-source discharges and inter-basin transfer schemes with reference to **Table 7.8**, and is based on any desktop information on transfers / point source discharges and supplemented through field observations in the wetland. Refer to **Table 7.3**, where transfers and point source discharges are recorded, but noting that in **Table**

7.3 they were scored with respect to inflow quantity while in Step 1D-2 their specific effect on seasonality of flows should be considered.

Table 7.8. Guideline for assessing the impact of transfers / point source discharges on the seasonality of inflows

Indicator	0	1.5	3	4.5	6	Score
A. Change in seasonality of inflows from transfers / point source discharges	Low: Seasonality of flows largely natural	Moderately low: Seasonality of flows slightly altered, e.g. flows slightly dampened in the wet season and correspondingly increased in the dry season.	Intermediate: Seasonality has been noticeably altered but the main inflows still occur in the wet season	Moderately high: The seasonality of inflows have been partially flipped/ reversed plants).	High: The seasonality of inflows has been completely flipped/ reversed	

Rationale for Table 7.8

Given the coarse level at which impacts are rapidly assessed, a simple broad distinction is made between wet season inflows and dry season inflows. The most extreme alteration is where these flows are completely “flipped”. It is also worth noting that the maximum impact score (6) is less than the maximum for reduced input quantities (10), given that even if the seasonality is flipped, the area is likely to persist as a wetland whereas if the quantity of inputs are substantially reduced (**Table 7.3**) the wetland’s hydrological characteristics may potentially be lost (i.e. the area may no longer persist as a wetland).

Hydro Step 1E: Assess the combined magnitude of impact of changes in water inputs

In this step the overall impact of altered quantity and pattern of inputs is determined from altered inflow quantity (**Hydro Step 1B**), changes in flood peaks (**Hydro Step 1C**) and altered seasonality of inflows (**Hydro Step 1D**). This score is based on the maximum of the individual impact scores (**Table 7.9**).

Table 7.9. Calculating the overall magnitude of impact for changes in the quantity and pattern of water inputs

Hydro Step 1B. Overall change in the quantity of water inputs (Table 7.5)	1B
Hydro Step 1C. Change in floodpeaks (Table 7.6)	1C
Hydro Step 1D. Change in seasonality of water inputs (Table 7.8)	1D
Overall impact score for water inputs: MAXIMUM of 1B, 1C and 1D	

Rationale for Table 7.9

When each of the individual impact scores are derived for change in the quantity of water inputs, change in floodpeaks and change in seasonality of water inputs, consideration is given to the overall impact of these changes on the hydrology of the wetland. As such, when combining the scores, it makes the most sense to take the maximum of the three because this represents the biggest impact on overall hydrology in terms of changes in water inputs to a wetland.

Hydro Step 2: Assess changes to natural water distribution and retention patterns based on impacts evident in the wetland

The focus of this section of the module is the evaluation of the degree to which human activities have affected the distribution and retention patterns of water within the wetland. This explicitly excludes the impacts of catchment changes on the wetland and therefore assumes a natural supply of water.

In South Africa, the formation of a wetland and the maintenance of wetland habitat are largely dependent on the input of water from the wetland's upstream catchment. Once the water has reached a wetland, the hydrology of the wetland is potentially also impacted upon by anthropogenic impacts evident within the wetland. One of the key factors impacting on wetland hydrology is the way in which water is distributed and retained within the wetland system. A change in water distribution generally results in altered wetness regime, which in turn affects the biophysical processes and the vegetation patterns. Some activities (e.g. deepening of the stream channel or excavation of drains) within the wetland may reduce the extent to which water is both distributed across the wetland surface and retained within the wetland. Other activities within wetlands (e.g. a dam in the wetland) may increase the retention times or result in deep flooding, which ultimately destroys wetland habitat. For practical purposes, on-site impacts on water distribution and retention have been grouped into five components according to the primary mode of impact (**Figure 7.5**).

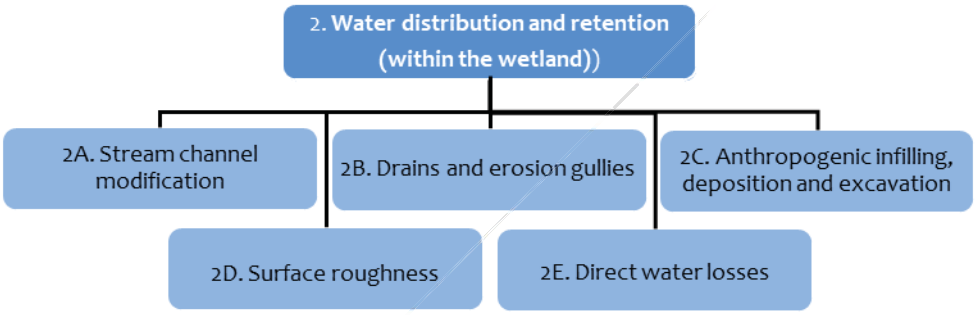

Figure 7.5. The components evaluated as part of the assessment of impacts on water distribution and retention in a wetland

In the case of a Level 1 assessment, impacts to water distribution and retention patterns are defined entirely based on the extent of activities in the wetland and default intensity scores allocated to each landcover class (**Section 4.2**). These scores were assigned by considering how different landuses impact on the different components evaluated above. In the case of a Level 2 assessment, landcover is not used as a basis for the assessment. Rather, each disturbance unit (as defined and described in **Section 6.2**) is assessed by first identifying which of the above impacts affect the unit and then using the guidelines provided to assess the intensity of impact on water distribution and retention patterns. The intensity scores are then combined for each disturbance unit and used with proportional extent to calculate a magnitude of impact score for each disturbance unit. These scores are then summed across the wetland to obtain an overall indication of the change in water distribution and retention patterns.

Hydro Step 2A: Assess changes to lateral connectivity based on stream channel modification and altered flood peaks

This step applies only to wetlands through which a natural stream channel flows, namely floodplains and channelled valley bottoms. In particular, it considers how the modification of the stream channel affects the connection between the stream and the floodplain/valley floor through its effect on overbank flooding. Typically, an enlarged channel reduces overbank flooding, and therefore reduces lateral connectivity.

The first step is to identify which disturbance units in the wetland are affected by modifications to the natural channel. In the example given in **Figure 7.6**, Disturbance unit 3 has been affected by channel straightening and upstream, Disturbance unit 2 has been affected by increased cross-sectional area as a result of channel incision. Disturbance units 1 and 4 are unaffected by channel modifications. It may be difficult to establish if a change in channel cross-sectional area of a natural channel has resulted from anthropogenic causes, and the Rationale for **Table 8.14** of the geomorphology module should be consulted.

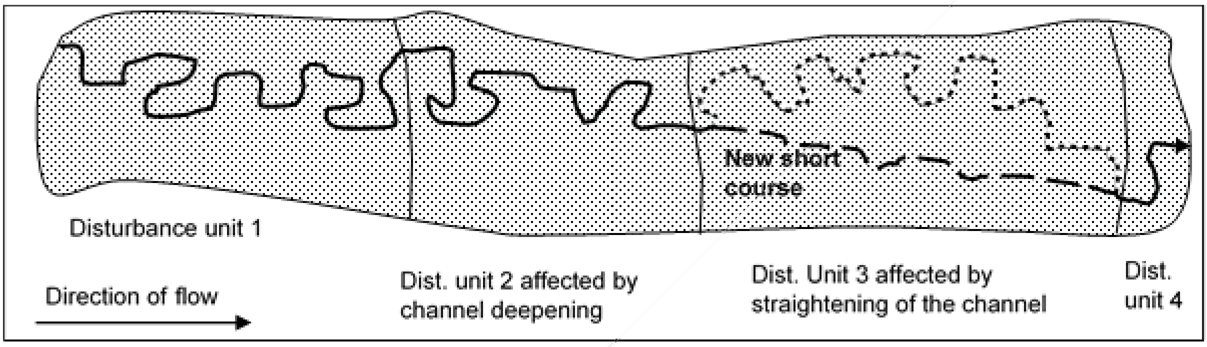

Figure 7.6. An example of an altered stream channel in a floodplain showing the effect of straightening of the channel

The next step is to determine the intensity of impact in the affected area by scoring the three factors given in **Table 7.10**. Each of these factors has a potentially important influence over the conveyance capacity of a channel, thereby affecting the readiness with which the channel will fill to capacity and spill across the wetland, thus promoting lateral connectivity.

Table 7.10. Assessing changes in conveyance capacity through modifications to the stream channel

<table>
<tr><th colspan="7">A. Assess changes in channel form relative to natural reference conditions</th></tr>
<tr><th>Indicator</th><th>0</th><th>-1</th><th>-2</th><th>-3</th><th>-5</th><th>Score</th></tr>
<tr><td>A1. Reduction in length of stream</td><td><5%</td><td>5-25%</td><td>26-50%</td><td>50-75%</td><td>>75%</td><td></td></tr>
<tr><td rowspan="3">A2. Changes in the cross-sectional area of the channel</td><td>No/negligible change</td><td>50% increase (1.5 x area)</td><td>100% increase (2x area)</td><td>150% increase (2.5x area)</td><td>200% increase (3x area)</td><td rowspan="3"></td></tr>
<tr><td>+2</td><td>+5</td><td colspan="3" rowspan="2">Note: +2 and +5 are the scores for the two classes given below</td></tr>
<tr><td>25% reduction</td><td>50% reduction</td></tr>
<tr><th>Indicator</th><th>+2</th><th>0</th><th>-1</th><th>-2</th><th>-3</th><th>Score</th></tr>
<tr><td>A3. Changes in the roughness of the stream channel.</td><td>Moderate increase in roughness (i.e. by 2 classes)</td><td>Roughness unchanged or small increase (i.e. by 1 class)</td><td>Decrease in roughness is low (i.e. by one class)</td><td>Decrease is moderate (i.e. by 2 classes)</td><td>Decrease is high (i.e. by 3 or more classes)</td><td></td></tr>
<tr><td colspan="6">Intensity Score[13] = (Indicator A1 + Indicator A2 + Indicator A3) x Geomorphological adjustment factor[1]</td><td></td></tr>
</table>

[1]The Geomorphological adjustment factor, which is taken from Table 8.14 ranges between 1 (if the above changes to the stream channel are related strongly to anthropogenic causes) and 0 (if the changes cannot be related to any anthropogenic causes and are therefore assumed to be part of the natural geomorphological dynamics of the channel, and as such any hydrological influence of this "natural" channel dynamic is also seen as a natural feature).

Rationale for Table 7.10

A. Assessing changes in channel form that affect the conveyance capacity of the channel

<u>A1 Reduction in the length of the stream channel</u>

For a given slope on the valley bottom, the greater the length of stream channel passing through the valley bottom, the gentler is the gradient on the bed of the stream channel. The gentler the slope, the lower is the velocity of flow in the channel, which in turn results in increased retention of water in the channel. This in turn, increases the possibility of bank overspill as the capacity of the channel is exceeded. A less-straight channel (i.e. one which is more sinuous) has more bends and this contributes to the slowing down of water-flow in the channel (Ward and Trimble, 2004).

Calculate the reduction in stream length by identifying the section of the river that has been straightened, and measuring its length along the old natural course. Next, measure the length of the straightened section, and calculate the difference between this and the old, natural section. Finally, express this difference as a percentage of the old natural course. In the example in **Figure 7.6**, the old course was 13 km long and following diversion the new course is 6 km long. Thus, the difference expressed as a percentage is (13 – 6)/13 x 100 = 53%.

<u>A2 Changes in the cross-sectional area of the channel.</u>

Changes in cross-sectional area are often precipitated by changes in the hydrology of the catchment that affects the stream power and associated erosivity of flows passing through the wetland. This is typical of urban wetlands where an increase in the proportion of impermeable area in the catchment typically increases peak discharge, which in turn stimulates channel incision. Poor landuse management in the catchment may also lead to erosion of headwater reaches and channel incision and straightening, as evident in the Bell River, Eastern Cape Province (Dollar and Rowntree, 1995) and upper Umzimvubu catchment (Van der Waal and Rowntree, 2017). Damming of streams is another common impact, particularly to floodplain wetlands. This is due to the ability of dams to trap sediment and release water that is effectively starved of sediment, and therefore with an increased capacity

[13] Further interrogation of available literature is needed here in order to determine the relative importance of channel straightening, cross-sectional area and roughness of the channel and how these interact to influence lateral connectivity. Note too that whilst a maximum intensity score of 13 can be obtained, this is capped to 10 in line with impact categories.

to scour the channel. This reduction in sediment load deprives floodplains of sediment required for floodplain construction and commonly leads to floodplain degradation.

A range of within-wetland activities are also known to cause channel incision either directly or through accelerated erosion (e.g. a lowering of the base level of the channel) and these are described in **Box 7.1**.

Box 7.1. ***Within-wetland activities commonly stimulating erosion***

A range of within-wetland activities are known to stimulate erosion and alter natural channel dimensions. These include:

- ***Changes to the local base level controls of the wetland***: This typically involves excavation that changes the base level of the wetland. This may involve direct modification to geomorphic controls (e.g. removal of rock material from dolerite dykes) or the excavation of alluvial controls that changes the base level of the wetland. This can cause major instability and initiate headword erosion (erosion that proceeds upstream) as water cuts down to the new base level.
- **Dredging and mining**: Dredging of channels and sand/gravel mining activities typically result in direct channel deepening and widening. Excavation in the active channel may also alter the equilibrium profile of the streambed, creating a locally steeper gradient upon entering the excavated area. This over-steepened nick-point (with its increased stream power) commonly erodes upstream in a process known as head-cutting which result in further channel incision over time.
- **Artificial canals**: Natural stream channels are often converted into artificial canals in urban environments. Such interventions may alter channel dimensions and, in the case on concrete-lined drains, also reduces channel roughness which can radically increase conveyance of water through a wetland and so reduce the flood risk to adjoining areas.
- **Roads**: Most existing roads established across watercourses involve flow diversion and concentration through road fill embankments via pipe and box culverts that are substantially narrower than the width of natural wetland flow. Channel and/or wetland scour is thus common below such crossings due to the increased flow velocities at the culvert outlets. If accompanied by a lowering of the channel bed (e.g. through the installation of a culvert below the natural channel bed), this may have a similar affect to a change in geomorphic controls by stimulating upstream erosion. Depending on the design, road crossings may dampen floodpeaks, reducing stream power and resulting in aggradation of the channel or they may promote channel incision by reducing sediment loads and increasing the erosive capacity of water flowing through the channel.
- **Dams**: Dams located within the wetland but upstream of the disturbance unit may have a similar effect to dams upstream of the wetland. By reducing sediment loads, they can increase the erosive capacity of water entering the channel that can result in channel instability and incision. Dams may however also reduce flood peaks downstream, potentially reducing the effects of “hungry water”, inducing channel shrinking or allowing fine sediments to accumulate in the bed (Kondolf, 1997). Spillways may also direct outflows away from the natural low-point or stream channel, and may have dramatic impacts, including the potential of cutting a new channel.
- **Drains and berms**: Drains and berms can concentrate flows in a similar way to road culverts. This can lead to major incision as flows become concentrated along a new preferential flow path. Berms alongside natural channel banks can also concentrate high flows rather than allowing such flows to be dissipated by over-topping the channel banks. This can increase the scouring capacity and stimulate channel erosion.
- **Channel straightening**: Channel straightening steepens channel slope and thus promotes headward erosion, lowering the channel bed. The intensity of incision here is typically linked to the level of straightening, with greater incision expected where the sinuosity of the stream has been appreciably altered.
- **Landuse impacts to wetland vegetation**: Impacts to wetland vegetation, particularly along channel banks (e.g. at livestock crossing points) can make stream banks more susceptible to erosion. Intense use by livestock can also reduce basal cover, increasing the risk of erosion.
- **Accelerated channel avulsions**: Channel avulsions may result in dramatic changes in channel form (and the length of the stream channel). Avulsion events are natural processes in floodplain wetlands and it is therefore important to be able to distinguish between natural events and avulsions that have been stimulated through anthropogenic activities (See **Box 8.2**).

The cross-sectional dimensions of any channels present are used as an initial indicator for assessing change in conveyance capacity. This is done by simply calculating the average effective cross-sectional dimension of the channel in the target area by multiplying the parameters of width & depth (to bank height). This is then contrasted against what are regarded as "natural / reference" channel dimensions.

An opportunity is also provided to rate impacts that have reduced channel dimensions, enhancing lateral connectivity. Such impacts could be in response to increased deposition in the channel (e.g. as a result of decreased discharge and/or increased sediment loads) or through obstructions in the channel that promote increased channel overtopping. Note in the case where rehabilitation measures have been implemented to elevate water levels, the assessment should be based on the average effective cross-sectional profile created by these interventions (assessed using the average low-water water level mid-way between successive interventions to assess the new cross-sectional area).

The class boundaries used to rate the intensity of impacts aim to provide a coarse measure of the degree to which changes in channel dimensions will affect the overtopping of the channel during flood events as it is these events that typically deliver pulses of sediment to channelled wetland systems. Recognition is also given to the fact that large sediment inputs are often delivered during infrequent flood events. As such, wetland geomorphology is regarded as less sensitive to changes in channel form than hydrology where relatively minor changes to channel form may have a dramatic impact on water distribution and retention patterns in the wetland.

A3. Changes in the roughness of the stream channel.

The roughness of the channel reflects the frictional resistance of the channel to water flows, and also affects the conveyance capacity of the channel. The higher the roughness, the higher the frictional resistance and therefore the lower the conveyance capacity. This is, however, regarded as having a smaller impact on lateral connectivity relative to channel dimensions, as reflected by the lower scores allocated relative to changes in cross-sectional area. This indicator is assessed by assigning a roughness class to the channel based on (a) current channel characteristics and (b) an estimate of historic characteristics (**Table 7.11**). Current roughness is then compared with historic conditions in order to assess the overall change in roughness of the stream channel (**Table 7.10**, row 6). Such changes can best be assessed from aerial photography or by interviewing local landholders.

A range of factors are known to affect the roughness of stream channels. Roughness is typically increased through encroachment by vegetation, often including alien invasive species. Such a change may be stimulated through a reduction in flow, particularly a reduction in flood peaks since floods are known to play an important role in maintaining channel form (e.g. Batalla, 2003). A reduction in roughness is commonly associated with bank erosion or channel incision and with activities that involve artificial clearing or removal of vegetation (e.g. through dredging or by formalising a concrete channel).

Table 7.11. Guideline for assessing the roughness of channels

Roughness class	Description of channel characteristics
Low	Channel banks have a relatively smooth surface with little or no vegetation to offer resistance to water flow (e.g. incised channel with steep un-vegetated vertical walls OR concrete-lined channel).
Moderately low	Vegetation is present but short (i.e. < 500 mm) along channel banks and not robust (e.g. rye grass).
Moderate	Vegetation offering slight resistance to water flow, generally consisting of short plants (i.e. < 1 m tall). Vegetation typically limited to banks, with little vegetation in the channel.
Moderately high	Robust vegetation (e.g. dense stand of reeds) on channel banks and with some vegetation extending into the channel.
High	Vegetation very robust along banks (e.g. dense swamp forest with a dense understorey OR dense alien plant stands) and offering high resistance to water flow. Channel floor also well vegetated, creating further resistance to flows.

It is recognized that bank overspill is profoundly affected by both the impact to floodpeaks entering the wetland from its catchment (**Table 7.6**) and by changes to the stream channel flowing through the wetland (**Table 7.10**). Thus, these two factors, which may either amplify or dampen each other, are considered jointly in **Table 7.12**, while also taking account of the dependence of the type of wetland on bank overspill vs. lateral inputs (assessed in **Table 7.13**).

Table 7.12. Assessing the degree and direction of changes in lateral connectivity from the main channel based on within-wetland and catchment impacts

	Change in conveyance capacity of the channel (From Table 7.10)						
Change in flood peaks (from Table 7.6)	Large decrease (5 to 7)	Moderate decrease (4 to 5)	Small decrease (2 to 3)	None (+1 to -1)	Small increase (-2 to -3)	Moderate increase (-4 to -6)	Large increase (-7 to -10)
Large increase (+5)	10	9.5	7.5	5	2.5	0.5	-3.5
Moderate increase (+3)	8.5	7.5	5.5	3	0.5	-1.5	-5.5
Small increase (+1)	7	5.5	3.5	1	-1.5	-3.5	-7.5
None	6	4.5	2.5	0	-2.5	-4.5	-8.5
Small decrease (-1)	5	3.5	1.5	-1	-3.5	-5.5	-9.5
Moderate decrease (-3)	3	1.5	-1.5	-3	-5.5	-7.5	-10
Large decrease (-5)	1	-0.5	-2.5	-5	-7.5	-9.5	-10

Rationale for Table 7.12

If the incidence of floods delivered by a wetland's catchment is decreased then an increased conveyance capacity of the channel will have an amplifying effect, further reducing the incidence of bank overspill, which will be particularly severe for those wetland is strongly dependent on bank overspill. However, in other cases the respective effects of catchment impacts and on-site effects on channel conveyance capacity may be dampening. For example, the effects of increased flood peaks delivered by the wetland's catchment may be accommodated by an increased conveyance capacity of the channel in the wetland, resulting in a dampening effect. Table 7.12 attempts to account for these amplifying and dampening effects.

Having determined, in **Table 7.12**, the overall change in bank overspill and lateral connectivity from the main channel, the impact of this change on the wetland is scored. This is based on the dependence of the wetland bank overspill, which is inferred from the wetland's HGM type, and then moderated by the MAP:PET ratio for the wetland (**Table 7.13**). Wetlands with high dependence on bank overspill (notably floodplains) in catchment contexts where the MAP:PET is lowest, would be most impacted by reduced overspill.

Table 7.13. Hydrological Impact intensity of altered streambank overspill (lateral connectivity) on a wetland area based on its HGM type and its MAP:PET ratio

	Alteration to the incidence of bank overspill (from Table 7.12)																				
	-10	**-9**	**-8**	**-7**	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Initial intensity score	10	9	8	7	6	5	4	3	2	1	0	0	1	1	1	2	2	2	3	3	3
Adjusted impact score = Above score x Lateral input adjustment factor[1] x MAP:PET adjustment factor from Table 6.1																					

[1]Lateral input adjustment factor relates to the likely contribution of bank overspill vs. lateral inputs to maintaining the unit. Low (Channelled valley bottom with substantial lateral inputs) = 0.3; High (Channelled valley bottom with limited lateral inputs) = 0.7; Very high (Floodplain with negligible lateral inputs) = 0.9.

Rationale for Table 7.13

The first step in assessing the impact intensity on a wetland of altered streambank overspill is to rate decreased incidence relative to increased incidence (in Row 3). Here, intensity of impact on wetland's hydrological condition is considered to be greater for a decreased incidence of bank overspill than an increased incidence, given the potentially critical role of bank overspill to sustaining a wetland. In the next step (Row 4) account is taken of the importance of bank overspill inputs vs. lateral inputs, and as lateral inputs become progressively more important the initial impact score from Row 3 is incrementally down-weighted. Finally, account is also taken in Row 4 of the vulnerability of the wetland based on the MAP to PET ratio.

Hydro Step 2B: Assess the impact of drains and erosion gullies

Drains (also referred to as drainage furrows) are typically straight features common in wetlands that have been used for agricultural purposes. Erosion gullies in a wetland may arise naturally or as a result of a suite of human activities (**Box 7.1**). Drains and erosion gullies both have a potentially high impact on the distribution and retention of water within a wetland. The modification of existing natural channels (straightening, deepening and reduced roughness) is dealt with in the previous step (**Hydro Step 2A**). If drains occur in an area also affected by stream channel modification (**Figure 7.7**) then the impacts of the drains need to be added to the impact already assessed in the previous step.

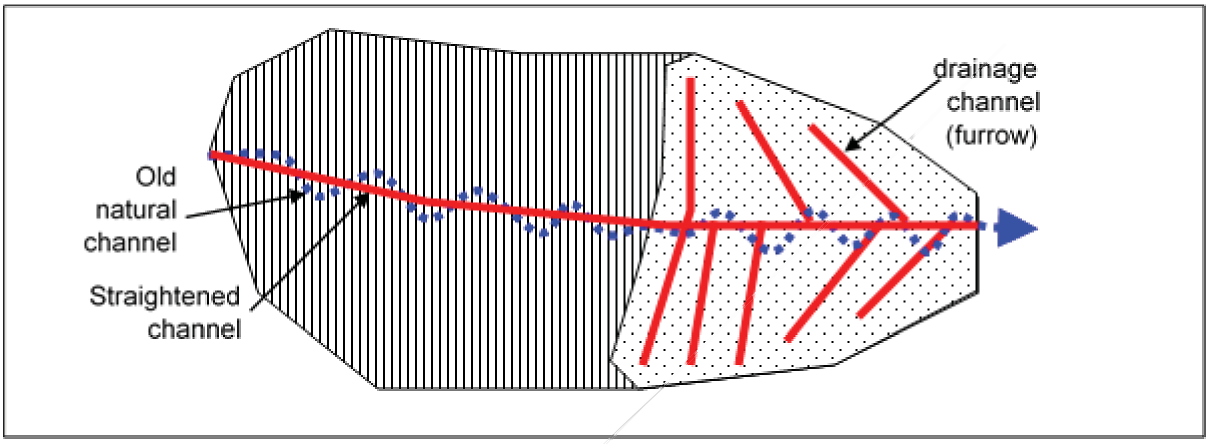

Figure 7.7. Representation of an wetland where the natural channel through the wetland (flowing from left to right in the diagram) has been straightened along its entire length (assessed in Step 2A), therefore affecting the entire HGM. Artificial drainage channels (assessed in Step 2A) affect only the lower (stippled) portion, thereby adding to the impact of the altered natural channel in this portion. Therefore, the lower portion is assessed using both Step 2A and 2B whereas the upper portion requires only Step 2A.

Erosion gullies and drains tend to reduce diffuse surface-flow and retention of water in favour of more concentrated flow. The effect on sub-surface flow should also be considered because it is influenced strongly by the hydraulic conductivity of the wetland sediments, which refers to the ease with which water moves through the sediments. If the hydraulic conductivity is high (i.e. water moves easily through the soil) then the effect of the drains is potentially great. If it is very low, then even large drains may have little effect on sub-surface flow within the wetland.

For those disturbance units considered to be directly affected by drains/gullies, assess the magnitude of impact by completing **Table 7.14**. You will notice that the calculation of intensity in **Table 7.14** is not the simple mean value, but involves several steps to account for the relative importance of the different factors and how they interact. Once you have calculated the intensity of impact, reflect on the final score in the light of any direct evidence you can see of the effect of the drains (e.g. water moving rapidly out of a drain or a decline in hydric vegetation) and, if necessary, adjust the score and document your justification for the adjustment. Remember, however, that vegetation may be very slow in responding to the effects of drainage, particularly where it is naturally dominated by a single species with high cover (see **Section 10**).

Table 7.14. Characteristics affecting the impact of drains (and erosion gullies) on the distribution and retention of water in a disturbance unit

Drains & erosion gullies						
A. Interception or deflection of flows						
Indicator	**0**	**-2**	**-5**	**-8**	**-10**	**Score**
A1. Location of drains, gullies &/or artificial berms in relation to flows delivered to disturbance unit *from the upstream catchment*. Location is such that flows are:	Very poorly intercepted	Moderately poorly intercepted	Intermediate	Moderately well intercepted	Completely intercepted	
A2. Location of drains, gullies &/or artificial berms in relation to diffuse flows (i.e. not in a channel) delivered *from lateral inputs* into the disturbance unit. Location is such that flows are:	Very poorly intercepted	Moderately poorly intercepted	Intermediate	Moderately well intercepted	Completely intercepted	
Indicator	0.3		0.7		0.9	**Adjustment Factor**
A3. Importance of water inputs from the upstream catchment relative to lateral inputs	Low: CVB wetland laterally maintained (i.e. with substantial lateral inputs)		High: All other HGM Types		Very High: Floodplains	
A. Interception Score: (A1 x A3 + A2 x (1-A3)) x Hydrological Vulnerability Factor						
B. Efficiency with which flows are conveyed through the wetland						
Indicator	**0**	**-2**	**-5**	**-8**	**-10**	**Score**
B1. Depth of the drains/gullies*	<0.20 m	0.20-0.50 m	0.51-0.80 m	0.81-1.10	>1.10 m	
B2. Density of drains /gullies (m/ha of wetland)	<25 m/ ha	26-100 m/ha	101-200 m/ha	201-400 m/ha	>400 m/ha	
B3(a). Texture of mineral soil, if present	Clay	Clay loam	Loam	Sandy loam	Sand/ loamy sand	
B3(b). Degree of humification of organic soil, if present	Completely amorphous (like humus)	Somewhat amorphous	Intermediate	Somewhat fibrous	Very fibrous	
Initial Intensity Score: A x Average (B1,B2,B3)/10						
B4. Obstructions in the drains/ gullies	Complete obstruction	High obstruction	Moderate obstruction	Low obstruction	No obstruction	
Refined Intensity Score (B): Initial Intensity Score x B4/10						
Erosion gullies (Not rated for drains)						
C. Accounting for the strength of cause-effect relationships						
C1. Adjustment factor for the direct & indirect evidence for human-induced erosion (from Table 8.17)						
C2. Inherent vulnerability of the wetland to erode						
Scaled intensity of Score (erosion gullies) B x C1 X C2						

*In some circumstances, a wetland may be artificially drained by tilling the soil and piling it up onto raised beds rather than digging a drainage channel down below the soil surface. Both methods, however, serve to dry out the area. In the case of raised beds, the height of the bed above the low ground between the beds is taken as the "Depth of the drains".

Rationale for Table 7.14

The logic of the above scoring system is as follows. Drains/gullies can act to desiccate an area of wetland by draining the wetland more quickly than would naturally occur, i.e. by intercepting flow entering the wetland (accounted for by factor A1 to A3) and by reducing the retention of water in a wetland (accounted for by factors B1 to B3). Interception of flows considers the degree to which the wetland area is supplied by a stream channel vs. lateral flows. In addition, the hydrological vulnerability factor (from **Table 7.1**) is included because the impact of intercepted flow is likely to increase with an increased vulnerability factor. Both the draining and intercepting effects may be negated to varying degrees by obstructions in the drains, such as rehabilitation plugs (accounted for by factor B4).

It is important to note that a dam wall may work together with an artificial drainage channel to effectively intercept flow through a wetland area. This applies particularly to situations where the dam wall spans the width of the unit and the outlet of the dam feeds directly into an artificial drainage channel.

A. Interception or deflection of flows

A1. Location of drains and gullies in relation to flows delivered by a channel

The interception by drains/gullies of water entering a disturbance unit is strongly affected by the location of the drains relative to the location of water inputs. Interception of water inputs from the main channel is first examined, and the impacts of this interception is then weighted according to the importance of inputs from the main channel vs. diffuse lateral inputs (see A3). For example, if the primary inputs are lateral inflows then the impacts of interception of the main channel inputs, is much less serious, and will be more strongly down-weighted than if the primary inputs were from the main channel.

A2. Location of drains and gullies in relation to diffuse flows delivered from lateral inputs

For the interception of lateral water inputs of diffuse flows, cut-off drains, constructed around the margins of the wetland, may successfully intercept a large proportion of inflows that would have naturally entered the wetland. However, it cannot be assumed that because a drain extends around the entire margin of the wetland that all of the inflow will be intercepted. In high rainfall events, the capacity of the channel may well be exceeded. In addition, some subsurface inflows may pass beneath the channel or some water may seep through the walls of the channel. The impacts of lateral interception are then weighted according to the importance of this source of water vs. inputs from the main channel (see A3).

A3. Importance of water inputs from the upstream catchment relative to lateral inputs

See rationale given in **Hydro Step 1B-2C** (Table 7.4). In addition, the lower the MAP:PET ratio, the more dependent is the wetland on inflows from its upstream catchment (as explained in **Hydro Step 1A**), and therefore the more vulnerable is the wetland to any interception of these flows.

B. Efficiency with which flows are conveyed through the wetland

B1. Depth of drains

The deeper the drains and gullies in the affected area, the greater is the potential of this conduit network to intercept sub-surface flow and to lead intercepted flow (both sub-surface and surface) out of the wetland.

B2. Drain density

The greater the density of drains, the more likely they are to effectively desiccate the section of wetland in which they occur.

B3. Texture of mineral soil and the degree of humification of organic soil

The greater the hydraulic conductivity of the wetland soils, the more effective the drains will be in removing sub-surface water from the wetland. If the wetland has mineral soil then the hydraulic conductivity is approximated based on soil texture. If the wetland has organic soil, then the hydraulic conductivity is based on the degree of humification of the soil. The finer the texture of the soil, the smaller the pore spaces between the particles, and the slower the water moves through the soil. Similarly, the more humified the organic soil, the finer the particles of organic matter, and the slower the water will move through the soil.

For mineral soil, take a teaspoon-size piece of soil and add sufficient water to work it in your hand to a state of maximum stickiness, breaking up any lumps that may be present. Now try to form the soil into a coherent ball.

- If this is impossible or very difficult (i.e. the ball collapses easily) then soil is sand or loamy sand.
- If the balls forms easily but collapses when pressed between the thumb and the fore-finger then soil is sandy loam.
- If the soil can be rolled into a thread but this cracks when bent then soil is loam.
- If the thread can be bent without cracking and it feels slightly gritty then soil is clay loam, but if it feels very smooth then soil is clay.

For organic soils,

- if the soil consists of large (>5 mm) fragments of identifiable plant material (e.g. of leaves, wood fibres, etc.) then soil is very fibrous.
- If it consists predominantly of small fragments (<5 mm) of plant material but these are still identifiable then soil is somewhat fibrous.
- If it consists of a mixture of identifiable plant fragments and amorphous material (which has the feel of humus or clay), but neither predominates, it is intermediate.
- If it consists of a mixture of fibrous and amorphous material, with amorphous material predominating then it is somewhat amorphous.
- If no fibres can be identified and the material feels like humus or clay, then soil is amorphous.

B4. Obstructions in drains and gullies

Obstructions (e.g. rehabilitation "plugs") reduce the speed of through-flows and the ability of the drains to effectively function. Obstructions may override the effect of all other features of a drain, and substantially reduce their ability to re-direct water through the wetland. At one extreme, the minimum score, there are no obstructions and at the other extreme, the maximum score, the obstructions are completely negating the effect of the drains/gullies. It is important to note that a key factor influencing the level of obstruction of plugs is the slope of the drain/gully, with the more gentle the slope, the more effective the plug will be and hence the greater the "push back" distance will be of a given "plug" in obstructing flow.

C. Adjusting the score to account for the direct & indirect evidence for human-induced erosion (score only for erosion gullies)

C1. Geomorphic adjustment factor

For erosion gullies the adjustment factor, which is taken from **Table 8.9**, ranges between 1 (if the gully can be related strongly to anthropogenic causes) and 0 (if the gully cannot be related to any anthropogenic causes and is therefore assumed to be part of the natural geomorphological dynamics of the wetland, and as such the hydrological influence of this "natural" gully is also seen as a natural feature). Drains are by definition entirely anthropogenic features and therefore for drains the Geomorphic adjustment factor is always taken as 1, which does not result in any change to the intensity score.

Hydro Step 2C: Assess the magnitude of impact of anthropogenic deposition, infilling or excavation (including dams)

This step involves the assessment of a variety of activities which either introduce material into the wetland (including anthropogenic deposition and infilling) or cause the excavation of material (e.g. for sand winning). The anthropogenic deposition of sediment includes sediment from sources within the wetland's upstream catchment (e.g. agricultural land and eroded areas) and activities in the wetland itself (e.g. poorly managed construction sites) that have been carried by water and deposited in the wetland. Infilling is the direct deposition by humans of fill material in the wetland (e.g. for road embankments, berms or dam walls or in order to prepare a site for construction). Excavation refers to the removal of sediment by humans from the wetland (usually with heavy machinery) and is commonly associated with mining and sand winning.

The hydrological impact of the feature/activity (e.g. the infill or the dam wall) is assessed by considering:

- Direct impacts, which are restricted to within the immediate footprint of the feature, beneath the deposition/infilling or within the excavation.
- Indirect impacts on additional areas of the wetland where the activity either (a) impedes (impounds) flows within an area upstream of the feature or (b) deflects (intercepts) flows away from the area located laterally or downstream of the feature, and often causes the desiccation of this area.

Dams and weirs are the most common features causing impeded flow upstream of the feature. Road embankments also result in impeded flows in an upstream direction especially where culverts inadequately accommodate the natural flow of water. In all of these scenarios, the extent of water retention is taken as the flooded area upstream of the impeding feature, which leads to changes to the hydrological integrity of the wetland. Affected areas should typically be mapped as discrete disturbance units, based on the perceived extent of back-flooding.

Impeding features may also result in the localized desiccation downstream of the feature. Here, several factors need to be considered, e.g. water abstraction (which refers to extracting/taking water, usually by means of pumping, for a variety of uses), and whether road culverts may confine through-flow, thereby exposing localized downstream portions of the wetland to reduced flows leading to desiccation.

Note: Trenches (drains) dug during road construction remove water from a wetland in the same way that artificial drains do, and this often results in the localized desiccation of the wetland, particularly if the base level has been lowered. The desiccating effects of drains associated with road crossings are covered in **Hydro Step 2B** (Drains and erosion gullies).

1. Areas directly affected by anthropogenic deposition, infilling and excavation

This assessment is carried out for disturbance units directly affected by deposition, infilling or excavation (**Table 7.15**). Whilst evidence of infilling and excavation is usually obvious, depositional features are difficult to spot, and even people with a basic training in geomorphology may have difficulty identifying depositional features in the field, on aerial photographs or even from a low-level aerial survey (See **Geo Step 1A-2c** for further guidance). Since depositional features often occur naturally in wetlands, impacts need to be tempered based on evidence that increased deposition is linked to anthropogenic activities. In the case of infilling and excavation, impacts are rated simply based on on-site indicators.

Table 7.15. Assessing the direct hydrological impacts of anthropogenic deposition

A. Areas directly affected by anthropogenic deposition						
Indicator	**0**	**-1**	**-2**	**-3**	**-5**	**Score**
A1. Average depth of recent sedimentary deposits	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
Scaled intensity of impact score = A1 x A2 (Geomorphological adjustment factor)						
B. Areas directly affected by infilling/excavation						
Indicator	**-1**	**-3**	**-5**	**-8**	**-10**	**Score**
B1. Average depth of excavation and removal	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
B2. Average depth of infill	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	

Rationale for Table 7.15

A. Areas directly affected by anthropogenic deposition

A1. Average depth of recent sediment deposits

Sediment deposited from fluvial processes results in an elevation of the valley floor relative to reference conditions but is regarded as less of an impact than fill that has been mechanically deposited. This is due to the fact that depositional features typically include the same types of sediment as would naturally be present in the wetland and such features rarely completely destroys wetland features although it can certainly result in notable structural modifications. Based on this rationale, intensity scores for depositional features are scaled from 0-5 rather than 0-10 in the case of mechanical infilling.

A2. Geomorphic adjustment factor

The Geomorphological adjustment factor, which is taken from **Table 8.20** ranges between 1 (if deposition is related strongly to anthropogenic causes) and 0 (if the changes cannot be related to any anthropogenic causes and are therefore assumed to be part of the natural geomorphological dynamics of the wetland, and as such any hydrological influence of this "natural" deposit is also seen as a natural feature of the wetland).

B. Areas directly affected by infilling/excavation

B1. Average depth of excavation and removal

Depending on the nature of activities associated with sediment excavation and removal, such activities may significantly alter water distribution and retention processes in the wetland. This typically includes increasing the extent of open water and levels of saturation. For the purposes of this assessment, depth is used as a course surrogate for estimating the impacts of infilling / excavation in targeted areas.

B2. Average depth of infill

In areas directly affected by deep infilling, wetland conditions are potentially lost completely, and these areas therefore receive a maximum intensity rating. Where infilling is relatively shallow the affected area may still be inundated during high flow periods or may come into contact with a high water table. Similarly, where excavation is shallow, the degree of inundation/soil saturation is likely to be less affected than where it is deep.

It is important to note that the depths given in **Table 7.15** for the intensity classes are intended as examples rather than as prescriptive thresholds. The assessor should also consider the natural water depths, with floodplain wetlands that are regularly inundated by deep flooding being inherently less vulnerable to infilling impacts than small unchannelled valley bottom wetlands that are very seldom deeply inundated. Other factors to consider include the nature of the fill material (the more that this differs in texture from the original sediment, the greater the potential impact) and direct evidence of wetland persistence under infilled conditions (e.g. evidence that hydric species have established on the fill material would indicate that the intensity of impact is less than critical). In the case of excavation, one of the most vulnerable situations is where a low permeability soil layer lies on top of much more permeable layer/s, resulting in a "perched" zone-of-saturation, which would be lost if the upper soil layer was removed. Without the impermeable layer to hold the water in the rooting zone of the wetland, wetland hydrological conditions may potentially be lost entirely.

2. Areas <u>indirectly</u> affected by anthropogenic deposition, infilling / excavation

In addition to the direct impacts dealt with above, anthropogenic deposition, infilling and excavation my indirectly impact upon wetland areas located upstream, downstream and/or to the side of the feature by affecting flows into and out of these areas. **Table 7.16** provides the means of assessing the indirect impacts of the feature, including: (A) impeding (impounding) flows within a wetland area upstream of the feature; and (B) deflecting (intercepting) and reducing flows to wetland areas located laterally or downstream of the feature.

Table 7.16. Assessing <u>indirect</u> impacts on water-distribution and -retention patterns within a wetland as a result of anthropogenic deposition, infilling or excavation (including dams)

A. Activities impeding (impounding) flows						
Roads and berms that extend laterally across the wetland (Upstream effects)						
Indicator	**1**	**3**	**4**	**5**		**Score**
A1. Degree to which flows are impounded	Limited (e.g. many culverts at ground level facilitating throughflow)	Moderate (e.g. under-sized culvert or few culverts at ground level with some disruption to flow)	Large (e.g. culverts very widely spaced or located above ground level causing localised impoundment)	High (e.g. culverts blocked / lacking and causing considerable impoundment)		
Dams that extend laterally across the wetland (Upstream effects)						
Indicator	**0**	**5**	**6**	**7**	**8**	**Score**
A2. Representation of different hydrological zones prior to flooding by the dam	-	Dominated by permanently saturated soils	Dominated by seasonally saturated soils	Mix of seasonal and temporarily saturated soils	Dominated by temporarily saturated soils	
B. Activities deflecting (intercepting) and reducing flows						
Berms and road embankments (Downstream effects)						
Indicator	**-1**	**-3**	**-5**	**-8**	**-10**	**Score**
B1. Degree to which flows are intercepted and deflected away from the disturbance unit	Limited	Moderate	Largely	Seriously	Complete	
Further guidance – *Low flows deflected?*	*Yes*		*Yes*		*Yes*	
Further guidance – *Annual floods deflected?*	*No*		*Yes*		*Yes*	
Further guidance – *Large floods deflected?*	*No*		*No*		*Yes*	
Indicator	**0.3**		**0.7**		**0.9**	**Adjustment Factor**
B2. Importance of water inputs from the upstream catchment relative to lateral inputs (see Table 7.4)	Low		High		Very High	
Intensity score: B1 x B2						

Dams that extend laterally across the wetland (Downstream effects)						
Indicator	**-0**	**-2**	**-4**	**-6**	**-8**	**Score**
B3. Degree to which dam/weir interrupts low flows to downstream or lateral areas	Increased low flows (e.g. earthen dam with considerable seepage below dam)	Slight interruption (e.g. earth dam with moderate seepage /low flow releases)	Intermediate interruption (e.g. earth dam with limited seepage / low flow releases)	Moderately high interruption (e.g. earth dam with very limited seepage/ ;low flow releases)	High interruption (e.g. a concrete dam with no seepage and no low flow releases)	
B4. Level of abstraction from the dam/s	Low	Moderately low	Intermediate	Moderately high	High	
B5. Interception by the dam of the streams entering the downstream wetland area		~25% of the stream network is intercepted	~50% of the stream network is intercepted	~75% of the stream network is intercepted	Most stream input is intercepted before entering the wetland	
B6. Collective volume of dam/s in relation to MAR	<20%	20-35%	36-60%	60-120%	>120%	
Indicator	**0.3**	**0.7**	**0.9**	**Adjustment Factor**		
B7. Importance of water inputs from the catchment relative to lateral inputs (see Table 7.4)	Low	High	Very High			
Intensity score: Mean score of the THREE highest scoring factors (B3 to B6) x B7						

Rationale for Table 7.16

A. Activities impeding (impounding) flows

Roads and berms that extend laterally across the wetland (Upstream effects)

A1. Degree to which flows are impounded

The impact of roads and berms depends on their ability to disrupt and impede flows, thereby increasing inundation and saturation upstream of the feature. The impounding effect of roads is generally less than for dams (A2), which are specifically designed for impoundment, and therefore score lower in terms of intensity of impact. Nonetheless, roads and berms may vary greatly in terms of the degree to which they impede flows. In the case of roads, culvert design is an important consideration and can be used as an indirect indicator to inform this assessment. The assessment should also be informed by direct evidence of increased inundation upstream of the road however (e.g. based on changes in plant composition and sediment accumulation).

A2. Representation of different hydrological zones prior to flooding by the dam

The impact that the flooded area behind a dam has on water distribution and retention patterns is related to the original wetness patterns in the flooded area. The alteration caused by flooding is therefore larger for previously infrequently flooded (e.g. temporary wetlands) areas than for permanently flooded wetlands. Where a dam has been present for many years, the original hydrological conditions would be challenging to determine, and will need to be inferred from a minimally impacted wetland which is comparable in terms of hydrogeomorphic type, hydrogeological type setting and climatic conditions.

B. Activities reducing water distribution and retention patterns

Berms and road embankments (Downstream effects)

B1. Degree to which flows are intercepted and deflected away from the disturbance unit

The degree to which infilling intercepts and deflects flows away from the disturbance unit is considered in terms of: (1) low flows, (2) annual floods and (3) large floods (which are taken as a flood exceeding a 1 in 10 year return interval). In the case of most roads and berms, low flows are intercepted, causing some (limited to moderate) change in saturation in affected areas. The impact is regarded as considerably higher however if floods are also deflected away from the disturbance unit.

B2. Importance of water inputs from the upstream catchment relative to lateral inputs

See rationale given in **Table 7.4**.

Dams that extend laterally across the wetland (Downstream effects)

B3. Degree to which dam/weir interrupts low flows to downstream or lateral areas

Dam/weirs have the potential to cause severe interruption of low flows to downstream or lateral areas of a wetland by (1) reducing the quantity of flow to this portion; and (2) through altering flow patterns to this portion. This impact may be mitigated by seepage, which is common below earthen dams or operating rules / designs that allow low-flows to be released.

B4. Level of abstraction from the dam/s

See the rationale concerning the downstream effects of dams given in **Table 7.6**.

B5. Interception by the dam of the streams entering the downstream wetland area

As indicated in the rationale for **Table 7.6**, the impact of dams will be most severe where dams are located directly upstream of the disturbance unit on the main trunk stream and intercept all water inputs. This would apply to many of the downstream wetland areas affected by a dam in the wetland. However, in some cases a major tributary may enter below the dam, thereby resulting in a lower level of interception as one progresses downstream of the dam.

B6. Collective volume of dam/s in relation to MAR

See the rationale concerning the downstream effects of dams given in **Table 7.6**.

B7. Importance of water inputs from the upstream catchment relative to lateral inputs

See rationale given in **Table 7.4**.

Hydro Step 2D: Assess the magnitude of impact of altered surface roughness

The important role played by surface roughness (as expressed in terms of Manning's Roughness Coefficient) in reducing the velocity of water movement and therefore in increasing the residence time of water in wetlands has been well-demonstrated (Ward and Trimble, 2004). The greater the surface roughness of a wetland, the greater is the frictional resistance to the flow of water and the more effective is the reduction of flow velocity through the wetland (Reppert *et al*., 1979; Adamus *et al*., 1987). The reduced flow-velocity, in turn, increases the retention of water in the wetland and potentially influences the distribution of water through the wetland.

The surface roughness of a wetland is usually determined primarily by vegetation, but hummocks can also significantly contribute to roughness. Hummocks are small earth mounds covered in vegetation. They are usually about 20-50 cm in diameter and 50 cm high, and are commonly found in high altitude (>1500 m) wetlands in South Africa.

Be warned that in herbaceous wetlands there may be a high degree of variation in roughness between seasons due to die-back of vegetation in winter and the occurrence of fires. In applying this tool, it is important to be aware of such variability. The wet season is the most important season to describe roughness because it is during the wet season that peak flows are likely to be highest and the effect of the roughness in reducing flow velocity is potentially the most significant. Therefore, base the assessment on the situation in the wet season.

For those disturbance units in the wetland within which surface roughness appears to be anthropogenically altered, the level of alteration of surface roughness should be assessed using the following three step process.

1) ***Assess current surface roughness****:* based on observation of the wetland in its current state, and thinking particularly in terms of the resistance offered to water flow by the vegetation during the wet season, assign the disturbance unit to one of the classes in line 2 of **Table 7.17**.

2***) Estimate historical surface roughness under natural conditions****:* obtain information about what the wetland looked like in its historical, natural state before it was impacted on by human intervention, and then using the average state, assign the wetland to one of the five classes in **Table 7.17**. If historical information on the wetland is not available it will be necessary to infer what the wetland is likely to have looked like, based on observation of a reference wetland (i.e. another wetland that is in a natural state and with the same hydro-geomorphic setting and a similar climate to the wetland being assessed).

3) ***Compare current roughness with historical natural conditions:*** assess the magnitude of impact by comparing the assigned class for the current state with that for the historical (natural, or reference) state (line 4 of **Table 7.17**).

Table 7.17. Comparison of surface roughness of a wetland in its current state compared with its natural reference state

Surface roughness classes for describing the wetland in its current state and natural reference state				
Very low: Smooth surface with no vegetation to offer resistance to water flow, or if vegetation present then very short (<0.05 m) or very sparse and/or flimsy	**Low:** Vegetation offering some resistance to water flow, but generally consisting of short plants (i.e. <0.5 m tall), e.g. creeping sedges such as *Pycreus mundii*.	**Intermediate:** Generally dense, intermediate height (0.5-1.0 m) vegetation, e.g. *Imperata cylindrica* grass or *Juncus effusus*.	**High:** Robust, tall vegetation (e.g. dense stands of reeds) offering high resistance to water flow	**Very high:** Very robust, tall (e.g. swamp forest) and offering very high resistance to water flow

Descriptor	+2	0	-1	-2	-3	Score
Change in surface roughness in relation to the surface roughness of the wetland in its natural reference state	Moderate increase in roughness (i.e. by 2 classes)	Roughness unchanged or small increase (i.e. by 1 class)	Low reduction in roughness (i.e. by one class)	Moderate reduction in roughness (i.e. by two classes)	High reduction in roughness (i.e. by three classes)	

Rationale for Table 7.17

It is considered to be of greater consequence to water retention and distribution if the surface roughness of a wetland is decreased than if it is increased, therefore the focus of this assessment is primarily on a decrease in surface roughness.

Hydro Step 2E: Assess the magnitude of impact of direct water loss

Water is naturally lost directly from a wetland to the atmosphere through evapotranspiration, but anthropogenic factors may increase this loss, which in turn may result in localized drying-effects and reduced water availability in downstream areas. Common factors resulting in increased atmospheric loss are dams, alien plants, commercial afforestation, and sugarcane within the wetland boundary. Direct water abstraction from a wetland may take place from a dam, well or borehole in the wetland. The loss associated with evaporation from dams is dealt with in **Hydro Step 2C** (**Table 7.16**). Here, we consider the other landuse and cover-types.

Within the wetland, identify disturbance units with atmospheric loss affected by alien plants, commercial afforestation (separate pines, wattle and eucalyptus), sugarcane based simply on observation of these landcovers in the wetland (**Table 7.18**). However, it is important to note that the impacts may also extend downslope/downstream from where they occur in the wetland, as elaborated upon in the Rationale of **Table 7.18**. Determining which disturbance unit/s are affected by direct abstraction of water is most difficult to identify and is based on a few key factors such as means of abstraction and duration of abstraction, which are described in detail in the Rationale for **Table 7.18**.

Table 7.18. Intensity of impact on water loss of alien woody plants, commercial plantations and sugarcane growing in the wetland

A. Changes in the nature of vegetation cover						
Indicator	0	2	5	8	10	Score
A1a. Alien woody plant type			shrubs	trees		
A1b. Plantation tree type				Wattle & pine	Eucalyptus	
A1c. Sugarcane growth		Poor growth	Good growth			
Indicator	0.3		0.6		1.0	Vulnerability Factor
A2. Native vegetation (Reference state)	Woody/forest		Tall herbaceous, e.g. *Phragmites australis*		Short herbaceous	
Intensity Score: A1 x A2 x Vulnerability based on MAP:PET ratio (from **Table 7.1**)						
B. Direct abstractions from the wetland						
Indicator	0	2	5	8	10	Score
B1, Direct water abstractions[1]		Low	Moderately low	Moderately high	High	

[1]See "Rationale" below for guidance in assessing the extent and intensity of direct water abstractions from the wetland

Note: When assessing the extent of water loss, remember that the impact may extend beyond the direct area in which the alien woody plants or plantations occur in the wetland to also include a downstream portion subject to reduced flows. If this is the case, adjust the score accordingly with documented justification.

Rationale for Table 7.18

A1. Alien woody plants, tree plantations and sugarcane

It is assumed that alien woody plants use more water than native wetland plants, particularly when they have direct access to the water table within the wetland. High densities of alien woody plants can significantly reduce the amount of water within a wetland (Gush *et al*., 2002). Timber plantations are recognized as reducing stream flow. With all other factors being equal, the greater the extent of timber plantations in a wetland, the greater is the reduction in quantity of water supplied downstream of the plantation. Different tree types have different rates of water consumption, and as a general rule, eucalyptus trees reduce water yield more so than do wattle and pine trees (Gush *et al*., 2002). Sugarcane is increasingly being recognized as reducing stream flow (Cheesman, 2004) when planted within wetlands.

A2. The native vegetation

When assessing increased atmospheric water loss from a wetland area, account needs to be taken of the fact that different native vegetation types may differ greatly in terms of natural rates of atmospheric water loss. As shown by Clulow *et al*. (2012) and Grundling *et al*. (2015) transpiration rates of forest/woody plants in wetlands tend to generally be significantly higher than herbaceous vegetation. This applies especially to short herbaceous vegetation, which has less transpiring surfaces than tall vegetation. Identifying what the native vegetation is likely to have been is dealt with in **Section 6.2** and **Section 10**.

B1. Direct water abstractions

The extent of the area affected by direct abstractions from the wetland depends on the location. If it is located at the upstream end of the wetland, it will potentially affect a greater extent of the wetland and disturbance units than if it was located near the downstream end of the wetland. Similarly, several abstraction points are likely to affect a greater extent than only one abstraction point. The intensity of abstraction relates to the volume of water abstracted, which may depend on the following.

- Duration of abstraction (e.g. abstraction throughout the year will have a greater impact than abstraction for only supplementary irrigation that occurs only occasionally during the year).
- Depth of abstraction. The deeper the abstraction, the greater will be the potential lowering of the water table in the wetland, unless the wetland is maintained by a perched water table and the abstraction is from a deeper water table below.

- Means of abstraction. Abstraction by hand with buckets will potentially have the lowest intensity of impact, followed by hand- or treadle-pumps. Motorized pumps, especially larger pumps, will potentially have the highest intensity of impact.

If the approximate volume of water abstracted on an annual basis is known then this can be compared with the MAR from the wetland's catchment, calculated based on the MAR for the quaternary (obtained from the Level 1B/2 spreadsheet tool, in the "Quat Catchments" Tab) reduced proportionately by the proportion of the quaternary occupied by the wetland's catchment (see example given in the Rationale of **Table 7.3**).

Hydro Step 2F: Determine the combined impact of on-site activities

Tables 7.13 to 7.18 provide an estimate of the impact of on-site activities on natural distribution and retention patterns within each disturbance unit. Once assessed, these scores are added together to get a combined intensity score for each disturbance unit, as shown in **Table 7.19**. These scores are then combined into an on-site score for the wetland as a whole by area-weighting the scores from each disturbance unit.

Table 7.19. Assessing the cumulative impacts of on-site activities on water distribution and retention patterns in the disturbance unit

Activity	Impact Score
Hydro Step 2A. Calculated intensity of impact of altered bank overspill from (**Table 7.13**)	
Hydro Step 2B. Calculated intensity of impact of drains/gullies (**Table 7.14**)	
Hydro Step2C. Calculated intensity of impact of anthropogenic deposition, infilling and excavation (including dams) (**Table 7.15** and **Table 7.16**)	
Hydro Step 2D. Calculated intensity of impact of altered surface roughness (**Table 7.17**)	
Hydro Step 2E. Calculated intensity of impact from direct water losses (**Table 7.17**)	
Total score of intensity of on-site activities in the disturbance unit	

Rationale for Table 7.19

The total score is calculated using the same algorithm used to integrate the three components of the inflows to the wetland. This algorithm ensures that the score does not exceed 10, and ecosystem health is conceptualized as beginning with a glass 100% full (10/10) for a pristine system, which is then successively drawn down by each of the 5 successive activities, with each successive impact only drawing down what has been "left over" following the draw-down of preceding activity. Furthermore, the final amount remaining in the glass (i.e. the overall integrated magnitude of impact score) is not affected by the order in which the successive impacts are considered.

Hydro Step 3: Determine the present hydrological state of the wetland by integrating the assessments from Steps 1 and 2

This final assessment is based on the joint consideration of all the impacts on catchment inputs (assessed in **Hydro Step 2E**) and the impacts of on-site activities on water distribution and retention patterns in the wetland (assessed in **Hydro Step 2F**) as summarized in **Table 7.19** above. The impacts are integrated) using the following algorithm, which is the same algorithm explained fully in **Table 7.9**.

Combined catchment and on-site impacts = Catchment impact score + (10 – Catchment impact score) x On-site impact score/10.

For example, if the score for the catchment activities altering water inputs is 4 and the score for the on-site activities altering water distribution and retention patterns in the disturbance unit is 5, then according to the algorithm, the score for the overall magnitude-of-impact is 4 + (10-4)*5/10=7. The rationale for combining impacts in this manner is that both catchment and on-site impacts may, on their own, exert a considerable influence over a wetland's hydrological state but also add to the respective impacts of each other. Therefore, taking the maximum of the two as an overall impact score would be inappropriate.

The total-impact score derived here falls into one of six categories given in **Table 3.1 (Chapter 3)**. This is a useful opportunity to compare the total magnitude-of-impact score above with the description of impact categories provided in **Table 3.1**. Does your impression of the score for the impact of on-site activities you have calculated match the impact category and description provided in **Table 3.1**? If not, consider where the tool is underestimating or overestimating impact, and consider modifying your score. Document any justification you have for modifying your score.

For example, a factor not accounted for in the tool is the proximity of the wetland to the flow-modifying activities in the wetland's catchment. You may choose to adjust the impact score down if, for example, a given area of hardened surfaces is located well away from the wetland or adjust the score up if the hardened surface is located immediately adjacent to the wetland.

The Ecological Category for wetland hydrology is determined based on its current impact score according to the ranges given in **Table 3.2**. If, for example, the overall magnitude-of-impact score was 7 then the health category would be E. An opportunity is provided to review the overall scores and Ecological Categories (as explained in **Chapter 11**). All that remains to be done is to identify the anticipated future trajectory of change for the hydrology component (refer **to Chapter 12** for guidance on how to carry this out).

8. GEOMORPHOLOGY MODULE

8.1. Introduction

Wetland formation and persistence is ultimately controlled by hydro-geomorphic and climatic factors that ensure that sufficient water is available at or close to the ground surface for sufficiently long periods of time for anaerobic conditions to form in the rooting zone (Ellery *et al*., 2008). These shallow flooding / waterlogged conditions, characteristic of wetland systems, are in turn a product of local and/or regional scale geological factors and geomorphological processes that facilitate the accommodation, retention and/or accumulation of surplus water at or near the earth's surface. The nature and processes of sediment accumulation and erosion also affect the structural characteristics of the wetland and provide the growth medium on which wetland vegetation is established. Building an understanding of wetland geomorphology is therefore fundamentally important to our understanding of wetland origins, structural characteristics and their response to anthropogenic impacts, and is therefore regarded as a critical component in any assessment of wetland ecological health.

8.1.1. Conceptual Framework

This module builds on the sound foundations for wetland assessment that were initially developed largely by Prof Fred Ellery as part of the initial WET-Health framework (Macfarlane *et al.,* 2008). It also draws on some of the strengths of the geomorphology component developed by Mark Rowntree as part of the Wetland IHI assessment framework (DWAF, 2007).

The module seeks to unpack the key elements of wetland geomorphology in a manner which enables the consistent assessment of PES by different users. This is done by conceptualising geomorphic state in terms of changes to (i) geomorphic processes and (ii) the geomorphic structure of the wetland (**Figure 8.1**).

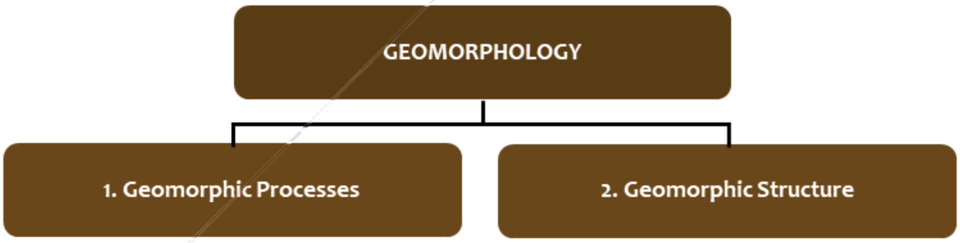

Figure 8.1. Primary components included in the assessment of wetland geomorphology

Geomorphic ***processes*** in this context, refers specifically to those ***physical processes that are currently shaping and modifying wetland form and evolution***. In the case of South Africa where most wetlands have a fluvial origin, the dominant geomorphic processes shaping and influencing wetlands are erosion and deposition. These processes can be affected either by changes in catchment characteristics that change water or sediment inputs or by impacts within the wetland itself that affect the distribution and retention of sediments in the wetland. The method also caters for wetlands characterised by in-situ organic matter accumulation.

Geomorphic ***structure*** on the other hand, refers specifically to the ***three-dimensional shape of sediment deposits on which wetland habitat is established***. Changes to the geomorphic structure are often directly observable through topographical changes in the wetlands surface morphology. Such changes may be attributed to anthropogenic activities within the wetland itself or may be triggered by catchment-related activities that have altered the processes of erosion or deposition in the wetland.

It is acknowledged that the geomorphic structure of a wetland and the processes that give rise to specific wetland features are inseparably interlinked (**Figure 8.2**). Indeed, a change in processes (either brought about by catchment changes or by changes in the wetland) will ultimately give rise to changes in the structure of the wetland (e.g. a reduction of sediment inputs in response to interception by a large upstream dam may result in channel incision & loss of sediment from the wetland). Equally, a change in structure will typically affect process (e.g. a berm constructed alongside a stream channel will reduce lateral connectivity and associated sediment deposition on the distal side of the berm). As such, anthropogenic activities that affect either geomorphic processes or the structure of the wetland are relevant to an assessment of geomorphic health and have been included in this module.

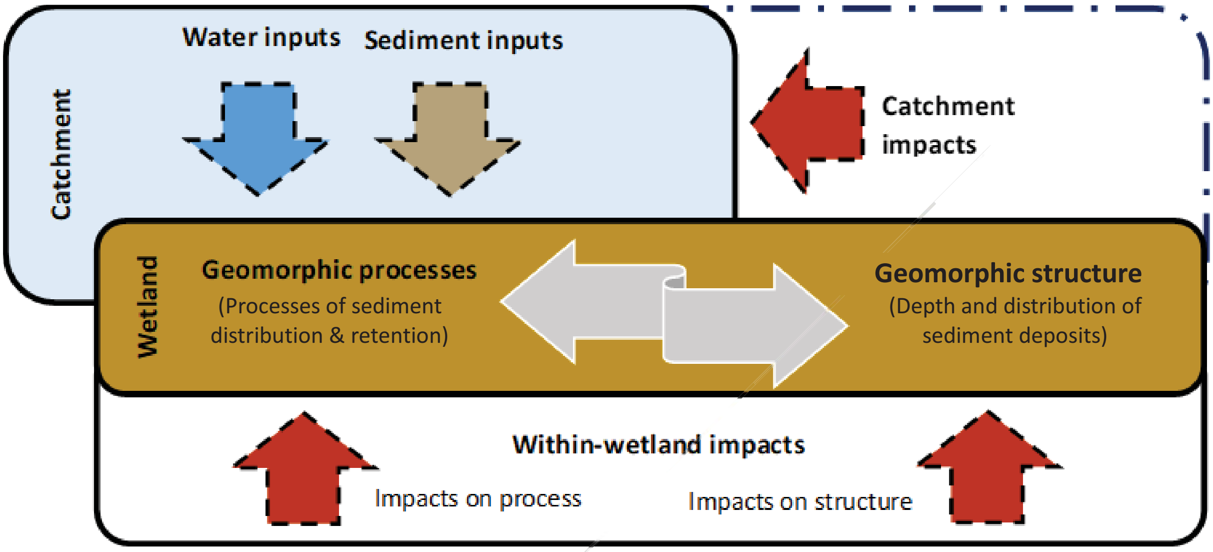

Figure 8.2. Conceptual framework for the geomorphology assessment

This module focusses specifically on assessing a range of anthropogenic activities that can impact on the various inter-related aspects of geomorphic integrity (**Table 8.1**). Whilst catchment drivers feed into the assessment indirectly, the assessment of impacts is ultimately based on an understanding of the degree to which within-wetland geomorphic processes and the associated structure of the wetland have been altered by a suite of anthropogenic activities. A range of measurable direct and indirect indicators are then used in the assessment to assess the impacts of anthropogenic impacts on different factors affecting geomorphic integrity. Whilst developed in line with best-available-science, we acknowledge that there is often little scientific basis for the scoring systems applied which have therefore been based on best professional judgement.

Table 8.1. Overview of key components included in the geomorphology module

Component	Aspects of integrity	Focus of the assessment
Geomorphic processes	Sediment budget linked to the upstream catchment.	Changes in catchment activities affect wetlands indirectly through their influence over discharge and sediment supply. In the case of wetlands dominated by clastic sedimentation processes, emphasis is placed here on assessing changes in catchment landuse and impacts of upstream dams and diversions on the sediment inputs.
	Processes affecting sediment distribution and retention patterns within the wetland.	The ability of a wetland to trap and retain clastic sediment or accumulate organic sediment is affected both by catchment impacts and structural changes to the wetland that affect rates of sediment accumulation. In the case of wetlands driven by clastic sediment accumulation, the emphasis is on assessing changes in distribution and retention patterns of sediment across the wetland. In wetlands characterised by organic sediment accumulation, emphasis is placed on assessing changes in wetland hydrology as hydrodynamics are critical to the process of organic accumulation.
Geomorphic structure	Morphological and sedimentary characteristics of the wetland.	Assessing the degree to which the morphological and sedimentary characteristics of the wetland have been altered by anthropogenic activities. Practically, this involves an assessment of changes to the nature and depth of sedimentary deposits. The assessment relies primarily on direct measures of sediment loss or deposition but draws on indirect indicators where necessary to support interpretations.

8.1.2. Recognizing natural variability in wetland characteristics

Wetlands systems are dynamic in nature and as such, are in a state of gradual transition in response to prevailing climatic conditions. Indeed, it has been proposed that long term climate change may contribute to alternating episodes of cutting and filling in valleys that dramatically affects the geomorphic structure of wetland systems (e.g. Bookhagen *et al*., 2006; Temme *et al*., 2008; Becker *et al*., 2016). Wetlands may vary considerably however in their geomorphic response in catchments with similar hydroclimates, physiography, lithology, vegetation assemblages and human impacts (Tooth, 2018). A key factor in determining the natural variability of the wetland is its proximity to geomorphic thresholds that affects the wetlands vulnerability to erosional processes. For wetlands operating close to the threshold, even minor changes to drivers (e.g. discharge & sediment inputs) may lead to crossing of that threshold and to significant changes in geomorphic structure and functioning (Tooth, 2018). This is relevant to channel-floodplain dynamics with some wetlands undergoing natural avulsions (rapid abandonment of a river channel and the formation of a new river channel) at regular intervals whilst changes in other wetlands are far more infrequent. Research undertaken by Ellery *et al*. (2016) also outlined how low order unchannelled valley bottom wetlands can be classified into stable (unincised) and incised (gullied/channelled) types based on longitudinal gradient and wetland area. This points to fuzzy thresholds (defined as a zone of vulnerability) which make certain wetlands more vulnerable to geomorphic changes than others.

When undertaking a geomorphological assessment of a wetland, it is therefore important to recognise that wetlands are in a process of constant flux as sediment is moved through the system. An overview of the geomorphic dynamics typical of different wetlands hydrogeomorphic (HGM) types has therefore been included in **Appendix B**. This is intended as an aid to assessing geomorphic integrity by assisting in describing the natural reference state(s) of a wetland, and informing decisions around whether to attribute observed deposition/erosion to natural or anthropogenic causes. Appreciating a wetlands natural vulnerability to change and integrating indicators to help diagnose natural and anthropogenic enhanced erosional processes is therefore important in the assessment of geomorphic state and has been specifically considered as part of this assessment.

8.1.3. *The "Time-window" for the geomorphology assessment*

Whilst it is important to recognise the role of geomorphic processes in wetland formation and the variability that may occur within a particular setting over time (**Appendix C**), it is important, for assessment purposes, to distinguish between these historical geomorphic processes, and current-day geomorphic processes that can be affected by anthropogenic impacts.

The geomorphic "reference state" of the wetland being assessed is therefore taken as that prior to European settlement. It needs to be emphasised, however, that this refers principally to geomorphological drivers, rather than the way the wetland appeared prior to European settlement as structural features may change in response to natural dynamics. This assessment therefore focusses specifically on evaluating impacts to geomorphic health that have taken place within the recent past. It can be taken practically as impacts that can be linked with human activities within the past 60 to 100 years. Changes must also be assessed with due consideration of the natural variability and drivers of change rather than simply focussing on structural changes. Thus, before proceeding with the stepwise assessment procedure described below, read through **Appendix C**, which attempts to describe the natural range of geomorphic variability typically associated with different HGM types. Focus particularly on the HGM type of the wetland area being assessed.

8.1.4. *Overview of the steps to be followed in the geomorphology assessment process*

To simplify the evaluation of the geomorphic health of a wetland, separate assessments are undertaken to assess changes to geomorphic processes and geomorphic structure and are then integrated into an overall health score. An overview of the steps involved in the geomorphology assessment process are outlined in **Figure 8.3** below whilst a schematic indicating how the different components of the method fit together is included in **Figure 8.4**.

Precursory steps:

- Mapping of wetlands and inflowing/out-flowing streams
- Classification of wetlands by HGM type
- Delineation of catchments and buffer areas ("external areas of influence")
- Calculate the extent of landcover classes in the wetlands and external areas of influence
- Delineation of disturbance units
- Determine the longitudinal slope of the HGM units
- Determine the dominant form of sediment accumulation in the wetlands

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Step 1A: Wetlands dominated by clastic sediment deposition

- Step 1A-1: Assess the degree to which sediment inputs from the wetland's topographical catchment have been altered
    - *Step 1A-1a. Accounting for changes in sediment inputs from the upstream catchment*
    - *Step 1A-1b. Accounting for changes in sediment inputs from diffuse lateral inputs*
    - *Step 1A-1c. Assessing the overall change in sediment inputs*
- Step 1A-2: Assess changes to wetland sediment distribution and retention processes as a result of within-wetland impacts
    - *Step 1A-2a. Assess the impact of stream channel modification (and altered flood peaks) on lateral connectivity and associated sediment distribution and retention processes*
    - *Step 1A-2b. Assess the impact of drains and erosion gullies on sediment distribution and retention processes*
    - *Step 1A-2c. Assess the impact of infilling and excavation (including dams) on sediment distribution and retention processes*
    - *Step 1A-2d. Assess the impact of changes in the surface roughness of wetland vegetation on sediment distribution and retention processes*
    - *Step 1A-2e. Integrate scores to obtain an overall indication of changes to the ability of the wetland to trap sediment*
- Step 1A-3. Assess overall changes to clastic sedimentation processes

↓

Step 1B: Wetlands dominated by organic sediment accumulation

- Step 1B-1: Assess changes in hydrological conditions
- Step 1B-2: Assess landuses affecting organic matter accumulation
- Step 1B-3: Assess the overall change to organic sedimentation processes

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Step 2 Identify and assess impacts to geomorphic structure

- Step 2A. Excavation & removal of sediment
- Step 2B. Erosional features
- Step 2C. Stream channel modification
- Step 2D. Sediment loss associated with peat fires
- Step 2E. Wetland infilling and excavation
- Step 2F. Depositional features
- Step 2G. Dams and impoundments
- Step 2H. Assess overall changes to geomorphic structure of the wetland

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Step 3: Derivation of a PES Score and Ecological Category for Geomorphology

- Step 3A: Combining scores for geomorphic processes and geomorphic structure to derive an Integrated Geomorphology Impact Score for each disturbance unit
- Step 3B: Derivation of a Geomorphology Impact Score, PES Score and Ecological Category
- Step 3C: Reviewing PES scores and assessing trajectory of change

Figure 8.3. An outline of the steps involved in the geomorphology module

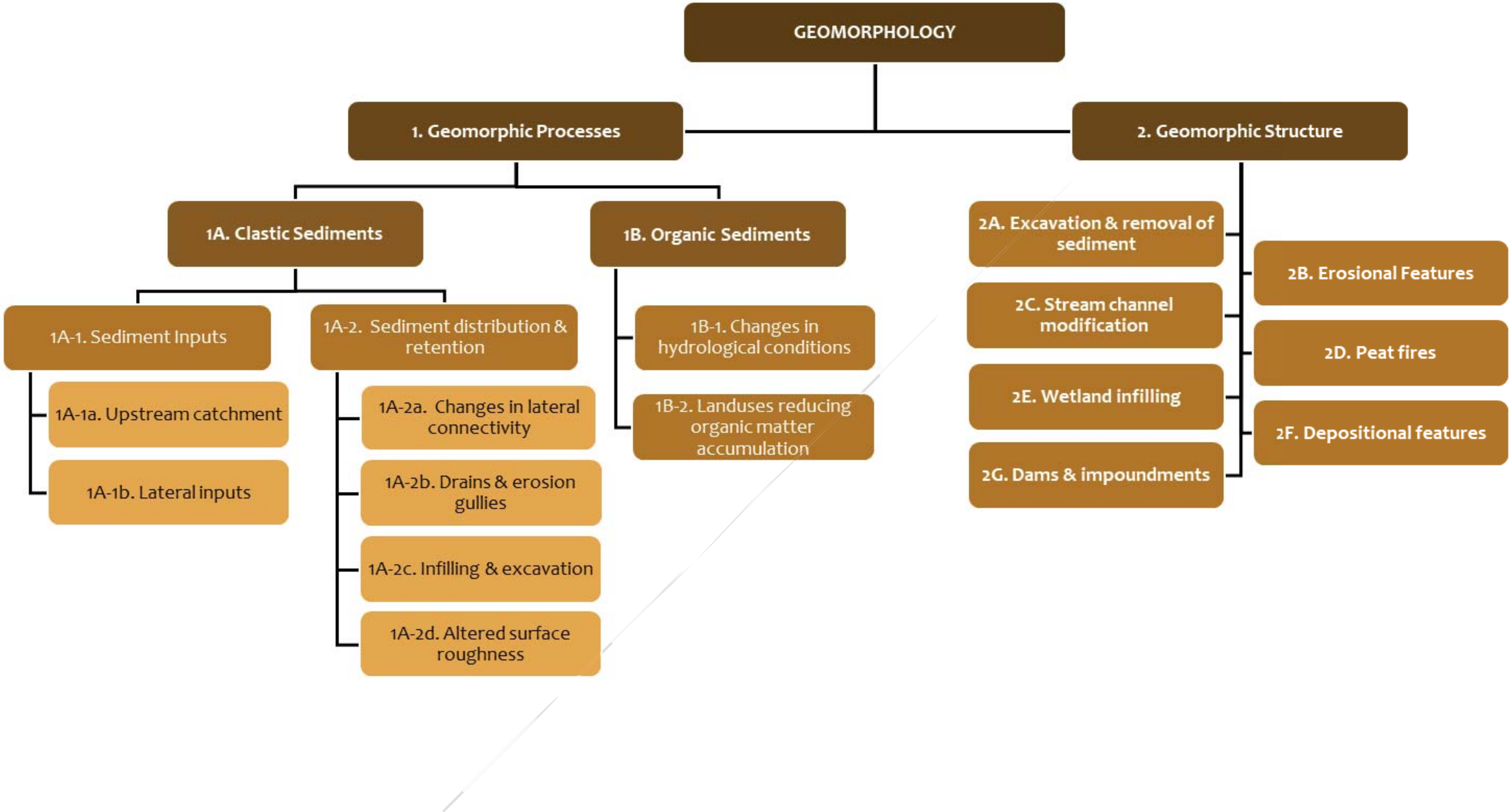

Figure 8.4. Schematic illustrating the overall structure of the geomorphology module

8.2. The Geomorphology Assessment Process

Geo Step 1: Identify and assess changes to geomorphic processes

The focus of this component of the assessment is specifically on evaluating the degree to which the wetland's natural processes of sediment deposition and erosion have been altered by anthropogenic activities in the wetland and upstream catchment. Processes of sediment accumulation differ considerably for wetlands dominated by clastic and organic depositional processes. As such, separate frameworks have been developed for assessing impacts to wetlands, dominated by clastic alluvial/colluvial sediment processes (Geo Step 1A) and organic accumulation[14] (Geo Step 1B).

Geo Step 1A Wetlands dominated by clastic sediment deposition

For wetlands characterised by clastic deposition, natural rates of sedimentation are determined based on the nature and volumes of sediment entering the wetland from the upstream catchment and the natural characteristics of the wetland that influence the distribution and retention of water that transports sediment across the surface of the wetland. An increase in sediment inputs (that increases the natural ratio of sediment discharge to water discharge (Qs/Q)) will typically promote increased deposition in the wetland whereas a reduction in sediment inputs (that decreases the natural Qs/Q) would slow the rates of sediment accumulation and could even stimulate erosion under some circumstances. In terms of this assessment, both changes are regarded as undesirable as they reflect a deviation from natural reference conditions.

Within the wetland itself, rates of sedimentation within different parts of the wetland are determined both by changes in sediment inputs and by impacts that affect the process of sediment distribution and retention in the wetland. Depending on the nature of these changes, on-site impacts may offset catchment impacts to the point that sediment accumulation rates decline, remain unchanged or increase relative to reference conditions. This assessment therefore sets out to broadly quantify changes to the natural rates of clastic sedimentation in the wetland by assessing the degree to which (1) catchment activities have affected sediment supply and (2) structural changes in the wetland have affected the natural processes of sediment deposition in the wetland (**Figure 8.5**).

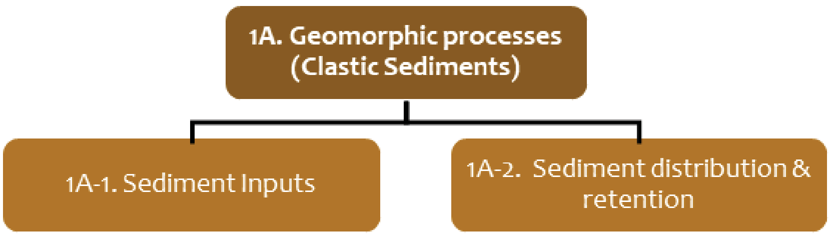

Figure 8.5. Secondary components included in the assessment of changes to the processes of clastic sediment deposition in the wetland

An initial assessment is undertaken to establish the degree to which sediment inputs have been affected based on catchment impacts (Step1A-1). An assessment of factors that affect the processes of sediment distribution and retention in the wetland is then undertaken (Step1A-2). The overall change to depositional processes is then assessed by integrating the scores for sediment inputs and within-wetland impacts that affect sediment exchange (Step1A-3).

[14] Whilst it is understood that chemical sedimentation (sedimentary deposition that forms when chemicals dissolved in water precipitates from the water) may be an important process in some wetlands (e.g. some pans), this process typically takes place over millennia and has not been included in this assessment.

Geo Step 1A-1: Assess the degree to which sediment inputs from the wetland's topographical catchment have been altered

Understanding changes to the sediment supply to the wetland is important as this has a direct bearing on the rates of sediment deposition and accumulation in the wetland. If sediment supply declines, this can result in lower rates of sediment deposition and / or increased erosion whereas an increase in sediment supply can promote increased rates of sediment deposition in the wetland. This assessment is therefore used to obtain a coarse estimate of changes to the sediment supply reaching the wetland by specifically identifying and assessing the impacts of landuses and upstream activities that can either increase or decrease sediment inputs into the wetland.

As for the hydrology module, where water inputs were assessed by jointly considering impacts from the upstream catchment and lateral inputs from the local upstream catchment, here we consider the relative amount of sediments arising from these different sources (**Figure 8.6**).

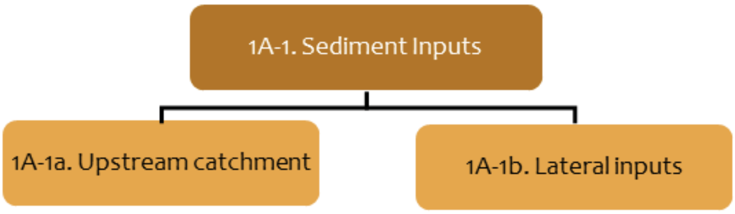

Figure 8.6. Sub-components used to evaluate changes in sediment inputs from the wetland's topographical catchment

For the purposes of level 1B and 2 assessments, the extent to which sediment inputs have been modified is determined largely based on the pre-assigned intensity scores for the respective landcovers (see **Section 5.2**) and their relative extents. For example, "tree plantations" have been assigned a score of +5 whilst "planted pastures (irrigated)" score a +2 based on the expected increases in sediment inputs from these landcover classes. Preliminary impact scores are then calculated for each area of influence based on the extent and associated intensity scores for each landcover type present. Thus if the area of influence in the upstream catchment comprised 60% timber plantations then the initial sediment impact score is estimated as (5 X 60/100) = 3.0.

<u>Geo Step 1A-1a. Accounting for changes in sediment inputs from the upstream catchment</u>

This assessment is structured to specifically assess anthropogenic activities which (A) increase or (B) decrease sediment inputs into the wetland. The results of these assessments are then integrated into an overall impact score that reflects the overall change in sediment inputs (C).

1. Estimating increases in sediment load from the upstream catchment

Increases in sediment inputs from the upstream catchment are associated with activities that alter flow patterns and / or increase the susceptibility of soils to erosion, thereby increasing the amount of sediment delivered to the wetland. Increases in sediment inputs are assessed primarily based on an understanding of changes in landcover in the catchment but are supplemented with catchment-related questions that seek to refine the assessment.

1.1. Accounting for landcover and catchment characteristics

For assessment purposes, the upstream catchment is further sub-divided into two areas of influence, (i) inflowing stream buffers and (ii) the remaining upslope catchment (**Section 4.3**). An assessment of sediment impacts emanating from each of these areas is undertaken separately and is then integrated into a final impact score for the upstream catchment. This assessment is based largely on desktop landcover mapping but is refined using a range of secondary indicators associated with each area of influence. Catchment slope & runoff potential of the soils are considered across all areas of influence. In the case of inflowing stream buffers an additional indicator is used to adjust the risk score down by accounting for the sediment trapping capacity of largely untransformed, vegetated land within this zone.

1.1.1 Increased sediment inputs emanating from landuses within inflowing stream buffers (200 m)

A preliminary sediment impact score reflecting the anticipated increase in sediment inputs with inflowing stream buffers is calculated based on available landcover mapping but specifically excluding the impact of eroded areas and dams since these are dealt with in detail later in the assessment. This score is then refined by accounting for the ability of inflowing stream buffers to trap sediment associated with diffuse runoff (**Table 8.2**).

Table 8.2. Estimating increases in sediment inputs associated with inflowing stream buffers

A. Preliminary sediment impact score from landcover mapping						
Accounting for catchment attributes that affect the risk of sediment runoff						
Adjustment Factor	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**Score**
B1. Average slope of the catchment		Gentle gradient (<=10%); Low relief	Moderate gradient (>10-20%); Moderate relief	Steep gradient (>20%); High relief		
B2. Inherent runoff potential of soils in the catchment		Low runoff potential (SCS-SA Categories A & A/B) High infiltration and permeability rates (deep, well-drained sands and gravels)	Moderate runoff potential (SCS-SA Categories B, B/C & C) Moderate infiltration rates, with permeability somewhat restricted (moderately fine soil textures)	High runoff potential (SCS-SA Categories C/D & D) Slow infiltration rates with permeability significantly restricted by layers that impede downward movement of water (clay-dominated soils)		
B3. Proportion of inflowing stream buffers occupied by largely untransformed, vegetated land	>80%	61-80%	41-60%	21-40%	<=20%	
B. Sediment Transport Capacity Modifier: [(B1 + B2)/2 + B3]/2						
C. Modified magnitude-of-impact score: A x B						

Rationale for Table 8.2

Indicators have been included so as to adjust the preliminary landcover score (A) to account for topographical (B1) and soil characteristics (B2) known to affect runoff and associated sediment transport potential. The potential of largely untransformed vegetated land to trap sediment (B3) and so reduce sediment inputs is well known and has also been used to refine the assessment. Further detail on the criteria and associated scoring is provided for **Table 9.6** in the Water Quality Module where adjustments to diffuse source pollutants are accounted for in the same manner.

1.1.2. Increased sediment inputs emanating from landuses within the remaining upslope catchment

The risk of increased sediment inputs emanating from the remaining upslope catchment (beyond the 200 m streamside buffer) is also evaluated by using the same approach taken for stream buffers but excluding the adjustment factor to account for the sediment trapping potential of untransformed land (**Table 8.3**). Ideally, one should specifically consider all lateral inputs by considering landcover types occurring alongside the wetland and up to the edge of the topographically defined catchment. For ease of assessment, an indication of changes to lateral water inputs is based on landcover types within 200 m of the wetland, which is the requirement for the water quality module.

Table 8.3. Estimating increases in sediment inputs associated with the remaining upslope catchment

A. Preliminary sediment impact score from landcover mapping						
Adjustment Factor	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**Score**
B1. Average slope of the catchment		Gentle gradient (<=10%); Low relief	Moderate gradient (>10-20%); Moderate relief	Steep gradient (>20%); High relief		
B2. Inherent runoff potential of soils in the catchment		Low runoff potential (SCS-SA Categories A & A/B) High infiltration and permeability rates (deep, well-drained sands and gravels)	Moderate runoff potential (SCS-SA Categories B, B/C & C) Moderate infiltration rates, with permeability somewhat restricted (moderately fine soil textures)	High runoff potential (SCS-SA Categories C/D & D) Slow infiltration rates with permeability significantly restricted by layers that impede downward movement of water (clay-dominated soils)		
B. Sediment Transport Capacity Modifier: (B1 + B2)/2						
C. Modified magnitude-of-impact score: A x B						

Rationale for Table 8.3

As in the case of inflowing stream buffers, the preliminary landcover impact score (A) is adjusted to account for topographical (B1) and soil characteristics (B2) known to affect runoff and associated sediment transport potential.

1.1.3. Calculating a combined score for landcover-related impacts in the upstream catchment

A score for landcover-related impacts associated with the upstream catchment is calculated by weighting the separate scores calculated for the inflowing stream buffers and upslope catchment (**Table 8.4**). In the case of floodplains, channelled and unchannelled valley bottoms, the score for stream buffers is weighted as 75% (A1) whereas the score for the remaining upslope catchment is only weighted as 25% (B1). This reflects the increased sediment risks associated with landuse activities closer to streams than those further way. In the case of other HGM types (namely seeps, depressions and flats) which may or may not have influent streams, weightings are calculated based on the proportional area of the upstream catchment represented by each area of influence.

Table 8.4. Desktop estimates of increases in sediment inputs based on catchment landcover

Aspects considered	Weight (%)	Score
1.1.1 Inflowing stream buffers score (Table 8.2)	A1	A
1.1.2. Remaining upslope catchment score (Table 8.3)	B1	B
Adjusted impact score: A x A1 + B x B1		

1.2. Accounting for other sediment-generating features in the catchment

The preliminary assessment outlined above, does not cater for a number of factors which can have a disproportionately high impact on sediment yields. A range of additional indicators are therefore assessed at a Level 2, based on a more focussed evaluation of the wetland's upstream catchment (**Table 8.5**).

Table 8.5. Refining desktop estimates of increases in sediment inputs based on additional indicators

Indicator	0	2	5	8	10	Score
A1. Presence, size and distribution of gullies or active erosion within the catchment (including stream channels[15])	None or very small	Limited extent and size (e.g. 2-5% catchment affected)	Moderate size and distribution (e.g. 5-10% catchment affected)	Large size or widespread distribution (e.g. >10% catchment affected)	Very large size or widespread distribution (e.g. >15% catchment affected)	
A2. Presence / extent of tracks and dirt roads in the catchment	None/ few	Moderate	Many/ extensive			
A3. Breaching of upstream dams in the catchment or wetland causing an increase in sediment supply	None	Yes – minor breaching	Yes – major breaching			
Combined Score: Max of the above scores						

[15] Note that in some instances, scouring of stream channels (e.g. as a result of elevated flows) may provide large volumes of sediment to the wetland being assessed. In contexts where elevated flows are known to exist, an inspection of historic aerial photography can help to inform this assessment.

Rationale for Table 8.5

<u>A1. Presence, size and distribution of gullies or active erosion within the catchment (including stream channels)</u>

This indicator is assessed by reviewing available imagery for the catchment, with a specific focus on assessing the degree to which active erosion (gully and sheet erosion) is evident in the catchment. A score is then allocated by considering the extent of areas impacted and expected increases in sediment inputs into the wetland).

<u>A2. Presence / extent of tracks and dirt roads in the catchment</u>

Dirt roads and animal tracks serve to effectively increase the connectivity of the drainage network and can lead to increased sediment inputs. This indicator is scored only where there is a moderate density of tracks and dirt roads (e.g. typical of forestry plantations in hilly terrain) or where an extensive network of tracks and dirt roads exists (e.g. informal peri-urban areas / steep and heavily overgrazed rangelands).

<u>A3. Breaching of upstream dams in the catchment or wetland causing an increase in sediment supply</u>

Slugs of sediment may also introduced into rivers directly as a result of human activities such as accidental dam breaching or deliberate dam removal. These sudden pulses of sediment have the potential to deposit large quantities of sediment in the wetland and are therefore also included in the assessment.

1.3. Estimating the overall increase in sediment inputs emanating from the upstream catchment

The overall magnitude of impact score is calculated by using the maximum score for the catchment landcover assessment and sediment generating features (**Table 8.6**). This effectively allows impact scores to be adjusted up in exceptional circumstances where secondary factors can have a disproportionately high impact on sediment yields.

Table 8.6. Refining desktop estimates of increases in sediment inputs based on additional indicators

Aspects considered	**Score**
1.1 Increased sediment inputs based on catchment landcover (Table 8.4)	A
1.2 Increased sediment inputs from sediment-generating features (Table 8.5)	B
Final magnitude-of-impact score: Max of above two scores	

2. Estimating decreases in sediment inputs from the upstream catchment

Whilst the above assessment serves to provide an indication of any *increases* in sediment input into the wetland, it is also important to account for any reductions in sediment inputs associated with (1) dams and (2) flow diversions upstream of the wetland since these impacts can significantly reduce sediment inputs.

2.1. Reduction in sediment inputs due to dams in the catchment

The *presence* of dams in the catchment disrupt the longitudinal continuity of the river system and interrupt the action of “the conveyor belt” of sediment transport, thereby altering the amount of sediment reaching downstream water resources, including wetlands. Upstream of the dam, all bedload sediment is typically deposited close to the inlet whilst the degree to which suspended loads may be deposited depends largely on the size of the dam (Kondolf, 1997).

Another factor influencing the impact on sediment loads, is the *location* of upstream dams relative to the wetland. Here, dams located on minor tributary streams or on trunk streams far upstream of the wetland would have a significantly lower impact than a dam located on the trunk stream, immediately above the wetland. The key factors that influence the sediment trapping potential of dams, and have been included in this assessment, therefore include the size of the dam relative to MAR, sediment load characteristics of the river and the location of dams relative to the wetland (**Table 8.7**).

Table 8.7. Estimating the impact of dams in the wetland's catchment on sediment inputs

Indicator	0	-2	-5	-8	-10	Score
A. Interception by dams of the streams entering the wetland	No dam/s to intercept stream input entering the wetland	~25% of the stream network is intercepted	~50% of the stream network is intercepted	~75% of the stream network is intercepted	Most stream input is intercepted before entering the wetland	
	B. Collective volumes of dams in the wetland's catchment in relation to mean annual runoff (MAR)					
C. Importance of bedload relative to suspended load	Small (<20% MAR)	Modest (20-35% MAR)	Medium (36-60%)	High (60-120%)	Very High (>120%)	**Score**
Low	-1	-2	-3	-4	-5	
Moderate	-2	-4	-6	-8	-10	
High	-4	-6	-8	-10	-10	
D. Final impact score: A x (BC)/10						

Note: In the case of a Level 1B assessment, interception and the relative importance of bedload relative to suspended load is not assessed. Scores are therefore assigned by assuming moderate interception and a moderate importance of bedload relative to suspended loads.

Rationale for Table 8.7

A. Interception by dams of the streams entering the wetland

The location of dams relative to the wetland and their associated level of interception of streams entering the wetland determines the potential of dams to intercept and reduce sediment inputs The impact of dams will be most severe where dams are located directly upstream of the wetland on the main trunk stream and intercept all sediment inputs. Impacts are less significant when dams only intercept flows from a small proportion of the catchment or are located some distance upstream of the wetland.

B. Collective volumes of dams in the wetland's catchment in relation to mean annual runoff (MAR)

The collective volume of upstream dams influences the retention time of water and associated settling time for sediments. Guidance for assessing this indicator is provided in **Table 7.6** of the Hydrology module.

C. Relative importance of bedload relative to suspended load

Sediment transported in rivers and streams can be broadly classified into two types (i) suspended load and (ii) bedload. Suspended load consists of fine sediment particles (typically clay & silt) which are held aloft in the water column by turbulence and which only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a dam or lake. In contrast, bedload includes course sediments (typically sand and gravel), cobbles and boulders that is transported along the bed by rolling, sliding or bouncing along the bed. Bedload moves at velocities slower than the flow and spends most of its time on or near the stream bed.

The impact of dams on sediment inputs is affected by the nature of sediment inputs, with rivers transporting a high proportion of bedload being more susceptible than those characterised largely by suspended loads. It is therefore useful to differentiate between wetlands that are fed by rivers naturally characterised by high bedloads and those that are suspended load dominated. Whilst it is not possible to establish sediment load characteristics as part of a rapid assessment, guidance included in **Box 8.1** can be used to inform the assessment.

D. Final impact score

A final impact score for dams is calculated by jointly considering the three indicators assessed. This score is set initially by the level of interception of catchment inflows and then adjusted based on factors that can affect the level of sediment retention in the dams. The assessor is, however, encouraged to refine this score based on professional opinion and additional information that may be available (e.g. bypass structures may be constructed to allow sediment through-flow or sediment may be added downstream of the dam to mitigate impacts).

Box 8.1. Guidance for determining the importance of bedload relative to suspended load in influent streams

A set of indicators have been included in Table 1, to inform this assessment. These indicators have been ordered from most to least important but can all be used to inform the assessment as some aspects may not be possible to assess during a site visit. Consideration should be given to at least two of these criteria, although more indicators should be considered if higher confidence is required in the assessment (e.g. where large dams are located directly upstream of the wetland).

Table 1 Guideline for assessing the importance of bedload relative to suspended load

	Importance of bedload relative to suspended load		
Indicator	**Low (Suspended load dominated)**	**Moderate (Mixed Load dominated)**	**High (Bedload dominated)**
A. Sediment characteristics	• Fine materials dominate (clay & silt deposits)	• Mix of fines and course material (clay, silt & sand deposits)	• Course materials dominate (sands and gravel deposits)
B. Channel characteristics	• Lowland River; • Upland floodplain	• Transitional; • Upper foothills; • Lower foothills; • Rejuvenated foothills.	• Source Zone; • Mountain headwater stream; • Mountain stream.
C. Longitudinal river zonation	• Lowland River; • Upland floodplain.	• Transitional; • Upper foothills; • Lower foothills; • Rejuvenated foothills.	• Source Zone; • Mountain headwater stream; • Mountain stream.
D. Dominant catchment geology	• 11 to 14	• 6 to 10	• 1 to 5
E. Bed characteristics	• Fine-grained rocks: ○ Igneous rocks ○ Shale • Mudstone	• Intermediate types	• Course-grained rocks: ○ Sandstone ○ Quartzite • Unconsolidated sediments on the coastal plain

Rationale for Table 1.

A. An assessment of sediment load characteristics can be best assessed by investigating the sediment characteristics of the wetland. This can be done using an auger and visual observations of sediment characteristics present in the wetland.

B. A range of alluvial channel patterns can be used to assess sediment load characteristics. These are (i) bed-load channel patterns, (ii) mixed load channel patterns and (iii) suspended load channel patterns (Figure 1). Channels with a high bedload are typically identified through bed characteristics and the presence of obstacles (e.g. large rocks) that deflect flows in the channel itself. Suspended load channels typically lack these characteristics and are typically more sinuous than bedload driven systems in a similar landscape setting.

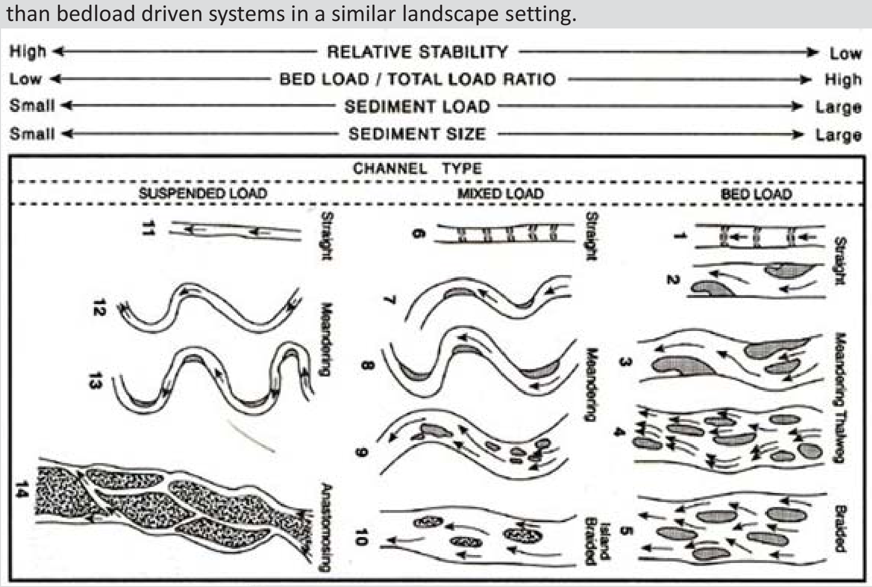

Figure 1. Typical channel characteristics in river channels characterised by different sediment loads (After Schumm, 1981)

C. The size of sediment typically transported by a river changes from gravel, cobbles, and boulders in steep upper reaches to sands and silts in low-gradient downstream reaches, reflecting diminution in size by weathering and abrasion, as well as sorting of sizes by flowing water. As such, the longitudinal zonation of a river can be used to provide an indication of the dominant sediment transport characteristics present at the assessment site.
D. The geology of the catchment can also be used to provide an indication of the nature of sediment transported in rivers and streams. In the case of igneous rocks and fine-grained shales and mudstones, weathering processes typically give rise to fine grained sediments. In contrast, courser sediments are typically present in catchments characterised by course grained sedimentary rocks and unconsolidated sediments on the coastal plain.
E. Whilst turbidity varies in response to a range of factors, high turbidity is associated with high loads of suspended sediments. Naturally turbid rivers are therefore likely to be dominated by suspended loads whereas naturally cleaner rivers are more likely to be bedload dominated.

2.2. Reduction in sediment inputs from flow diversions in the catchment

As for dams, flow diversion in the catchment may also reduce sediment inputs into a wetland by effectively deflecting sediment-laden water away from the wetland. In the urban context, this is typically associated with stormwater drains whilst in a rural context, this may be linked with irrigation canals or transfer schemes that deflect flows past the wetland. This impact is simply assessed by rating the degree to which flood waters are intercepted and diverted away from the wetland (**Table 8.8**).

Table 8.8. Estimating the impact of flow diversion upstream of the wetland on sediment inputs

Indicator	0	-2	-5	-8	-10	Score
A. Interception and deflection of floodwaters	Small reduction in flood inputs (e.g. 15% reduction in flood flows)	Moderate reduction in flood inputs (e.g. 30% reduction in flood flows)	Large reduction in flood inputs (e.g. 50% reduction in flood flows)	Serious reduction in flood inputs (e.g. 70% reduction in flood flows)	Critical reduction in flood inputs (e.g. >70% reduction in flood flows)	

2.3. Calculating the overall reduction in sediment inputs from the upstream catchment

Any reductions in sediment inputs are simply calculated by summing the intensity of impact scores from upstream dams and diversions (**Table 8.9**).

Table 8.9. Calculating the overall change in sediment inputs from the topographically defined catchment

2.1 Reduction in sediment inputs from dams (Table 8.7)	**A**
2.2 Reduction in sediment inputs from flow diversions (Table 8.8)	**B**
Overall reduction in sediment inputs: A + B	

3. Calculating the overall change in sediment supply from the upstream catchment

Once the above assessments have been completed, the user is required to provide an overall assessment of the degree to which sediment supply from the upstream catchment has been altered. Where there are no notable upstream dams or diversions, the assessment is simply based on the impact score for increased sediment supply. Where upstream interventions do reduce sediment supply, scoring is adjusted down accordingly (**Table 8.10**).

Table 8.10. Overall change in sediment inputs

	Increase in supply (Table 8.6)				
Decrease in supply (Table 8.9)	None (0)	Small (2)	Moderate (5)	High (8)	Very High (10)
None	0	2	5	8	10
Small (-2)	-2	0	-3	6	8
Moderate (-5)	-5	-3	0	3	5
High (-8)	-8	-6	-3	0	2
Very High (-10)	-10	-8	-5	-2	0
Overall Change in Sediment Supply					

Geo Step 1A-1b. Accounting for changes in sediment inputs from diffuse lateral inputs

An assessment of sediment impacts emanating from the landuse activities in the wetlands buffer is assessed initially based on the extent and intensity of scores for landcover classes present within the wetlands buffer. This score is then refined to accommodate selected attributes of the buffer and wetland that are likely to affect the ultimate impact of sediment inputs on wetland dynamics (**Table 8.11**).

Table 8.11. Refining desktop estimates of increases in sediment inputs based on additional indicators

A. Preliminary sediment impact score from landcover mapping						
Indicator	0.5	0.75	1	1.25	1.5	**Adjustment Factor**
B1. Proportion of 200 m buffer occupied by largely untransformed, vegetated land	>80%	61-80%	41-60%	21-40%	<=20%	
B2. Location of largely untransformed land in relation to the wetland	Concentrated around the wetland		Equally distributed across the 200 m buffer		Mostly located away from the wetland (distal upslope areas)	
B3. Structural characteristics of the dominant vegetation in the buffer	Dominantly robust vegetation with high interception potential (e.g. dense stands of tall or tufted grass)		Dominantly moderately robust vegetation with fair interception potential (e.g. tufted grass stands but with lowered basal cover) OR less robust vegetation with good interception potential (e.g. kikuyu pasture)	Dominantly short vegetation (<5 cm) offering little resistance to flow (e.g. maintained lawns) OR more robust but sparse vegetation providing poor interception (e.g. trees/shrubs with poorly vegetated understorey, or degraded grassland with poor basal cover)		
B. Overall score for vegetation characteristics: (B1 + B2 + B3) / 3						
Indicator	0.5	0.75	1	1.25	1.5	**Adjustment Factor**
C1. Average slope of the buffer			Gentle (<=10%)	Moderate (>10-20%)	Steep (>20%)	
C2. Soil permeability			High: High infiltration and permeability rates (deep, well-drained sands and gravels)	Moderate: Moderate infiltration rates, with permeability somewhat restricted (moderately fine soil textures)	Low: Slow infiltration rates with permeability significantly restricted by layers that impede downward movement of water (clay-dominated soils)	
C3. Concentration of flows		No concentrated flow paths observed		Few/minor concentrated flow paths to reduce interception	Some major concentrated flow paths (i.e. erosion gullies, drains) that will substantially reduce interception	
C. Overall score for other factors: (C1 + C2 + C3) / 3						
D. Sediment Trapping Capacity Modifier for wetland buffer: (B + C) / 2						
Indicator	**0.8**		**1**		**1.2**	**Modifier**
E1. Area: Perimeter Ratio (m/ha)	<500		500-1500		>1500	
E. Final magnitude-of-impact score for lateral inputs: D x E1						

Rationale for Table 8.11

A range of indicators have been included to adjust the preliminary landcover score (A) to account for vegetation characteristics in the buffer (B) and a suite of other buffer attributes known to affect sediment trapping potential (C). These criteria and scoring guidelines have been largely informed by Buffer Zone Guidelines developed for wetlands (Macfarlane & Bredin, 2017a, b). The sensitivity of a wetland to lateral sediment inputs is also taken into account by considering the perimeter-to-area ratio, which varies according to the shape of a wetland. Further detail on the criteria and associated scoring is detailed in the Water Quality module where adjustments to diffuse source pollutants are accounted for in the same manner (See **Tables 9.4 to Table 9.6**)

Geo Step 1A-1c. Assessing the overall change in sediment inputs

Once changes to sediment inputs from the upstream catchment (Step 1A-1a) and from lateral inputs (Step 1A-1b) have been assessed, an integrated score is calculated that reflects an overall change in the contribution of sediment inputs from the topographically defined catchment. This is done simply by weighting the scores for upstream and lateral inputs based on the perceived importance of sediment inputs from the catchment relative to lateral inputs for different HGM types (**Table 8.12**). This final score is then used to broadly allocate the wetland to an impact class reflecting the degree to which sediment inputs have been altered (**Table 8.13**).

Table 8.12. Calculating the overall change in sediment inputs from the topographically defined catchment

1A-1a. Impact Score for the upstream catchment (Table 8.10)					A
1A-1b. Impact Score for lateral inputs (Table 8.11)					B
Indicator	**0.2**	**0.3**	**0.7**	**0.9**	**Score**
C1. Importance of sediment inputs from the catchment relative to lateral inputs	Low: Seep, flat and depressions not fed by a channel	High: Channelled valley bottom laterally maintained & depressions fed by channel	High: Channelled valley bottom not laterally maintained & unchannelled valley bottom	Very High: Floodplains	
D. Increase in sediment inputs from the catchment: A x C1 + B x (1-C1)					

Table 8.13. Description of alteration classes for sediment supply

Combined Score	Impact Class	Description
>6	Large increase	A large increase in sediment inputs is expected relative to baseline conditions.
4 to 6	Moderate increase	A moderate increase in sediment inputs is expected relative to baseline conditions.
1.6 to 3.9	Small increase	A slight increase in sediment inputs is expected relative to baseline conditions.
-1.5 to 1.5	No effect	Anthropogenic activities in the catchment have not had any clearly evident effect on sediment inputs.
-1.6 to -3.9	Small decrease	A slight decrease in sediment inputs is expected relative to baseline conditions.
-4 to -6	Moderate decrease	A moderate decrease in sediment inputs is expected relative to baseline conditions.
<-6	Large decrease	A large decrease in sediment inputs is expected relative to baseline conditions.

Rationale for Table 8.12

C1. Accounting for the relative importance of sediment inputs from the catchment relative to lateral inputs

There is likely to be considerable variability in the relative contributions of sediment inputs from upstream and lateral sources within and between HGM types. For the purposes of this rapid assessment, weightings applied to sediment input sources have been aligned with those applied for water inputs as part of the hydrology module. The implication is that sediment inputs from the upstream catchment are weighted most heavily for floodplains, followed by unchannelled valley bottoms and channelled valley bottoms that are not laterally maintained. In the case of other types (often lacking any influent stream), sediment inputs from landuses in the immediate buffer are weighted considerably higher. Whilst there is likely to be some correlation between water inputs and sediment inputs, this does not specifically account for the importance of flood events in mobilising and depositing sediments. This is therefore recognised as a simplification and limitation to the assessment.

D. Assessing the overall change in sediment inputs

This is simply calculated based on the individual impact scores and weightings allocated to different input contributions based on HGM type, as described above.

Geo Step 1A-2: Assess changes to sediment distribution and retention processes based on impacts evident in the wetland

For sediment deposition to occur, sediments must first be conveyed from the influent stream onto the wetland floor. Thereafter, flows must be distributed across the wetland surface and sufficiently slowed down such that sediment load exceeds flow transport capacity and deposition occurs. Natural processes of clastic sediment deposition in a wetland are thereafter influenced not only by changes in sediment inputs from the upstream catchment but by factors that affect the distribution and retention of sediment in the wetland, namely the degree of channelled flow, frequency of channel overtopping, sediment barriers and impoundments, general flow capacity and flow velocity / energy, and surface roughness.

This section of the assessment therefore deals specifically with changes within the wetland itself that affects the conveyance of sediment through and across the surface of the wetland. Given that water transports sediment into and through the wetland, many of the impacts assessed here are also assessed as part of the hydrology module (see **Section 7.3**). In the case of channelled HGM types, the initial focus is on changes in lateral connectivity which may either increase or decrease the extent to which sediment is distributed across the wetland surface. An assessment is then undertaken to assess the degree to which other anthropogenic impacts are likely to enhance or reduce the processes of sediment retention relative to reference conditions in each disturbance unit. For practical purposes, on site impacts affecting the distribution and retention of sediment in the wetland have been grouped into four sub-components (**Figure 8.7**) which are assessed individually and then integrated into a composite score.

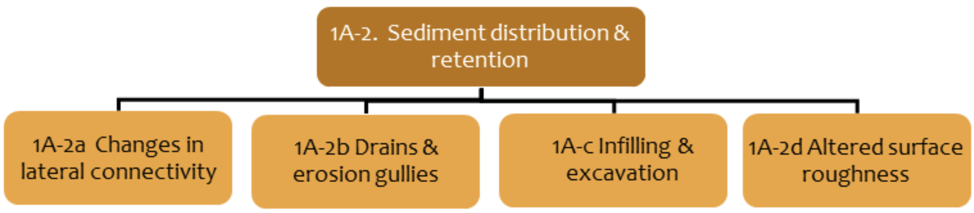

Figure 8.7. Sub-components used to assess changes to the conveyance of sediment through the wetland

It is important to note here that channels adjust and re-equilibrate to natural seasonal, annual, and decadal cycles of discharge and sediment supply and extreme events like droughts and floods. Erosion gullies are also natural features in many wetlands. Checks have therefore been integrated into the method to help differentiate between accelerated erosion as a result of human activities and natural erosional processes.

In the case of a Level 1B assessment, impacts to sediment distribution and retention patterns are defined entirely based on the extent of activities in the wetland and default intensity scores allocated to each landcover class (**Section 4.2**). These scores were assigned by considering how different landuses impact on processes of sediment distribution and retention in a wetland. In the case of a Level 2 assessment, landcover is not used as a basis for the assessment. Rather, each disturbance unit (as defined and described in **Section 6.2**) is assessed by first identifying what impacts affect the unit and then using the guidelines provided to assess the intensity of impact on sediment distribution and retention patterns. The intensity scores are then combined for each disturbance unit and used to calculate a combined intensity score reflecting an overall change in sediment accumulation processes relative to reference conditions.

Geo Step 1A-2a. Assess changes to lateral connectivity based on stream channel modification and altered flood peaks

This step applies only to HGM units through which a natural stream channel flows, namely floodplains and channelled valley bottoms. It considers how the modification of the stream channel affects the connection between the stream and the floodplain/valley floor through its effect on overbank flooding. Typically, an enlarged channel reduces overbank flooding, and therefore reduces lateral connectivity although this may be affected by additional factors such as the roughness of the channel and altered floodpeaks.

For those disturbance units considered to be affected by a change in lateral connectivity, the initial focus is on changes in channel form that affects the conveyance capacity of the channel. This is then integrated with an understanding of changes in flood peaks to obtain an indication of the degree to which the lateral connectivity between influent water and the wetland has been altered. These factors are then integrated to obtain an overall score that reflects the degree to which lateral connectivity has been altered.

1. Assess changes in stream channel characteristics

A number of factors can alter the conveyance capacity of a natural channel. For the purposes of this assessment, three indicators need to be considered including (A1) any reduction in the length of the stream (in the case of channel straightening / avulsions); (A2) changes in the cross-sectional area of the channel and (A3) changes to the roughness of the channel itself (**Table 8.14**). This assessment is then moderated based on the evidence that such changes are anthropogenic as opposed to being in response to natural channel processes (B1 to B3).

Table 8.14. Assessing changes in conveyance capacity through modifications to the stream channel

A. Assess changes in channel form relative to natural reference conditions						
Indicator	**0**	**-1**	**-2**	**-3**	**-5**	**Score**
A1. Reduction in length of stream	<5%	5-25%	26-50%	50-75%	>75%	
A2. Changes in the cross-sectional area of the channel	No change	50% increase (1.5 x area)	100% increase (2x area)	200% increase (3x area)	400% increase (5x area)	
	+2	+5				
	25% reduction	50% reduction				
Indicator	**+2**	**0**	**-1**	**-2**	**-3**	**Score**
A3. Changes in the roughness of the stream channel.	Moderate increase in roughness (i.e. by 2 classes)	Roughness unchanged or small increase (i.e. by 1 class)	Low reduction in roughness (i.e. by one class)	Moderate reduction in roughness (i.e. by two classes)	High reduction in roughness (i.e. by three classes)	
Initial Intensity Score = A1 + A2 + A3						
B. Adjusting the score to account for the direct & indirect evidence for human-induced changes						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	**Score**
B1. Risk of channel incision based on changes in catchment hydrology (Table 8.15)	Very high	High	Moderate	Low	None	
B2. Risk of channel modification in response to a change in sediment inputs (Table 8.16)		High (Large decrease / increase)	Moderate (Moderate decrease / increase)	Low (Small decrease / increase)	None (No effect)	
B3. Within wetlands factors causing changes in channel form clearly discernible	Yes – clear evidence		Possible – contributing factors		None evident	
Adjustment factor = Max of above three scores						
Scaled intensity of impact score = A x B						

Rationale for Table 8.14

A. Assessing changes in channel form that affect conveyance capacity of the channel

As noted in the Hydrology Module (**Table 7.10**), a range of factors are known to affect conveyance capacity of the channel, thereby altering the incidence of overbank flooding and associated sediment depositional processes. An overview of within-wetland factors commonly affecting channel characteristics is provided in **Box 7.1** whilst further information about channel avulsions is included in **Box 8.2**.

A1 Reduction in the length of the stream channel

See **Table 7.10** for a detailed rationale.

A2 Changes in the cross-sectional area of the channel.

See **Table 7.10** for a detailed rationale.

A3. Changes in the roughness of the stream channel.

The rationale for this indicator is included in Table 7.10 whilst guidelines for assessing the roughness of channels is provided in **Table 7.11**.

B. Adjusting the score to account for the direct & indirect evidence of human-induced changes

Erosional processes may be enhanced as a result of catchment or within-wetland activities. An assessment of key changes in the catchment that are known to accelerate erosional processes including (B1) changes in catchment hydrology and (B2) a change in sediment inputs is therefore undertaken to inform this assessment. Evidence of anthropogenic impacts in the wetland that are likely to have stimulated erosion (B3) can also be used as direct evidence of a cause-effect relationship. Once assessed, these scores are used to refine the initial intensity rating score. Where risks of channel incision are clearly very high (suggesting good justification for intensity ratings), the intensity score remains unchanged, whereas if there is little supporting evidence to suggest that channel incision is linked to anthropogenic activities, the intensity score is adjusted downwards. Note here that the method does not include adjustment factors for a reduction in the conveyance capacity of a channel, since this is rarely encountered in practice.

B1. Risk of changes in channel incision based on changes in catchment hydrology

Changes in runoff characteristics alter the ability of water to lift, transport and deposit sediment, causing channel instability. During storm events, increased impervious surfaces in a catchment generate increased volumes of runoff and increase the velocity of runoff that ultimately increases flood peaks and the frequency of flood events, which leads to channel adjustments in the form of bed and bank erosion. An increase in sediment transport capacity, linked with either an increase in flows or floodpeaks is therefore regarded as one of the most significant factors contributing to erosion and channel incision of valley bottom wetlands. These criteria have already been assessed as part of the hydrology module and are referred to here in order to provide an initial indication of erosion risk in response to catchment alterations (**Table 8.15**).

Table 8.15. Assessing the risk of accelerated erosion based on changes in catchment hydrology

		Increased floodpeaks (Table 7.6)			
		No effect (0-1.5)	Small increase (1.6.1-3.9)	Moderate increase (4.1-6)	Large increase (>6)
Increased flows (Table 7.5)	Small increase (0-1.5)	None	Low	Moderate	High
	Moderate increase (1.6-3.9)	Low	Moderate	High	Very High
	Large increase (4.1-6)	Moderate	High	Very High	Very High
	Very Large increase (>6)	High	Very High	Very High	Very High

B2. Risk of channel incision in response to a change in sediment inputs

A reduction in sediment supply (typically linked with the presence of dams in the upstream catchment) leads to a reduction in the sediment load carried by water passing through the wetland. This in turn can increase the erosive capacity of influent water, leading to accelerated erosion and associated channel incision. Equally, an increase in sediment inputs can trigger erosional processes such as avulsions, through accelerated aggradation of levees and alluvial ridges adjacent to an active channel, which increases lateral floodplain slope and makes the floodplain more susceptible to an avulsion during high flow events (See **Box 8.2**). Erosion risk is therefore also evaluated based on an assessment of any change in sediment supply (**Table 8.16**).

Table 8.16. Assessing the risk of accelerated erosion based on a change in sediment inputs

Change in sediment inputs (from Table 8.12)	No effect	Small decrease / increase	Moderate decrease / increase	Large decrease / increase
Risk rating	**None**	Low	Moderate	High

B3. Within wetlands factors causing changes in channel form

Whilst the above assessment can be used to provide an indication of the risk of channel incision linked to catchment activities, there are also a range of within-wetland impacts that can stimulate channel incision. This includes lowering of base levels, roads, dams, berms, channel straightening & within-wetland activities that increase the frequency of avulsions. The assessor is required to specifically consider whether any of these impacts have occurred, and to use this as a basis for assessing the degree to which within wetland factors are seen to be contributing towards channel incision evident in the wetland. In the case of floodplain systems, particular care needs to be taken to accurately differentiate between natural avulsion processes and avulsions that have been stimulated by anthropogenic activities (**Box 8.2**). Users are also encouraged to read **Appendix B** which outlines the geomorphic dynamics typical of different HGM types.

Box 8.2. A note on channel avulsions in floodplain wetlands

Avulsion is a process whereby flow is diverted out of an established river channel into a new course on the adjacent floodplain. Channel avulsion is a complex and natural process that is influenced by a range of regional and site-specific factors, and the relationships between sedimentation rate, frequency, and styles of avulsion are yet to be fully clarified. A good understanding of floodplain dynamics is therefore required to differentiate between natural and human induced avulsion events. As such, consultation with experts should ideally be undertaken when evaluating changes in channel dynamics of floodplain wetlands. There are nonetheless some practical pointers that can be used to improve the assessment process.

Historical aerial photograph analysis is a useful starting point to understanding floodplain dynamics and is critical for understanding how channel patterns have changed over time. Thus, whilst changes in geomorphological processes should ideally be validated through further research, an assessment of changes in channel patterns from the earliest available photographic records can add considerable insight into the dynamic nature of the floodplain and channel characteristics.

Irrespective of the frequency and style of avulsion, previous studies have shown that for an avulsion to occur the river must be near an avulsion threshold and that the final trigger is typically a large flood or closely spaced series of floods or a human activity. Some indications that could be used to help evaluate whether or not a channel was near an evulsion threshold prior to human intervention include:

- ***The sinuosity of the channel:*** Other factors being equal, avulsion frequencies are likely to be higher in highly sinuous channel reaches. This is linked with a reduction in channel efficiency due to a reduction in slope and the ability of the channel to transport sediment. As such, avulsions can be expected in river reaches with high sinuosity.
- ***Lateral slopes:*** The formation of levees and alluvial ridges adjacent to an active channel increases lateral floodplain slope which makes the floodplain more susceptible to an avulsion during high flow events. A section of a floodplain characterized by high lateral variation in elevation is therefore primed for avulsions to occur.
- ***Sedimentation rates***: Recent research suggests that avulsion frequency increases with rapid sedimentation rates on the floodplain. As such, floodplains naturally characterized by high sediment loads are likely to have a greater propensity for avulsions than floodplains characterized by lower rates of sediment inputs. On the contrary, floodplains characterized by low sediment inputs are least likely to be affected by channel avulsions.

There may however be instances where anthropogenic activities in the wetland have clearly stimulated an avulsion event. This may include purposeful intervention in the channel or banks (e.g. diversion of flows for agricultural use) or un-natural obstructions in the channel (e.g. weirs or willows growing into the channel of a naturally grass-dominated floodplain). The alluvial ridge along the channel may also be compromised through animal paths that essentially introduce knick-points which can stimulate an avulsion event.

Adapted from Larkin *et al. (*2017)

2. Assess changes in flood peaks

Changes in flood peaks can counteract or enhance the impact caused by changes in channel form. An assessment of changes in flood peaks has already been undertaken as part of the hydrology module (**Table 7.6**). A score that reflects the impact of flood peaks on lateral connectivity is simply allocated based on this initial assessment[16] (**Table 8.17**).

Table 8.17. Scores allocated based on changes in flood peaks from the upstream catchment

Indicator	-5	-3	-1	0	+1	+3	+5	Score
Change in flood peaks (Table 7.6)	Large decrease	Moderate decrease	Small decrease	None	Small increase	Moderate increase	Large increase	

3. Evaluate the overall change in lateral connectivity by accounting for both within-wetland and catchment-related impacts

Once the above assessments have been completed, the user is required to provide an overall assessment of the degree to which lateral connectivity has been affected. This is determined by summing the impact score obtained for changes in lateral connectivity (**Table 8.14**) and changes in flood peaks (**Table 8.17**) which recognizes that these aspects may either dampen or amplify each other. A description of the resultant alteration classes is provided in **Table 8.18**.

Table 8.18. Description of alteration classes for changes in lateral connectivity between the channel and wetland floor

Combined Score	Alteration Class	Description
>=6	Large increase	A large increase in lateral connectivity is expected relative to baseline conditions.
3	Moderate increase	A moderate increase in lateral connectivity is expected relative to baseline conditions.
1	Small increase	A slight increase in lateral connectivity is expected relative to baseline conditions.
0	No change	No significant changes in lateral connectivity is expected.
-1	Small decrease	A small decrease in lateral connectivity is expected relative to baseline conditions.
-2	Moderate decrease	A moderate decrease in lateral connectivity is expected relative to baseline conditions.
-5	Large decrease	A large decrease in lateral connectivity is expected relative to baseline conditions.
-8	Serious decrease	A serious decrease in lateral connectivity is expected relative to baseline conditions.
-10	Critical decrease	A critical decrease in lateral connectivity is expected relative to baseline conditions.

[16] Note: Scores indicated here are based on the class mid-point. A refined score is calculated in the spreadsheet based on the actual score calculated.

Geo Step 1A-2b. Assess the impact of drains and erosion gullies on sediment distribution and retention processes

Drains and gullies concentrate flows, reduce the width of flow, increase flow transport capacity, and ultimately reduce lateral connectivity and rates of deposition. For those disturbance units considered to be directly affected by drains/gullies, the impact on the distribution and retention of clastic sediment is based initially on the level of interception of water inputs from the upstream catchment or the level to which overspill from a channel is intercepted in the case of naturally channelled wetlands (**Table 8.19**). This is then modified by criteria that affect the efficiency with which flows are conveyed across the valley floor. Where erosion is the cause, the scoring is refined to cater for the strength of cause-effect relationships and the natural vulnerability of the wetland to erosion.

Table 8.19. Assessing the degree to which drains, erosion gullies and artificial berms have affected the distribution and retention of sediment

1. Drains & erosion gullies						
Indicator	**0**	**-2**	**-5**	**-8**	**-10**	**Score**
A. Interception or deflection of flows						
A1. Location of drains and gullies in relation to flows delivered into the disturbance unit from the upstream catchment	Very poorly intercepted	Moderately poorly intercepted	Intermediate	Moderately well intercepted	Completely intercepted	
B. Efficiency with which flows are conveyed through the wetland						
B1. Depth of the drains/gullies	<0.20 m	0.20-0.50 m	0.51-0.80 m	0.81-1.10	>1.10 m	
B2. Density of drains /gullies (m/ha of wetland)	<25 m/ ha	26- 100 m/ha	101- 200 m/ha	201- 400 m/ha	>400 m/ha	
Initial Intensity Score: A1 x Average (B1,B2)/10						
B3. Obstructions in the drains/ gullies	Complete obstruction	High obstruction	Moderate obstruction	Low obstruction	No obstruction	
Refined Intensity Score (B): Initial Intensity Score x B3/10						
2. Erosion gullies						
C. Adjusting the score to account for the direct & indirect evidence for human-induced erosion						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	
C1. Risk of accelerated erosion based on changes in catchment hydrology (Table 8.15)	Very high	High	Moderate	Low	None	
C2. Risk of accelerated erosion in response to a change in sediment inputs (Table 8.16)		High	Moderate	Low	None	
C3. Evidence of within wetland anthropogenic factors causing erosion	Yes – clear evidence		Possible – contributing factors		None evident	
Adjustment factor (C) = Max of above three scores						
D. Accounting for the natural propensity of the wetland to erode						
Indicator	**1**	0.9	**0.8**	**0.7**	**0.5**	**Score**
D1. Inherent vulnerability of the wetland	0 (Very Low)	2 (Low)	5 (Moderate)	8 (High)	10 (Very High)	
Scaled intensity of Score (erosion gullies) B x C X D						

Rationale and guidance for Table 8.19.

A. Interception or deflection of flows

A1. Location of drains, gullies and/or artificial berms in relation to flows delivered from the upstream catchment.

The focus here is specifically on the interception or deflection of flows from the upstream catchment that enter the wetland either via overbank flooding (channelled wetlands) or in the form of channelled inflows at the head of the wetland (unchannelled valley bottoms). The intensity rating is based on the proportion of the influent water from the upstream catchment that is believed to be intercepted by drains or erosion gullies.

So, in the case of a naturally unchannelled wetland, the worst-case scenario would involve the construction of a drain or the formation of an erosion gully that extends through the wetland and effectively acts as a continuation of the upstream channel. Such a feature would effectively intercept any major pulses of sediment, and depending on other secondary features, could divert all sediment away from the wetland floor. Whilst most networks of artificial drains are designed for optimal interception, there are situations where these may be incomplete or where drains are located in such a manner that some flows remain un-intercepted.

In the case of a naturally channelled wetland, interception would be highest where the drainage network effectively intercepts flows that overtop the main channel and directs flows back into the main channel. Interception would be adjusted downwards where drains are located some distance from the main channel and areas closer to the channel are not adversely impacted.

B. Efficiency with which flows are conveyed through the wetland

B1. Slope of the wetland

The steeper the slope of the wetland, the more efficiently the water drains from the wetland through any drains or gullies.

B2. Depth of the drains/gullies

The deeper the drains and gullies in the affected area, the greater is the potential of the drain and gully network to efficiently intercept and to convey intercepted flow (with associated sediment) out of the wetland.

B3. Density of drains /gullies (metres per hectare of wetland)

The greater the density of drains, the more likely they are to effectively intercept and deflect flows from the section of wetland in which they occur.

C. Adjusting the score to account for the direct & indirect evidence for human-induced erosion (score only for erosion gullies)

Whilst erosion may be clearly evident within a wetland, it is important that accelerated erosion (as a result of human activities) is separated as far as possible from natural erosional processes. This interpretation is aided by an assessment of key changes in the catchment that are known to accelerate erosional processes including (C1) changes in runoff characteristics and (C2) a reduction in sediment supply. Evidence of anthropogenic impacts in the wetland that are likely to have stimulated erosion (C3) can also be used as direct evidence of a direct cause-effect relationship. Once assessed, these scores are used to effectively refine the initial intensity rating score. Where risks are clearly very high (suggesting good justification for intensity ratings), the intensity score remains unchanged, whereas if there is little supporting evidence to suggest that gully erosion is linked to anthropogenic activities, the intensity score is adjusted downwards. If there is no evidence of human causes of the erosion gully then it is assumed to be part of the natural dynamics of the wetland and its impact on geomorphic integrity is adjusted down to 0 irrespective of its extent and dimensions.

C1. Risk of accelerated erosion based on changes in catchment hydrology:

See guidance provided for **Table 8.15**.

C2. Risk of accelerated erosion in response to a change in sediment inputs:

As in the case of channel modification, erosion may also be stimulated through either an increase or decrease in sediment inputs. An increase in sediment inputs can cause aggradation, often with steepening at the toe of the depositional area, stimulating erosion. A reduction in sediment inputs on the other hand, can increase the erosive capacity of influent water, leading to accelerated erosion. See further guidance in **Table 8.16**.

C3. Within wetlands factors causing erosion clearly discernible:

Whilst the above assessment can be used to provide an indication of erosion risk linked to catchment activities, there are also a range of within-wetland impacts that can lead to accelerated sediment loss as outlined in the introductory discussion. This includes a range of changes to geomorphic controls, and within-wetland activities such as roads, dams and drains or berms that can stimulate erosion. The assessor is required to specifically consider whether any of these impacts have occurred, and to use this as a basis for assessing the degree to which within wetland factors are seen to be contributing towards the erosion evident in the wetland.

D. Accounting for the natural propensity of the wetland to erode

Whilst erosion is dependent upon many factors (such as soil type, vegetation cover and type, rainfall events, etc.), one of the most critical and overriding factors is slope. For any given discharge, the steeper the longitudinal slope the more likely that erosion will take place. Understanding the natural dynamic of the wetland is therefore central to correctly assessing anthropogenic impacts. Of particular relevance here is the inherent propensity of the wetland to erode. This is important as some wetlands persist near a threshold where minor changes in discharge or within-wetland practices will induce erosion whereas others have passed this threshold and are in a natural erosional phase. Some wetlands are inherently more stable and less vulnerable to change and thus erosion is considered more significant in terms of deviation from "reference" conditions.

It is this relationship between longitudinal slope and discharge of a wetland that is used here to assess the inherent vulnerability to erosion. For the purposes of this assessment wetland area (ha) is used as a proxy for discharge. Therefore, for a given discharge, which is approximated in **Figure 8.8** by wetland size (ha), an estimate of wetland vulnerability is obtained based upon longitudinal slope. This concept is then integrated into the assessment by down-weighting impacts caused by erosion for wetlands that have a high natural propensity to erode.

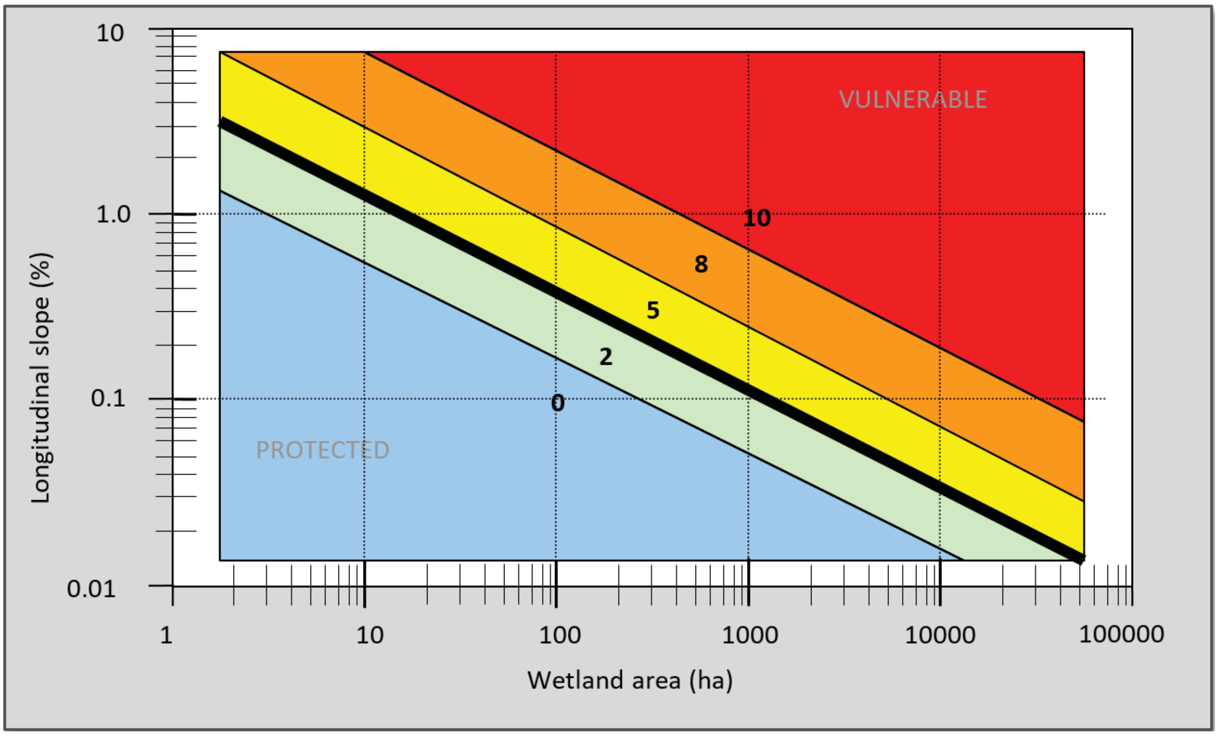

Figure 8.8. Propensity of a wetland to erode based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope (Macfarlane et al., 2008)

In interpreting the figure, the assessor must be aware that both the area and slope are plotted logarithmically. In other words, each interval on the x- and y-axes increases by a factor of 10. Therefore, points between the plotted intervals need to be plotted on the same scale. Thus, if the area is 20 ha and slope is 0.5%, the location of the area measurement is roughly ⅓of the way between the 10 ha and 100 ha marks on the x-axis, and the slope measurement is about ⅔ of the way between the 0.1% and 1% marks on the y-axis. Users also need to be aware that the relationship plotted in **Figure 8.8** is based on ongoing research into the relationship between discharge (area) and slope in various HGM types (Ellery *et al*., 2016; Tooth, 2018).

Geo Step 1A-2c. Assess the impact of infilling and excavation (including dams)

This step involves the assessment of a variety of activities which through either the introduction of material into the wetland or excavation of material, affect the natural processes of sediment distribution and retention in the wetland. Infilling refers to the direct deposition by humans of fill material in the wetland (e.g. for road embankments, berms or dam walls or in order to prepare a site for construction). Excavation refers to the removal of sediment by humans from the wetland (usually with heavy machinery) and is commonly associated with mining and sand winning.

The impact of the feature/activity (e.g. the infill or the dam wall) on sediment distribution and retention processes is assessed by considering:

- Direct impacts, which are restricted to within the immediate footprint of the feature, beneath the deposition/infilling or within the excavation.

- Indirect impacts on additional areas of the wetland where the activity either (a) impedes (impounds) flows and increases rates of deposition within an area upstream of the feature or (b) intercepts or deflects flows away from the area located laterally or downstream of the feature, reducing rates of sediment deposition.

Dams and weirs are the most common features causing impeded flow upstream of the feature. Road embankments also result in impeded flows in an upstream direction especially where culverts are inadequate to accommodate the natural flow of water. In all of these scenarios, the areas assessed is taken as the flooded area upstream of the impeding feature, which is typically mapped as a discrete disturbance unit.

Roads and berms running longitudinally along the wetland and bridges and culverts located across the wetland may also serve to deflect flows and associated sediment away from parts of the wetland. Dams also trap sediment, affecting sediment accumulation processes in downstream disturbance units which also needs to be accounted for. The impact of dams in particular, typically affect all disturbance units downstream of the feature. The impact may however be moderated through the contribution of secondary tributaries in downstream disturbance units.

1. Areas directly affected by infilling and excavation

This assessment is carried out for disturbance units directly affected by infilling or excavation. For the purposes of this assessment, the extent of infilling / excavation should be mapped out as a discrete disturbance unit unless it only occupies a very small portion of the wetland (e.g. <3%). Impacts to geomorphic processes are then rated based on the indicators and scoring guidelines provided in **Table 8.20**.

Table 8.20. Assessing the direct impacts of anthropogenic infilling and excavation

Indicator	1	2	3	4	5	Score
A1. Average depth of excavation and removal	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
Indicator	**-1**	**-3**	**-5**	**-8**	**-10**	**Score**
A2. Average depth of infill	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	

Rationale for Table 8.20.

A1. Average depth of excavation and removal

Excavation and infilling will typically result in areas of standing water where sediments will accumulate unless water is deflected away from such areas by berms or other infrastructure. For the purposes of this assessment, excavation and removal is therefore seen as typically enhancing sediment retention (though typically not to the same extent as impoundments), with depth used as a course surrogate for estimating the intensity of impact.

A2. Average depth of infill

In areas directly affected by deep wetland infilling (e.g. elevated industrial platforms), geomorphic processes may be effectively de-activated and as such, these areas receive a maximum intensity rating. There may however be instances where infilling / anthropogenic deposition is relatively shallow in nature, allowing the affected area to still be connected during high flow periods. An intensity score is assigned using depth of infill / anthropogenic deposition used as a course indicator for the level of de-activation. In reality however the level of de-activation is dependent on other factors such as natural inundation depth, with floodplain wetlands that are regularly inundated by deep flooding being inherently less susceptible than small unchannelled valley bottom wetlands that are rarely inundated by more than 50 cm.

2. Areas indirectly affected by infilling / excavation

In terms of indirect impacts, a distinction is made between areas downstream of anthropogenic impacts that impede flows (affected by *reduced* rates of sediment deposition) and areas upstream of impeding features (affected by *increased* rates of sediment deposition). Such areas should be delineated as separate disturbance units due to the differing impacts on processes of sediment distribution and retention. The approach for rating impacts on sediment distribution and retention patterns is similar to that used in the hydrology module (**Table 7.16**). Guidance for rating such impacts on geomorphic processes is provided in **Table 8.21**.

Table 8.21. Assessing <u>indirect</u> impacts associated with anthropogenic deposition, infilling and excavation (including dams) on sediment distribution and retention processes

<table>
<tr><th colspan="8">A. Activities enhancing rates of sediment accumulation</th></tr>
<tr><th colspan="8">Roads and berms that extend laterally across the wetland (Upstream effects)</th></tr>
<tr><th colspan="2">Indicator</th><th>1</th><th>3</th><th>4</th><th>5</th><th></th><th>Score</th></tr>
<tr><td colspan="2">A1. Degree to which flows are impounded</td><td>Limited</td><td>Moderate</td><td>Large</td><td>High</td><td></td><td></td></tr>
<tr><th colspan="8">Dams that extend laterally across the wetland (Upstream effects)</th></tr>
<tr><td colspan="8">A2. Determine the size of dam and the nature of sediment load being transported</td></tr>
<tr><td colspan="2"></td><td colspan="6">Volume of dam in relation to MAR (in the wetland)</td></tr>
<tr><td colspan="2">Relative importance of bedload relative to suspended load</td><th>Small (<20% MAR)</th><th>Modest (20-35% MAR)</th><th>Medium (36-60%)</th><th>High (60-120%)</th><th>Very High (>120%)</th><th>Score</th></tr>
<tr><td colspan="2">Low</td><td>1</td><td>2</td><td>4</td><td>6</td><td>8</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Moderate</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td></tr>
<tr><td colspan="2">High</td><td>4</td><td>6</td><td>8</td><td>10</td><td>10</td></tr>
<tr><th colspan="8">B. Activities reducing rates of sediment accumulation</th></tr>
<tr><th colspan="8">Roads and berms that extend laterally across the wetland (Downstream effects)</th></tr>
<tr><th colspan="2">Indicator</th><th>-1</th><th>-3</th><th>-5</th><th>-8</th><th>-10</th><th>Score</th></tr>
<tr><td colspan="2">B1. Degree to which flows are intercepted and deflected away from the disturbance unit</td><td>Limited</td><td>Moderate</td><td>Large</td><td>Serious</td><td>Complete</td><td></td></tr>
<tr><td rowspan="3">Further guidance</td><td>Low flows deflected?</td><td>Yes</td><td rowspan="3"></td><td>Yes</td><td rowspan="3"></td><td>Yes</td><td rowspan="3"></td></tr>
<tr><td>Annual floods deflected?</td><td>No</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Large floods deflected?</td><td>No</td><td>No</td><td>Yes</td></tr>
<tr><th colspan="8">Dams that extend laterally across the wetland (Downstream effects)</th></tr>
<tr><th colspan="2">Indicator</th><th>-1</th><th>-3</th><th>-5</th><th>-8</th><th>-10</th><th>Score</th></tr>
<tr><td colspan="2">B2. Interception by the dam of the streams entering the downstream wetland area</td><td>Dam intercepts <20% of the affected area's catchment</td><td>Dam intercepts 21-40% of the affected area's catchment</td><td>Dam intercepts 41-60% of the affected area's catchment</td><td>Dam intercepts 61-80% of the affected area's catchment</td><td>Dam intercepts >80% of the affected area's catchment</td><td></td></tr>
<tr><td colspan="8">B3. Determine the size of dam and the nature of sediment load being transported</td></tr>
<tr><td colspan="2"></td><td colspan="6">Volume of upstream dam/s in relation to MAR (in the wetland)</td></tr>
<tr><td colspan="2">Relative importance of bedload relative to suspended load</td><th>Small (<20% MAR)</th><th>Modest (20-35% MAR)</th><th>Medium (36-60%)</th><th>High (60-120%)</th><th>Very High (>120%)</th><th>Score</th></tr>
<tr><td colspan="2">Low</td><td>-1</td><td>-2</td><td>-4</td><td>-6</td><td>-8</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Moderate</td><td>-2</td><td>-4</td><td>-6</td><td>-8</td><td>-10</td></tr>
<tr><td colspan="2">High</td><td>-4</td><td>-6</td><td>-8</td><td>-10</td><td>-10</td></tr>
<tr><td colspan="7">Intensity Score for Dams (Downstream Effects) = B2 x B3/10</td><td></td></tr>
</table>

Rationale and scoring guidelines for Table 8.21

A. Activities enhancing rates of sediment accumulation

Roads and berms that extend laterally across the wetland (Upstream effects)

A1. Degree to which flows are impounded

Impoundment of flows, reduces flow rates, promoting sediment deposition. The impact of roads and berms is therefore assessed simply based on the perceived level of upstream impoundment. Guidance for categories:

- Limited – e.g. many culverts at ground level facilitating throughflow
- Moderate – e.g. under-sized culvert or few culverts at ground level with some disruption to flow
- Large – e.g. culverts very widely spaced or located above ground level causing localised impoundment
- High – e.g. culverts blocked / lacking and causing considerable impoundment

Further guidance for rating this criterion is provided in the Hydrology module (**Table 7.16**).

Dams that extend laterally across the wetland (Upstream effects)

A2. Determine the size of dam and the nature of sediment load being transported

This assessment is informed by the same rationale as provided in B3 although the focus is on impoundment (and enhanced depositional processes) upstream of the dam wall.

B. Activities reducing rates of sediment accumulation

Intensity scores should be assigned here based on the perceived level to which sediment inputs are likely to be intercepted or deflected away from the disturbance unit. It is important to note here, that the focus is on assessing the degree to which flows from the upstream catchment (as opposed to runoff from adjacent hillslopes) will be deflected as this is typically the primary source of sediment input.

Roads and berms that extend laterally across the wetland (Downstream effects)

B1. Degree to which flows are intercepted and deflected away from the disturbance unit

In the case of anthropogenic deposition and infilling (e.g. berms), an intensity score is allocated based on the degree to which the feature is likely to deflect water (and associated sediment) away from the affected disturbance unit. In the case of lateral features that cross the wetland, such as roads, for example, interception is affected largely by the design and spacing of culverts. While interception is an important consideration, the intensity score must be assigned by specifically considering to what degree low flows, annual floods and large floods (> 1:10 year) would be intercepted and deflected by these features.

Dams that extend laterally across the wetland (Downstream effects)

B2. Interception by the dam of the streams entering the downstream wetland area

The impact of dams will be most severe where dams are located directly upstream of the disturbance unit on the main trunk stream and intercept all water inputs. This would apply to most disturbance units located directly downstream of a dam. However, in some cases a major tributary may enter below the dam, thereby resulting in a lower level of interception as one progresses downstream of the dam.

B3. Determine the size of dam and the nature of sediment load being transported

This assessment is based on the same rationale used to assess the impacts of dams on sediment inputs from the catchment. Essentially, the greater the volume of the dam relative to MAR, the greater likelihood that sediments will settle in the dam rather than being transferred downstream. The same is relevant to sediment loads, with wetlands fed by rivers dominated by bedload sediment transport processes being more susceptible to trapping than wetlands characterised by mixed or suspended loads. Users should refer to the rationale and associated guidance for **Table 8.7** when undertaking this assessment.

The scores for B2 and B3 are integrated by first scoring B2, which effectively sets the maximum impact score for the disturbance unit. The score is then moderated down depending on the score obtained for indicator B3 by multiplying B2 by B3/10.

Geo Step 1A-2d. Assess the impact of changes in the surface roughness of wetland vegetation on sediment distribution and retention processes

Transport capacity of water flowing through the wetland can also be affected by changes in wetland surface characteristics and vegetation characteristics that serve to intercept and slow flows and enhance sediment deposition. Where roughness has increased, this will act to slow the velocity and energy of flows, decrease flow transport capacity, and promote sediment deposition whereas a reduction in roughness will have the opposite effect. For those disturbance units considered to be affected, **Table 8.22** is used to score this impact.

Table 8.22. Assessing the impact of surface roughness on the process of sediment accumulation

Indicator	+2	0	-1	-2	-3	Score
A1. Change in surface roughness	Moderate increase in roughness (i.e. by 2 classes)	Roughness unchanged or small increase (i.e. by 1 class)	Low reduction in roughness (i.e. by one class)	Moderate reduction in roughness (i.e. by two classes)	High reduction in roughness (i.e. by three classes)	

Rationale for Table 8.22

<u>A1. Change in roughness</u>

Guidance on assessing changes in surface roughness have already been provided in the hydrology module where the importance of surface roughness in reducing the velocity of through flows has been emphasised (**Hydro Step 2D**).

Geo Step 1A-2e. Integrate scores to obtain an overall indication of changes to the ability of the wetland to trap sediment

The approach to calculating a final score differs between naturally channelled and unchannelled wetlands (**Table 8.23**). In the case of channelled systems, an impact score is based initially on the impact score for lateral connectivity and then adjusted further to account for any additional impacts on the wetland floor. The rationale here, is that it is lateral connectivity which is fundamentally important to sediment transport from the channel to the wetland floor. Once this has been accounted for, secondary impacts associated with changes to the topology of the wetland floor that affects the distribution and retention of sediment can be accounted for. In the case of naturally unchannelled wetlands, the assessment is simply calculated by summing the intensity scores for any relevant impacts that affect the distribution and retention across the surface of the wetland (**Table 8.23**).

Table 8.23. Assessing changes to the ability of the wetland to trap sediments

Change in lateral connectivity (only for channelled wetlands)	
1A-2a. Intensity score based on stream channel modification and flood peaks (1)	
Factors affecting processes of distribution and retention across the surface of the wetland	
1A-2b. Intensity score for drains and erosion gullies (2)	
1A-2c. Intensity score for artificial wetland infilling (3)	
1A-2d. Intensity score for changes in surface roughness (4)	
Total score for impacts evident in the disturbance unit	

Rationale for Table 8.23

The total score is calculated using an algorithm which ensures that the score does not exceed 10. Ecosystem health is conceptualized as beginning with a glass 100% full (10/10) for a pristine system, which is then successively drawn down by each of the different impacts, with each successive impact only drawing down what has been "left over" following the draw-down of preceding activity. In the case of naturally channelled wetlands, all four indicators area assessed, whilst only the last three indicators are used to calculate an integrated score for naturally unchannelled wetlands. Note too, that the final amount remaining in the glass (i.e. the overall integrated magnitude of impact score) is not affected by the order in which the successive impacts are considered.

Geo Step 1A-3. Assess overall changes to clastic sedimentation processes

Actual rates of sediment deposition are often slow and cannot be measured in a rapid assessment of this nature. The approach here, therefore, is to obtain an indication of changes in depositional processes for each disturbance unit by jointly considering the impact of sediment inputs (Section 1A-1) and within-wetland factors that affects the natural processes of sediment accumulation in the wetland (Section 1A-2). This is assessed by using the within wetland score as a starting score, and the adjusting this further based on changes to sediment inputs from the catchment. The impacts are integrated) using the following algorithm:

Overall change in clastic sedimentation accumulation processes = On-site impact score + (10 – On-site impact score[17]) x Catchment impact score/10.

The rationale for combining impacts in this manner is that both catchment and on-site impacts may, on their own, exert a considerable influence over clastic sedimentation processes but may also add to or counter-balance the respective impacts of each other. For example, if there is a moderate reduction in sediment inputs (Catchment Score = -3) and channel incision has resulted in a large decrease in lateral connectivity (On-site Score = -5), then according to the algorithm, the score for the overall change in geomorphic processes is -3 + (10-3)*-5/10 = -6.5. This intensity score may, however, be moderated considerably in situations where there is a notable increase in sediment inputs into the wetland.

Table 8.24. Table used to calculate a final intensity score for geomorphic processes for each disturbance unit based on changes in sediment inputs and changes in sediment distribution and retention patterns within the wetland. Positive scores reflect an anticipated increase in sediment accumulation whilst negative scores reflect a reduction in sediment accumulation processes.

			Catchment score: Change in sediment inputs (Section 1A-1)										
			-10	-8	-5	-3	-1	0	1	3	5	8	10
On-site score: Change in sediment distribution and retention (Section 1A-2)	Major decrease	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
	Serious decrease	-8	-10	-9.6	-9	-8.6	-8.2	-8	-7.8	-7.4	-7	-6.4	-6
	Large decrease	-5	-10	-9	-7.5	-6.5	-5.5	-5	-4.5	-3.5	-2.5	-1	0
	Moderate decrease	-3	-10	-8.6	-6.5	-5.1	-3.7	-3	-2.3	-0.9	0.5	2.6	4
	Small decrease	-1	-10	-8.2	-5.5	-3.7	-1.9	-1	-0.1	1.7	3.5	6.2	8
	No change	0	-10	-8	-5	-3	-1	0	1	3	5	8	10
	Small increase	1	-8	-6.2	-3.5	-1.7	0.1	1	1.9	3.7	5.5	8.2	10
	Moderate increase	3	-4	-2.6	-0.5	0.9	2.3	3	3.7	5.1	6.5	8.6	10
	Large increase	5	0	1	2.5	3.5	4.5	5	5.5	6.5	7.5	9	10

17 Note that an absolute value is used here in order to account for positive and negative values.

Once scores have been calculated for each disturbance unit the extent and intensity scores for each disturbance unit are used to calculate a final combined magnitude of impact score is calculated for the wetland.

Note: It is important to note here that the algorithm used to integrate scores is a simplification of a complex reality, which is difficult to assess accurately in a rapid assessment of this nature. A limitation that must be pointed out specifically here, is that the integration is undertaken at a disturbance unit level although the catchment score is assessed at an HGM unit level. As such, the tool is not sensitive to situations where lateral sediment inputs, vary considerably across different disturbance units.

Geo Step 1B Wetlands dominated by organic sediment accumulation

Organic matter accumulation (including peat formation) occurs where the rate of local plant productivity and associated organic matter inputs, exceeds decomposition. While a range of factors can affect the level of biotic activity and associated decomposition processes, lack of oxygen is recognised as the dominant cause of peat formation in nature (Moore, 1989). Waterlogging reduces oxygen availability, and for this reason organic matter accumulation is closely linked with hydrologic factors and permanently saturated conditions.

For the purposes of this assessment, changes in the rates of organic matter accumulation are assessed by evaluating proxies that are known to affect the rates of this process (**Figure 8.9**). This includes factors that can affect local hydrological conditions, i.e. the extent of wetness (1B-1) and landuses within the wetland itself that affect organic matter input or increase mineralisation by disturbing the soil surface (1B-2). The overall change to organic matter accumulation processes are then assessed by integrating the scores for these two assessments whilst also taking local climatic conditions into account (1B-3).

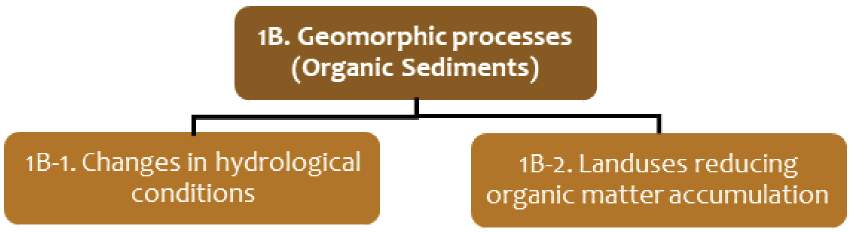

Figure 8.9. Secondary components included in the assessment of changes to the processes of organic sediment deposition in the wetland

Geo Step 1B-1: Assess changes in hydrological conditions

Processes of organic sediment accumulation are sensitive to relatively small changes in the hydrological system. Human activities such as groundwater abstraction and stream flow reduction activities can result in less water reaching the wetland, thereby contributing to a lowering of the water table. Permanent wetness is critical for the accumulation and maintenance of organic matter. The water table in the wetland itself may also be reduced through a range of within wetland activities such as artificial drainage and direct abstraction (**Hydro Step 2**). A reduction in the quantity of water inputs reaching the wetland and / or factors negatively affecting water distribution and retention patterns in the wetland are therefore used to provide an indication of expected changes in organic matter accumulation processes (**Table 8.25**).

Wetlands may also become wetter because of changing water regimes which may result in increased rates of organic accumulation. This is an uncommon occurrence and is not specifically integrated into this assessment.

Table 8.25. Assessing the potential for mineralization of organic sediments based on changes in water inputs

Indicator	0	2	5	8	10	Score
A1. Reduction in the quantity of water inputs (Table 7.4)	None (>-1)	Small (-1 to -1.9)	Moderate (-2 to -3.9)	Large (-4 to -5.9)	Serious / Critical (<-6)	
A2. Reduction in water distribution and retention patterns (Table 7.19)	None (>-1)	Small (-1 to -1.9)	Moderate (-2 to -3.9)	Large (-4 to -5.9)	Serious / Critical (<-6)	
Intensity Score: A1 + (10-A1) x A2/10						

Rationale for Table 8.25

Organic matter accumulation is regarded as equally susceptible to changes in the wetland that alter water distribution and retention patterns and catchment activities that reduce water inputs. As such, they receive equal weightings when calculating an intensity score. The formula applied does however mean that any impacts to the wetland serve to further magnify impacts from the upstream catchment.

Geo Step 1B-2: Assess landuses affecting organic matter accumulation

A range of activities in the wetland may also reduce organic matter inputs or cause disturbance to the soil surface (increasing oxygen levels) which can halt or reverse the accumulation of organic sediments (**Table 8.26**). For disturbance units affected by agricultural activities, the nature of agricultural activities is used to estimate impacts on organic matter accumulation whilst areas affected by inundation are also considered. It is important to note that these impacts are rated in addition to the impacts that such landuses may have on water distribution and retention patterns.

Table 8.26. Assessing the potential for a reduction in organic matter accumulation based on agricultural activities in the wetland

Indicator	1	3	5	Score
A1. Landuses potentially affecting organic matter accumulation	Tree plantations Orchards & vineyards	Sugarcane Subsistence crops	Commercial annual crops	
A2. Inundation from impoundments	Shallow flooding from impoundments	Deep flooding from impoundments		

Rationale for Table 8.26

<u>A1. Landuses potentially affecting organic matter accumulation</u>
Agricultural landuses were rated based on an understanding of factors such as the nature and frequency of tillage that disturbs the soil surface, and expected reductions in organic matter contributions linked with crop management. In the absence of further impacts to wetland hydrology, the effect of agricultural activities is likely to be limited to surface layers. As such, the maximum intensity score was capped at a score of five for commercial annual crops.

<u>A2. Inundation from impoundments</u>
Landuse activities promoting increased saturation in the wetland may also affect organic matter accumulation rates. As such, this indicator is used to rate disturbance units affected by increased inundation (e.g. in response to flooding by dams). Since the assessment is made relative to reference conditions (characterised by permanently saturated conditions), this impact is treated as undesirable, though not to the same extent as agricultural activities that can reverse organic matter accumulation processes. Shallow flooding is therefore

expected to have a very limited impact on organic matter accumulation rates since such areas typically remain well vegetated. Where deep flooding occurs, vegetation growth is typically halted and whilst organic deposits may remain, ongoing accumulation is likely to be largely halted as reflected by a higher impact score.

Geo Step 1B-3: Assess the overall change to organic sedimentation processes

The impact on organic matter accumulation is calculated initially based on changes to wetland hydrology in each disturbance unit. This score is then adjusted further to account for landuses within the wetland itself that may further affect organic matter inputs and mineralization of organic matter through soil disturbance and inundation (**Table 8.27**).

Table 8.27. Calculating the overall magnitude of impact on organic matter accumulation processes in each disturbance unit

Geo Step 1B-1 Change in hydrological conditions (Table 8.25)	A
Geo Step 1B-2 Landuses affecting organic matter accumulation (Table 8.26)	B
Overall change in geomorphic process: A + (10-A) x B/10	

Geo Step 2: Identify and assess impacts to the geomorphic structure

The focus here, is on assessing the degree to which the geomorphic structure of the wetland has been altered by anthropogenic activities. Here, "geomorphic structure" refers to the morphological and sedimentary characteristics of the wetland which in practice involves an assessment of changes to the nature and depth of sedimentary deposits. This assessment is carried out regardless of the nature of the sedimentary deposits (clastic or organic) or the HGM type and addresses a suite of anthropogenic impacts known to affect the geomorphic structure of a wetland (**Figure 8.10**).

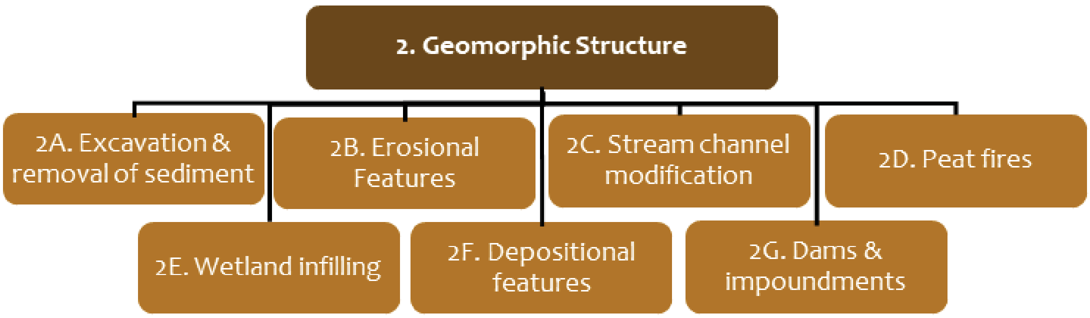

Figure 8.10. Sub-components included in the assessment of changes to the geomorphic structure of the wetland

The assessor is required to specifically consider and assess relevant impacts for each disturbance unit. In instances where sediment loss/removal has taken place, scores used for rating the intensity of impacts, are based on an estimate of the proportion of sediment lost from the wetland (2A to 2D). Where additional sediment has been introduced by anthropogenic impacts, the intensity of impact is assessed based on infill depth or suitable surrogates (2E to 2G). Once each unit has been assessed, individual scores are then combined to obtain an overall magnitude of impact score for each type of impact.

Geo Step 2A. Excavation & removal of sediment

A range of anthropogenic activities may entail direct disturbance or removal of sediment from the wetland. Such activities include mining of peat or deeper excavations linked to coal or mineral extraction. The excavation of drains in a wetland also affects the geomorphic structure of the wetland, although typically at a more localised scale.

For those disturbance units considered to be affected by soil excavation and removal, impacts are assessed by estimating the proportion of sediments lost from the wetland through the use of simple indicators (**Table 8.28**).

Table 8.28. Guideline to assess the impact of activities involving mining and drainage on geomorphic structure

A. Mining & Excavation						
Indicator	**-1**	**-2**	**-5**	**-8**	**-10**	**Score**
A1. Average depth of excavation & removal	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
B. Drainage						
Indicator	**0**	**-0.5**	**-1**	**-2**	**-3**	**Score**
B1. Density of drains (metres of drains per hectare of wetland)	<25 m/ha	26-100 m/ha	101-200 m/ha	201-400 m/ha	>400 m/ha	
Indicator	**-1**	**-2**	**-5**	**-8**	**-10**	**Score**
B2. Average depth of drains/gullies	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
Intensity Score (B): B1 x -B2/10						

Rationale for Table 8.28.

<u>A1. Average depth of excavation & removal:</u>

The intention of scoring is to reflect the proportion of sedimentary deposits excavated and removed relative to the average depth of such deposits. Given that measuring actual depth of sediment deposits is onerous, a simplified approach was adopted based on the actual depth of excavations. This assumes that most wetlands are characterised by relatively shallow sedimentary deposits (<2 m). Where further information on the depth of sediment deposits is known, scores should be adjusted accordingly (e.g. for a wetland with sediment deposits of 5 m, impacts associated with excavation of 1 m should be moderated to an intensity score of 2).

<u>B1. Density of drains (metres of drains per hectare of wetland):</u>

Density of drainage is also assessed as part of the hydrology module (**Hydro Step 2B**) and is used to set the starting intensity score by better accounting for the actual area of the wetland affected by excavation. So, in the worst case scenario, where drainage density is >400 m/ha, the actual proportion of sediment deposits excavated is likely to be <30%. As such, the maximum intensity score for drains is set at 3/10.

<u>B2. Average depth of drains/gullies:</u>

Depth of drains is also assessed as part of the hydrology module (**Hydro Step 2B**) and provides an indication as to the degree to which natural sedimentary deposits have been removed through drainage activities. This score is calculated based simply on the average depth of drains and using an assumption that most wetlands are characterised by relatively shallow sedimentary deposits (<2 m). Where further information on the depth of sediment deposits is known, scores should be adjusted accordingly (e.g. for a wetland with sediment deposits of 5 m, impacts associated with drains of 1 m deep should be moderated to an intensity score of 2).

Geo Step 2B. Erosional features

This assessment is focussed specifically on loss of sediment linked to gully erosion in wetlands. This is often precipitated by changes in the hydrology and sediment dynamics of the catchment that affects the erosivity of flows passing through the wetland. A range of within-wetland impacts are also known to stimulate erosion in wetlands and also need to be considered (see **Box 7.1**).

This assessment is primarily relevant to unchannelled valley bottom and seep wetlands. There are however instances where gully erosion does occur in naturally channelled systems affected by channel incision. In such situations, erosion gullies may develop where water re-enters the main channel resulting in further export of sediment from the wetland. Impacts of gully erosion are specifically dealt with here whereas channel incision is dealt with through a separate (though comparable) process (**Geo Step 1C**).

For those disturbance units considered to be affected by erosional features, this impact is scored using the guidance provided in **Table 8.29**. An important point to emphasise here, is that whilst erosion accelerated by anthropogenic activities is regarded as one of the most critical factors affecting the state of wetlands in South Africa, erosion also operates as a natural process in wetlands. As such, it is important that the cause of erosional features is appropriately diagnosed. In order to cater for risks of possible misinterpretation, the initial intensity score is moderated based on the direct & indirect evidence for human-induced erosion.

Table 8.29. Assessing the impact of erosional features on geomorphic structure

Indicator	-1	-3	-5	-8	-10	Score
A. Initial intensity rating for erosional features						
A1. Average gully width in relation to wetland width	<20%	21-40%	41-60%	61-80%	>80%	
A2. Mean depth of gullies	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
Unscaled intensity score = A1 x -A2/10						
B. Adjusting the score to account for evidence for human-induced erosion						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	**Score**
B1. Risk of accelerated erosion based on changes in catchment hydrology (Table 8.15)	Very high	High	Moderate	Low	None	
B2. Risk of accelerated erosion in response to a reduction in sediment inputs (Table 8.16)		High	Moderate	Low	None	
B3. Within wetlands factors causing clearly discernible erosion	Yes – clear evidence		Possible – contributing factors		None evident	
Adjustment factor = Max of above three scores						
C. Accounting for the natural propensity of the wetland to erode						
Indicator	**1**	0.9	**0.8**	**0.7**	**0.5**	**Score**
C1. Inherent vulnerability of the wetland (Figure 8.8)	Low	Moderately Low	Moderate	Moderately High	High	
Scaled intensity of impact score = A X B X C						

Rationale and guidance for Table 8.29

A. Initial intensity rating for erosional features

An initial intensity score is calculated simply based on the average width (A1) and depth (A2) of erosion gullies within the area being assessed. An average of these scores is then used as the initial average intensity unscaled score for this assessment.

A1. Average gully width in relation to wetland width:

This simply requires a course estimate of gully width relative to the width of the wetland, expressed as a percentage (%).

A2. Mean depth of gullies:

This simply requires a course estimate of gully depth and assumes that most wetlands are characterised by relatively shallow sedimentary deposits (<2 m). Where further information on the depth of sediment deposits is known, scores should be adjusted accordingly (e.g. for a wetland with sediment deposits of 5 m, impacts associated with excavation of 1 m should be moderated to an intensity score of 2).

B. Adjusting the score to account for the direct and indirect evidence for human-induced erosion

Guidelines for assessing the risk of erosion is provided in **Geo Step 1A-2c**.

C. Accounting for the natural propensity of the wetland to erode

Wetlands differ in the inherent vulnerability to erosion. Whilst erosion is dependent upon many factors (such as soil type, vegetation cover and type, rainfall events, etc.), one of the most critical and overriding factors is slope. For any given discharge, the steeper the slope the more likely that erosion will take place. It is this relationship between longitudinal slope and discharge of a wetland that is used to assess the inherent propensity of the wetland to erode (**Figure 8.8**).

C1. Inherent vulnerability of the wetland:

Wetlands characterised by a high vulnerability scores can be expected to show evidence of erosion as part of the natural dynamic of the wetland whereas erosion in wetlands that are naturally stable (low vulnerability score) is less common and can be more easily linked with anthropogenic impacts. This vulnerability score is therefore used as a modifier to adjust the intensity score downwards in instances where erosion can be strongly linked to inherent wetland factors.

Note too that the vulnerability of the wetland to erosion may also be linked to the type of base level control. For example a dolerite geological control is generally very resistant to change whereas an alluvial control is a more transient type of control because it is influenced by present erosional and depositional processes and is thus undergoing continual change and evolution. So if there is a large gradient change associated with the toe end of an alluvial base level control, then there is an inherent erosion risk associated with such a slope. Where such a scenario is present, the vulnerability score should be manually adjusted based on this additional information.

Geo Step 2C. Stream channel modification

Enlargement of the stream channel, including channel incision and widening is another form of erosion that may have serious impacts on wetland geomorphology. This assessment is specifically focussed on channelled valley bottoms and floodplain systems that are characterised by natural channels.

As is the case with gully erosion, a change in channel dimension is often precipitated by changes in the hydrology of the catchment that affects the erosivity of flows passing through the wetland. Damming of streams is perhaps one of the most serious risks, particularly to floodplain wetlands. This is due to the ability of dams to trap sediment and release water downstream that is effectively starved of sediment. This reduction in sediment load deprives floodplains of sediment required for floodplain construction and commonly leads to floodplain degradation. A range of within-wetland impacts are also known to cause channel incision either directly or through accelerated erosion and also need to be considered (see **Box 7.1**).

For those disturbance units considered to be affected by channel incision, impacts are assessed using **Table 8.30** as a guide. As is the case for gully erosion, correctly differentiating between natural erosion and artificial channel erosion is not easy to do when undertaken as part of a rapid assessment. The assessment should ideally be informed by historic aerial photography in which natural channel dimensions can be established. In order to cater for risks of possible misinterpretation, the assessment uses a combination of direct and indirect indicators to help establish the strength of cause-effect relationships and to modify the score accordingly.

Table 8.30. Assessing the impact of channel incision

A. Initial intensity rating for channel modification						
Indicator	**-1**	**-3**	**-5**	**-8**	**-10**	**Score**
A1. Increase in average channel width (current vs reference) relative to the wetland width	<20%	21-40%	41-60%	61-80%	>80%	
A2. Increase in average channel depth (current vs reference) in relation to the average depth of sediment deposits	<20%	21-40%	41-60%	61-80%	>80%	
Unscaled intensity rating = A1 x -A2/10						
B. Adjusting the score to account for the direct & indirect evidence for human-induced changes						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	**Score**
B1. Risk of channel incision based on changes in catchment hydrology (Table 8.15)	Very high	High	Moderate	Low	None	
B2. Risk of channel incision in response to a reduction in sediment inputs (Table 8.16)		High	Moderate	Low	None	
B3. Within wetlands factors causing channel incision clearly discernible	Yes – clear evidence		Possible – contributi ng factors		None evident	
Adjustment factor = Max of above three scores						
Scaled intensity of impact score = A x B						

Rationale and guidance for Table 8.30

A. Calculate an initial intensity rating for channel modification

An initial intensity score is allocated based on the perceived changes in the width and depth of the channel relative to reference conditions. This should be based on visible signs of channel incision / widening and should be supported with evidence from historic aerial photography and/or anecdotal evidence from people with a sound knowledge of the wetland where possible (e.g. Land owners / local community members).

A1. Increase in channel width in relation to wetland width:
This is determined based on the difference between channel width under Reference Conditions and Channel width under Present Conditions, which is then expressed as a percentage of the width of the wetland.

A2. Increase in channel depth in relation to reference conditions:
This is determined based on the difference between channel depth under Reference Conditions and Channel depth under Present Conditions, which is then expressed as a percentage of the depth of sediment deposits (%). Where depth is known, this can be used, alternatively, a depth of 2 m may be assumed for assessment purposes.

B. Adjusting the score to account for the direct and indirect evidence for human-induced erosion

Guidelines for assessing the risk of channel incision is provided in **Geo Step 1A-2c**.

Geo Step 2D. Sediment loss associated with peat fires

Peat fires may also significantly affect structural characteristics of wetlands dominated by organic sediment accumulation. Whilst peat fires may occur naturally, particularly in response to extreme drought events, the frequency and depth of peat fires can be significantly exacerbated by changes in wetland hydrology that results in desiccation of wetland soils. Once desiccated, decomposition rates increase and the deposits become vulnerable to fires that vary from relatively short, intense surface burns to longer, lower intensity, subsurface burns. Peat fires often completely destroy plant communities in the wetland, and the presence of ash deposits or stands of ruderal / pioneer species in localized areas of the wetland may indicate recent burning of peat.

Where peat fires have occurred, disturbance units should be defined in such a manner that impacts within a unit are relatively homogenous. Such areas can sometimes be detected from aerial photography (particularly where swamp forest habitats have been affected). An initial intensity score is then allocated for affected disturbance units based on the depth of peat fires (**Table 8.31**) which need to be assessed during a site inspection. It is however important to recognise that peat fires occur naturally, typically in response to drying out of sediments during drought periods. As such, the score is moderated down in situations where there is limited evidence for human-induced changes.

Table 8.31. Guideline to assess the impact of peat fires and cultivation on organic sediment deposits

Indicator	**-1**	**-2**	**-5**	**-8**	**-10**	**Score**
A. Initial intensity rating based on direct indicators						
A1. Depth of peat fires	<20 cm	21-50 cm	51 cm- 1 m	1-1.5 m	>1.5 m	
B. Adjusting the score to account for the direct & indirect evidence for human-induced changes						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	**Score**
B1. Risk of elevated peat fires based on a reduction in the quantity water inputs (Table 7.4)	Serious – Critical (6-10)	Large (4-5.9)	Moderate (2-3.9)	Small (1-1.9)	None (0-0.9)	
B2. Risk of elevated peat fires based on within-wetland impact score for water distribution and retention patterns (Table 7.19)	Serious – Critical (6-10)	Large (4-5.9)	Moderate (2-3.9)	Small (1-1.9)	None (0-0.9)	
Confidence Score: Maximum of B1 or B2						
C. Final Intensity Score: A x B						

Rationale for Table 8.31.

A. Initial intensity rating based on direct indicators

<u>A1. Depth of peat fires</u>

Peat fires typically burn to the depth at which the water table limits further combustion. As such, loss of organic sediments will vary depending on the depth of the water table at the time that the fire occurred. In instances where the water table has been lowered significantly by landuse activities (e.g. coastal aquifers affected by afforestation around Richards Bay), there is a high risk that ground fires may completely destroy peat deposits. Whilst the assessment aims to provide an indication as to the degree to which peat deposits have been destroyed, it may not be possible to accurately determine the depth of peat fires nor the depth of peat deposits during a rapid assessment of this nature. Depth of peat fires is therefore estimated based on the assumption that organic deposits are 1.5 m deep. Where supplementary information or field indicators are available to indicate otherwise, the impact scores should be moderated accordingly. Note too that impact scores should be moderated in instances where the wetland contains a combination of clastic and organic sediments since clastic sediments remain largely unaffected by peat fires.

B. Adjusting the score to account for the direct & indirect evidence for human-induced changes

B1. Risk of elevated peat fires based on a reduction in water inputs

As noted previously, a reduction in water inputs can lead to a lowering of the natural water table and so leave a wetland susceptible to peat fires. This assessment is based on assessments previously undertaken as part of the hydrology module (**Table 7.4**).

B2. Risk of elevated peat fires based on within-wetland impact score for water distribution and retention patterns

Within wetland impacts can also lower the water table, leaving organic soils susceptible to desiccation and peat fires. This assessment is based simply on the score for within-wetland impacts to water distribution and retention patterns, assessed as part of the hydrology module (**Table 7.19**).

Geo Step 2E. Wetland infilling

Wetland infilling includes a range of impacts associated with platforms created for construction purposes, infill associated with road construction and fill used to build dam walls, etc. For those disturbance units affected, an intensity is score is assigned based on the average depth of fill in the affected area.

Table 8.32. Assessing the impact of wetland infilling

Indicator	1	2	5	8	10	Score
A1. Average depth of fill material	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	

Rationale for Table 8.32

A1. Average depth of fill material:

Wetland infilling alters the template of the wetland and in the worst cases, leads to total transformation of wetland features. For the purposes of this assessment, scores are moderated down for shallow infilling that could be easily reversed whereas intensity scores are regarded as high where fill material is >1.5 m in depth.

Geo Step 2F. Depositional features

Depositional features are difficult to spot, and even people with a basic training in geomorphology may have difficulty identifying depositional features in the field, on aerial photographs or even from a low-level aerial survey. We are only interested here in notable recent depositional features that are clearly linked with anthropogenic impacts and this assessment should therefore be informed by available aerial photography and supplemented by evidence obtained from field investigations (see **Box 8.3**).

It is also important to note that some depositional features such as the presence of laterally impinging alluvial fans may be the very reason why some wetlands exist. Such features are typically encountered where tributary streams join the main wetland system. Recent sediment deposits may therefore exist in response to natural erosional processes or may have been deposited in response to exacerbated erosion in the catchment or the wetland. Obvious signs of erosion in the catchment or wetland should be the trigger for investigating possible excessive deposition of sediment in the wetland.

In some urban areas, evidence of recent sediment deposition can sometimes be assessed by investigating the profile of channel banks. In this context, recent deposits can often be differentiated from historic deposits by noting the presence of unnatural material (e.g. plastic bags, litter, etc.) in the sedimentary layers. This assessment is undertaken based on the indicators outlined in **Table 8.33**.

Table 8.33. Assessing the impacts of recent sediment deposits on the geomorphic structure of the wetland

A. Initial intensity rating for depositional features						
Indicator	**1**	**2**	**5**	**8**	**10**	**Score**
A1. Average depth of recent sedimentary deposits	<20 cm	21-50 cm	51 cm-1 m	1-1.5 m	>1.5 m	
B. Adjusting the score to account for the direct & indirect evidence for human-induced impacts						
Indicator	**1**	0.8	**0.5**	**0.2**	**0**	**Score**
B1. Risk of increased deposition based on changes in geomorphic processes (Table 8.25)	Very high >=8	High 5-8	Moderate 2-5	Low 0-2	None <=0	
B2. Direct evidence of erosion in the catchment linked to identified sediment deposits	Yes				No	
B3. Evidence of within-wetlands factors contributing to sediment deposition	Yes – clear evidence		Possible – contributing factors		None evident	
Adjustment factor = Max of above three scores						
Scaled intensity of impact score = A x B						

Rationale and guidance for Table 8.33

A. Initial intensity rating for depositional features

A1. Average depth of recent sediment deposits

Sediment deposited from fluvial processes results in an elevation of the valley floor relative to reference conditions and is assessed simply based on the average depth of sediment deposits across the disturbance unit.

B. Adjust the score to account for the direct & indirect evidence for human-induced impacts

Whilst on-site observations may point to increased levels of sediment deposition in the wetland, it is very important that such changes can be linked to anthropogenic activities. This interpretation is therefore aided by a range of factors used to differentiate between natural and human-induced sedimentary deposits.

B1. Risk of increased deposition based on changes in geomorphic processes:

Enhanced deposition is likely to be evident in disturbance units assessed as having enhanced rates of sediment deposition relative to reference conditions. The risk of sediment deposition is there used as a confirming indicator for depositional features.

B2. Direct evidence of erosion in the catchment linked to identified sediment deposits

Whilst an assessment of changes in geomorphic processes may help to flag the potential for increased deposition, there are instances where deposits may be linked directly with erosional gullies / activities alongside the disturbance unit or from inputs of sediment from secondary tributaries that are diluted in the catchment-scale assessment. An opportunity is therefore provided here to account for situations where a strong direct link can be made between sediment deposits and activities in the catchment.

B3. Evidence of within-wetlands factors contributing to sediment deposition

A range of within-wetland impacts may contribute directly to sediment deposition in the wetland. This includes gully erosion, road crossings, dam breaches and construction activities either directly in or adjacent to the wetland. Where evidence of such impacts exists, these can be used as a justification for being more confident in the assessment.

Box 8.3. Identifying recent sediment deposits

The occurrence of recent sediment deposits is often most easily diagnosed through aerial photography or available satellite imagery. Google Earth^{TM} can be particularly useful here since one is usually able to investigate changes in site conditions over a period of time. Areas of recent sedimentary deposits can usually be identified based on the lack of vegetation cover linked with a clear sediment input source, such as that indicated in Figure 1, below.

Figure 1. Recent sediment deposit located directly downstream of an excavated drainage channel.

Whilst the above example is clearly linked with anthropogenic impacts, it is important to note that some wetlands may be subject to large natural pulses of sediment. An example is provided in Figure 2 below in the Goukou River catchment in the Western Cape. In this instance, a large pulse of sediment entered the head of the wetland after a period of heavy rains but cannot be linked with any anthropogenic activities in a largely pristine upstream catchment.

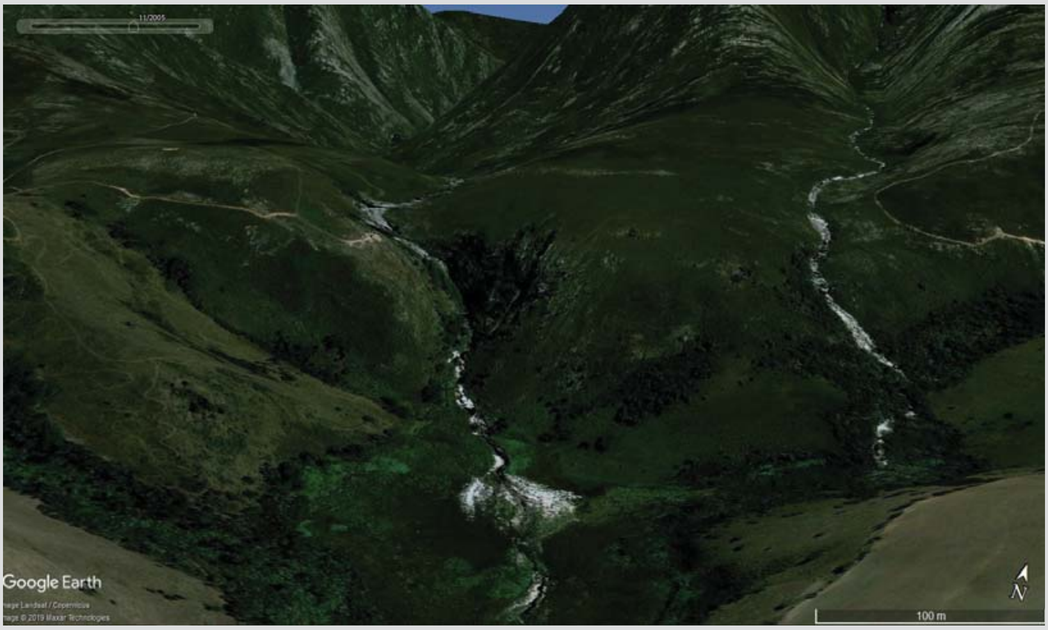

Figure 2. Alluvial sediment fan at the head of a large wetland and linked with natural erosional processes.

Geo Step 2G. Dams and impoundments

Dams or other impoundments (e.g. road crossings) in a wetland promote increased sediment retention and in so doing alter the geomorphic structure of the wetland. Whilst the direct impacts of the dam wall or road are best assessed under artificial wetland infilling (Section 2E), accumulation of sediment upstream of such features is assessed here based on some rapid indicators that affect the level of accumulation of sediment. For disturbance units upstream of impoundments and believed to be subject to increased deposition, impacts are assessed using the guidance provided in **Table 8.34**. This includes (A1) an assessment of changes in geomorphic processes and (A2) the age of the dam. Where information on the actual depth of sediments is available, the impact of dams can be assessed more directly with reference to indicator A1 in **Table 8.33**.

Table 8.34. Assessing the impacts of sedimentation linked with dams and impoundments

A. Intensity rating for dams & impoundments				
A1. Intensity score for impoundments based on changes in geomorphic processes				
Adjustment factor	0.25	0.5	1	Score
A2. Age of the dam	<5 years	5-20 Years	>20 years	
Intensity = A1 x A2				

Rationale and guidance for Table 8.34

A. Intensity rating for dams & impoundments

Rating the intensity of impact from dams is complicated by the fact that such areas are typically inundated, making a direct assessment of sediment accumulation depths difficult to achieve. Impacts to geomorphic structure are therefore coarsely estimated based on the change in geomorphic processes (indicating a change in the rates of sediment accumulation) and the age of the dam.

A1. Intensity score for impoundments based on changes in geomorphic processes

Rating the intensity of impact from dams and other impoundments is based initially on the assessment of changes in geomorphic processes which integrates scores from indicators used to assess increases in depositional processes (**Table 8.21**) and changes in sediment inputs (**Table 8.25**).

A2. Age of the dam:

The depth of sediment accumulation will increase with the age of the dam. An adjustment factor is thus allocated by assessing available 1:50 000 maps and historic aerial photography, including that available in Google Earth.

Geo Step 2H. Assess overall changes to geomorphic structure of the wetland

Once an assessment of all potential impacts to geomorphic structure of the wetland has been completed, a final intensity of impact score is calculated for each disturbance unit by simply summing the impact scores for all sub-components (**Table 8.35**).

Table 8.35. Assessing cumulative impacts on the geomorphic structure of the disturbance unit

Impacts to the geomorphic structure of the wetland	**Impact score**
Geo Step 2A. Excavation and removal of sediment	
Geo Step 2B. Erosional features	
Geo Step 2C. Channel Incision & widening	
Geo Step 2D. Peat fires	
Geo Step 2E. Artificial wetland infilling	
Geo Step 2F. Depositional Features	
Geo Step 2G. Dams & impoundments	
Overall intensity score: (Sum of individual scores)	

Geo Step 3: Derivation of a PES Score and Ecological Category for Geomorphology

Geo Step 3A: Combining scores for geomorphic processes and geomorphic structure to derive an Integrated Geomorphology Impact Score for each disturbance unit

Once Geo Steps 1 and 2 have been completed, scores for geomorphic processes and geomorphic structure are combined to provide an overall PES score reflecting impacts of anthropogenic activities on wetland geomorphology. This entails first calculating a final intensity of impact score for each disturbance unit and then calculating the average score for these components (**Table 8.36**). A final intensity score is then calculated for each disturbance by averaging the scores for changes in geomorphic processes and geomorphic structure.

Table 8.36. Integrating scores for processes and structure to obtain a composite PES score for wetland geomorphology

A. Change in Geomorphic Processes (Geo Step 1)	
B. Change in Wetland Structure (Geo Step 2)	
Final intensity score: Average of A and B	

Rationale and guidance for Table 8.36

Much thought was given to how the sub-component scores should be integrated in this assessment, given that both approaches provide important insights into geomorphic state. Changes to geomorphic processes provide an indication of long-term changes in structure, which may or may not be evident in the wetland. Changes in geomorphic structure on the other hand provides a snapshot of changes currently evident in the wetland. By averaging these scores, equal consideration is given to both components. So, if for example, sediment inputs are expected to increase significantly as a result of changes in catchment landcover, this is documented as a change, even though impacts may not yet be visible in the wetland. Over time, sediment deposits are likely to accumulate in the wetland, altering wetland structure. The overall score for wetland geomorphology will therefore increase as observable changes become evident in the wetland.

Geo Step 3B: Derivation of a Geomorphology Impact Score, PES Score and Ecological Category

Once these calculations have been completed for each disturbance unit, an overall magnitude of impact score is calculated for the wetland by multiplying intensity of impact scores for each disturbance unit by the proportional area and then summing these scores across all disturbance units. The health category the wetland is determined based on its current impact score according to the ranges given in **Table 3.2** (**Chapter 3**). If, for example, the overall magnitude-of-impact score was 7 then the health category would be E.

Geo Step 3C: Reviewing PES scores and assessing trajectory of change

We do acknowledge that this assessment may not cater adequately for all wetland types and circumstances. Allowance is therefore made in the method for assessors to also reflect on the outcomes of the assessment and to then refine the outcomes based on supplementary information and best-professional judgement (see **Chapter 11**). It is also important to assess the anticipated future trajectory of change for the geomorphology component (see **Chapter 12**).

9. WATER QUALITY MODULE

9.1. Introduction

The original version of WET-Health (Macfarlane *et al.*, 2008) does not include a module for water quality and, while the Wetland Index of Habitat Integrity (Wetland-IHI, after DWAF, 2007) does, it is rudimentary and not particularly user-friendly. As such, a Water Quality module has been developed essentially "from scratch" for this revised version of WET-Health. A number of tools relating to the water quality of wetlands have, however, been developed subsequent to the publication of the original WET-Health and Wetland-IHI methods, and these have been used to inform the development of the Water Quality module presented here.

9.1.1. Major informants to the approach used

The approach that has been followed in the development of the Water Quality module has been informed, to a large extent, by the following 'tools' that already exist in South Africa:

- A landuse – water quality model developed for rapid Reserve determination studies for wetlands (Malan *et al*., 2013), which derives a Water Quality PES Category for a wetland primarily based on landuse in the catchment surrounding the wetland [this tool, in itself, was based on previous work by Malan & Day (2012) linking landuse and wetland water quality];
- A GIS-based tool developed by DWA (2013) to assess the impact of land-based activities on water resources in South Africa, called the Automated Land-based Activity Risk Assessment Method (ALARM);
- A method developed by Kotze (2016a, b) to assess wetland ecological condition based on landcover type, which was itself informed by the "Level 1" Vegetation module of WET-Health (Macfarlane *et al*., 2008) and the above-mentioned landuse-WQ model; and
- The recently revised buffer zone guidelines for rivers, wetlands and estuaries in South Africa (Macfarlane & Bredin, 2017a,b) and accompanying literature review (Macfarlane *et al*., 2009), particularly aspects relating to evaluation of the level of threat posed to water resources by specified landuses.

In addition to using the above-mentioned tools as a starting point for the development of the Water Quality module, the approach has been informed by an extensive review of South African and international literature relating to the assessment of wetland water quality.

9.1.2. Conceptual framework and primary components included in the assessment

The main impacts on the water quality of a wetland are considered to be diffuse runoff from landuses within the wetland and from the areas surrounding the wetland, together with point-source discharges of pollution entering directly into the wetland and/or into streams that flow into the wetland. In addition, for wetlands that are connected to a regional aquifer, the water quality of the aquifer and its degree of connectivity to the wetland will have an influence on wetland water quality. To align with the Hydrology and Geomorphology modules, in terms of the structure of the modules, external inputs/impacts on water quality (i.e. those originating from outside of the wetland itself) are dealt with separately from within-wetland activities that have an influence on wetland water quality (see conceptual diagram in **Figure 9.1**).

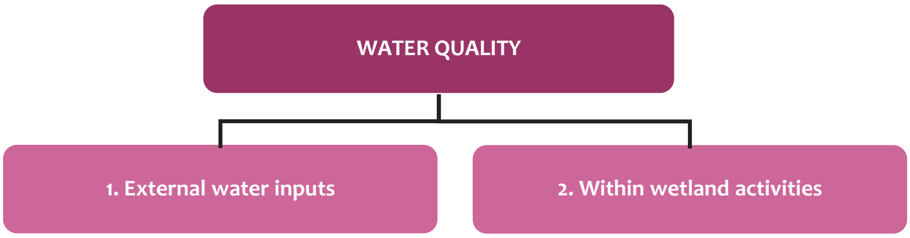

Figure 9.1. Conceptual diagram showing the primary components included in the assessment of wetland water quality

Within-wetland activities included in the Water Quality module are within-wetland landuses and point-source discharges that enter directly into the wetland. For external water inputs, consideration is given to the regional aquifer and surface water inputs (see schematic overview in **Figure 9.2**).

Surface water inputs are taken to include diffuse runoff from landuses in the catchment of the wetland and point-source inputs discharging into the inflowing streams of the wetland. Diffuse runoff from the catchment consist of that from landuses in the immediate (200 m wide) wetland buffer and that from the broader catchment beyond the wetland buffer, considered separately. Runoff from the broader catchment beyond the wetland buffer is, in turn, separated into diffuse runoff from landuses within the buffers of inflowing streams that enter the wetland and from landuses in the remaining upslope catchment. The reason for distinguishing between diffuse runoff from the immediate wetland buffer, the buffers of inflowing streams and the remaining (more distant) upslope catchment, in terms of diffuse surface water runoff from external areas beyond the wetland boundary, is that runoff from the landuses located closer to a wetland (or to the streams flowing into a wetland) typically have a greater influence on the water quality of the wetland than runoff from landuses located further away. This aspect is discussed in more detail in **WQ Step 1B.**

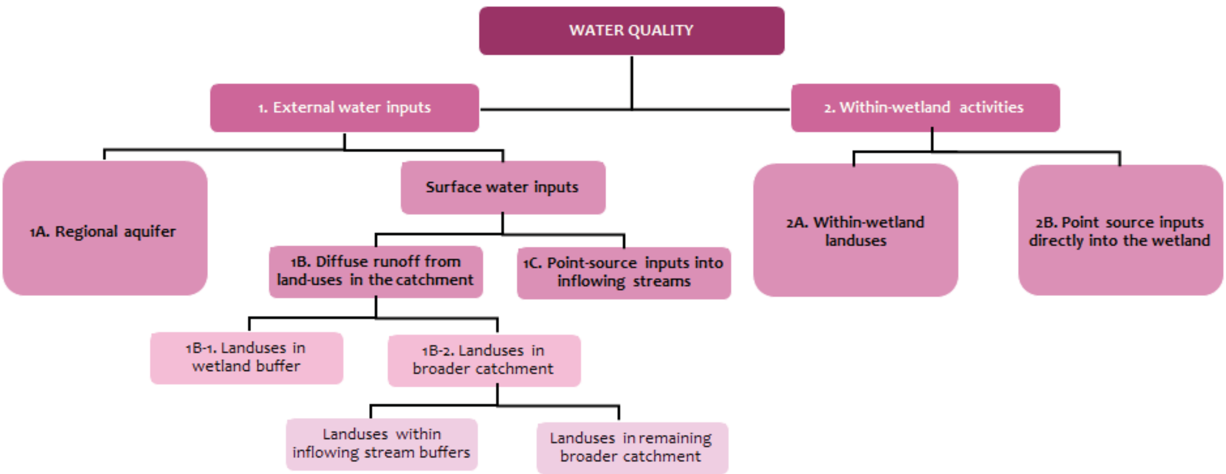

Figure 9.2. Schematic illustrating the overall structure of the Water Quality module

9.1.3. Overview of the steps to be followed in the assessment process

The Water Quality module consists of a series of steps that are sequentially applied, with the endpoint depending on the level of assessment and the amount of information that is available for a particular assessment. The steps in the assessment process are summarised in **Figure 9.3** and described below, with a focus on aspects that are of particular relevance to the more detailed "Level 2" assessment process.

Precursory steps:
- Mapping of wetlands and inflowing/out-flowing streams
- Classification of wetlands by HGM type
- Delineation of catchments and buffer areas ("external areas of influence")

↓

Step 1: Assess potential impact of external water inputs on wetland water quality
- Step 1A: Account for the degree of connectivity to, and water quality of, a regional aquifer
- Step 1B: Assess potential impact of diffuse runoff from surrounding landuses in the catchment
- Step 1C: Assess potential impact of point-source inputs discharging into inflowing streams
- Step 1D: Derive score for overall impact of external surface water inputs on wetland water quality
- Step 1E: Derive combined impact score for all external water inputs

↓

Step 2: Assess potential impact of within-wetland activities on wetland water quality
- Step 2A: Assess potential impact of within-wetland landuses on wetland water quality
- Step 2B: Assessing potential impact of point-source inputs discharging directly into the wetland
- Step 2C: Derive combined impact score for within-wetland activities

↓

Step 3: Derive overall PES Score and Ecological Category for Water Quality
- Step 3A: Compare scores for external water inputs and within-wetland activities to derive an Integrated Water Quality Impact Score
- Step 3B: Account for endorheic drainage and the impact of reduced water inputs
- Step 3C: Derive a Final Water Quality Impact Score, PES Score and Ecological Category

↓

Step 4: Review outputs, derive Revised Final PES Score for Water Quality and assess anticipated trajectory of change
- Step 4A: Review predicted degree to which individual water quality parameters have changed relative to the presumed natural reference state
- Step 4B: Derive Revised Final Impact Score, PES Score and Ecological Category for water quality
- Step 4C: Assess anticipated trajectory of change for Water Quality PES

Figure 9.3. An outline of the steps involved in the application of the Water Quality module

For a "Level 1" (desktop-based) assessment, some of the steps (or sub-components of the steps) are not typically relevant. For a field-based "Level 2" assessment, however, all the steps are mandatory. Each of the steps is explained, in turn, in the sections that follow.

9.2. Precursory steps: Mapping and classification of wetlands, and delineation of "areas of influence"

As explained in **Section 4**, there are a number of precursory steps that should be completed in preparation for completing the modules of WET-Health Version 2. The most important of these, in terms of application of the Water Quality module, are the following steps:

- Mapping of wetlands and inflowing/out-flowing streams;
- Classification of wetlands by HGM type; and
- Delineation of catchments and buffer areas (i.e. the "external areas of influence").

9.3. The Water Quality assessment process

WQ Step 1: Assess the potential impact of external water inputs on wetland water quality

As shown in **Figure 9.3**, the first step in the assessment process for the Water Quality module is to assess the potential impact of external water inputs on the water quality of a wetland. The external water inputs may be from groundwater associated with a regional aquifer (Step 1A) and/or from surface water sources in the catchment of the wetland (Step 1B), as shown in **Figure 9.4** (below).

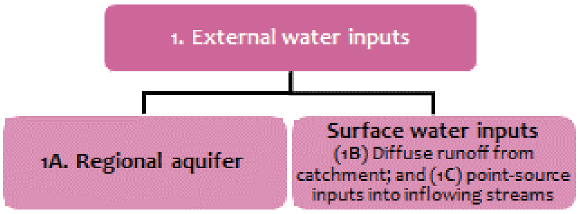

Figure 9.4. Conceptual diagram showing the secondary components included in the assessment of the potential impact of external water inputs on wetland water quality

WQ Step 1A: Account for the degree of connectivity to, and water quality of, a regional aquifer

In addition to determining the degree of connectivity to surface drainage lines (during the precursory mapping step), in terms of understanding the impacts on water quality, it is important to know whether a wetland is connected to an underlying aquifer. This is because wetlands that are closely linked to an aquifer will be significantly affected by the quality of that groundwater, whereas this is not the case for the water quality of wetlands with little or no connection to an aquifer.

Firstly, for all levels of assessment, an indication must be given of which hydrogeological type setting a wetland is located within – "Coastal Plain", "Karst landscape", or "Other". Following the explanations provided in **Appendix A**, it is then assumed that wetlands in the Coastal Plain and Karst landscape settings have a much higher likelihood of being connected to an underlying regional aquifer than other type settings. No further details are required for a Level 1A assessment and this information is simply used to "flag" wetlands that have a relatively high likelihood of being connected to a regional aquifer. The PES results for such wetlands from a Level 1A assessment are considered to be of very low confidence, specifically for water quality and overall wetland ecological condition, because the potentially important influence of the water quality of the regional aquifer is not factored in.

When conducting assessments at Level 1B or 2, for all wetlands in a Coastal Plain or Karst landscape setting, an evaluation must be made of both the degree of connectivity to the regional aquifer and the degree to which the regional aquifer has been lowered. Such an evaluation should also be done for any wetlands in other hydrogeological type settings but for which there is assumed to be some connectivity with the regional aquifer (e.g. a hillslope seep overlying the Table Mountain Group Aquifer that is known to be groundwater-fed). The guidelines and scoring system presented in the Hydrology module to account for impacts associated with the lowering of the regional aquifer are used for this evaluation (see **Hydro Step 1B-1**). For a Level 1B assessment, the option is available of selecting "unknown" for the degree to which the regional aquifer has been lowered. In these cases, the tool automatically assigns a score of -3 to the wetland (representing "moderate lowering of the water table in the regional aquifer").

For the Water Quality module, when conducting assessments at Level 1B and 2, in addition to providing an evaluation of the degree to which a wetland is connected to a regional aquifer and (for wetlands with some degree of connection) the degree to which the regional aquifer has been lowered (or raised), an evaluation must also be made of the water quality of the regional aquifer. This is only necessary in the case of wetlands that have been evaluated to have some degree of connectivity to the regional aquifer. The categories and associated impact scores provided in **Table 9.1**, below, are used for this evaluation. For a Level 1B assessment, the option is available of selecting "unknown" for the water quality of the regional aquifer. In these cases, the tool automatically assigns a score of 4.5 to the wetland (representing intermediate moderately-to-largely polluted conditions).

Table 9.1. Impact intensity scores for categorising the water quality of the regional aquifer (only applicable to wetlands with some degree of connectivity to a regional aquifer)

Score:	1	3	6	9
Water quality of regional aquifer	Near-natural	Moderately polluted	Moderately to severely polluted	Critically polluted

Rationale for scores in Table 9.1

The descriptive categories for the water quality of the regional aquifer are aligned to the descriptions used for the A-F Ecological Categories typically used for PES assessments of aquatic ecosystems in South Africa (as explained in **Section 3.4**). The corresponding impact intensity scores that have been assigned to each category are generally near the centre of the range of PES scores typically associated with each of the Ecological categories, subtracted from 100 and divided by 10 to convert the "PES score" into an "impact intensity score". For example, "moderately polluted" (Ecological Category C), is represented by a PES score range of 60-80, with a median score of 70, which translates into an "impact intensity score" of 3 [= (100-70)/10].

It is important to note that, while WET-Health Version 2.0 has now explicitly factored consideration of the water quality of an underlying regional aquifer into the assessment of PES for wetlands that are understood to be connected to an underlying aquifer, the tools that have been developed at this stage do not assist the assessor in gauging the level of impact/pollution to an underlying aquifer. Instead, until such time as a scoring system is developed for this aspect, the user is required to obtain information from available sources about the water quality of the underlying aquifer for wetlands that have some degree of connectivity to a regional aquifer. Geohydrologists with knowledge of the area within a wetland is located could be consulted for this information, and/or the assessor could check whether locally relevant information about groundwater quality is available via the National Groundwater Information System (NGIS) of DWS[18] or the SADC-GMI Groundwater Information Portal[19]. A good source of information about the natural salinity levels of an underlying aquifer is the relevant 1:500 000 scale hydrogeological map for the study area, as produced by DWS as part of the Hydrogeological Map Series for the country[20]. The Mine Water Atlas (WRC, 2016) can also be consulted

[18] Available: http://www.dwa.gov.za/Groundwater/NGIS.aspx

[19] Available: https://apps.geodan.nl/igrac/ggis-viewer/viewer/sadcgip/public/default

[20] Available: http://www.dwa.gov.za/Groundwater/hydromaps.aspx

for information on mining-related risks to water quality in your study area. Finally, it is important to remember that the dominant landuses within (and beyond) the catchment of a wetland, as evaluated in **WQ Step 1B**, will have a strong influence on the quality of the underlying aquifer.

The score for the degree of connectivity to the regional aquifer (a number between 0 and 1, as derived from **Table 7.2** in the Hydrology module) is multiplied by the score for the water quality of the regional aquifer (a number between 0 and 10, as derived from **Table 9.1**), to derive an overall score for the "contribution of regional aquifer to water quality impacts". This score (ranging between 0 and 10) is then combined with the score for the contribution from external surface water inputs in **WQ Step 1C**, to derive an overall water quality impact score for external water inputs.

WQ Step 1B: Assess the potential impact of diffuse runoff from surrounding landuses in the catchment

One of the most influential impacts on the water quality of a wetland from non-groundwater sources, besides landuses within the wetland and the direct input of point-source pollution into the wetland itself (dealt with in Step 2), is runoff from the surrounding landuses situated up-slope of the wetland. In recognition of this, an approach has been developed to assign a preliminary PES score to a wetland on the basis of the potential impact of "external" landuses surrounding the wetland. It simply requires the assessor to estimate the areal extent of different landuses within the external "areas of influence" of the wetlands that are to be assessed[21].

For national- or regional-scale assessments, existing landcover maps can be used to infer landuse types. In particular, for broader-scale (Level 1A) assessments, the National Land Cover 2014 dataset (NLC-2014) can be used for this purpose. As explained previously, one of the outputs of the current project is a national landcover map of amalgamated landcover categories based on NLC-2014, with additional datasets used to split up some of the NLC-2014 landcover classes (see **Table 4.1**). For more localised assessments (at Level 1B or 2), more accurate mapping of landuse types within the external areas of influence should be completed through the interpretation of available aerial imagery by the assessor.

A spreadsheet-based tool has been developed to assess the predicted impact of different landuses on wetland water quality, which requires the assessor to estimate the proportional extents of the pre-specified landcover categories within the specified areas of influence and enter these data into the relevant spreadsheet. The spreadsheet then automatically derives a preliminary impact score for the predicted water quality of a wetland. These results are based on the pre-assigned impact intensity scores for the various landcover categories, multiplied by the proportional extent of each landuse category. Separate sets of impact intensity scores have been developed for landuse types within the wetland itself (see Step 2A) and landuse types in the "external" areas of influence (as illustrated on the graph in **Figure 9.5**). The presence of a particular landuse within a wetland typically represents the worst-case scenario in terms of the potential impact of that landuse on wetland water quality, whereas runoff from the same landuse located in the surrounding areas outside of the wetland would generally have less impact on the water quality of the wetland. In recognition of this, the default impact intensity scores for landuse types in the external areas of influence are lower than those for the same landuse types occurring within a wetland, by a factor of 1.5.

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[21] This would be done once the precursory steps of mapping the wetlands and their catchments (or pseudo-catchments) and buffer areas, as well as mapping any inflowing channels and the buffer area along these channels have been completed, and the degree of connectivity to a regional aquifer has been accounted for (in WQ Step 1A).

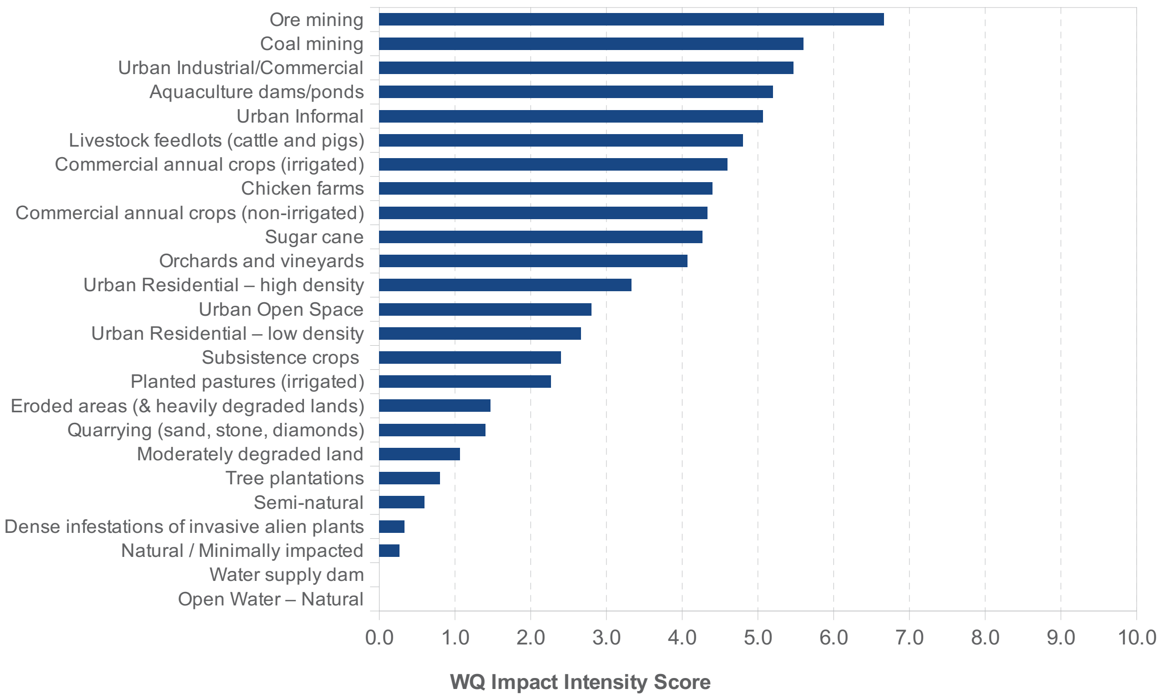


Figure 9.5. Pre-assigned water quality intensity scores (normalised sum) for the landcover categories considered within the external areas of influence (i.e. wetland buffer, inflowing stream buffers and remaining upslope catchment) in "Level 1B" and "Level 2" assessments

Rationale for scores in Figure 9.5 (and Table 9.2)

Preliminary impact intensity scores have been assigned to the proposed landcover categories for a suite of water quality parameters, namely nutrients (N and P), BOD/COD, dissolved salts (TDS), suspended sediments, heavy metals and other toxics (see **Table 9.2**). The intensity scores range from 0-10 and are an attempt to quantify the propensity of a particular landcover type to alter a particular water quality parameter from the reference range. References that were consulted to inform the assignment of parameter-specific "intensity scores" for the different landcover categories included Malan & Day (2012), Malan *et al*. (2013), the documentation for the ALARM tool (DWA, 2013), the documentation for the Buffer Zone Guidelines project (Macfarlane & Bredin 2017a, and relevant appendices), and the appendix of 'Event Mean Concentrations and Export Coefficients' accompanying the P-Load tool developed by USEPA (2001). The individual parameter-specific intensity scores were summed for each landcover category, and these scores were then normalised so that the category with the highest summed score is assigned a value of 10 (as shown in **Table 9.2**). These scores were then taken as the default impact intensity scores for within-wetland landuses (as shown in **Figure 9.13**). For landuses within the external areas of influence outside of the wetland, the default impact intensity scores were derived by dividing the within-wetland scores by 1.5 (these are the values shown in **Figure 9.5**). The reason for applying a factor of 1.5 was to allow for the maximum attainable impact intensity score for each landuse (as assigned for within-wetland landuses) to be obtained for the external areas when the transport capacity modifiers for the buffers and catchment (which range from 0.5 to 1.5, as applied and explained in **WQ Steps 1B-1b and 1B-2b**) represent the worst-case scenario (which equates to a multiplier of 1.5).

Table 9.2. Default impact intensity scores associated with the pre-determined Level 1B/2 landcover categories for the various water quality parameters that have been considered, showing the summed intensity scores in the third-last column and the final (normalised) intensity scores for within-wetland and "external" landuses in the last two columns on the left (landcover categories highlighted in green are only applicable within wetlands)

Level 1B / 2 Refined Landcover Category	Default Intensity Scores									
	Nutrients		COD/BOD	Dissolved Salts (TDS / Conductivity)	TSS / Turbidity	Toxics		Summed Intensity Score (pre-normalisation)	Final (normalised) WQ Intensity Score: WITHIN-WETLAND	Final (normalised) WQ Intensity Score: EXTERNAL AREAS
	N	P				Heavy metals	Other			
Open Water – Natural	0	0	0	0	0	0	0	0	0.0	0.0
Deep flooding from impoundments	0	0	0	0	0	0	0	0	0.0	0.0
Shallow flooding from impoundments	0	0	0	0	0	0	0	0	0.0	0.0
Aquaculture dams/ponds	8	8	8	2	8	0	5	39	7.8	5.2
Natural / Minimally impacted	0.5	0.5	0	0	0.5	0	0.5	2	0.4	0.3
Semi-natural (undrained)	0.75	0.75	0	0	1	0	0.5	3	0.6	0.4
Semi-natural (drained)	1	1	0	0	2	0	0.5	4.5	0.9	0.6
Moderately degraded land	1.5	1.5	0	0.5	4	0	0.5	8	1.6	1.1
Orchards and vineyards	6.5	6	4	4	4	1	5	30.5	6.1	4.1
Sugar cane	6	6	4	6	6	0	4	32	6.4	4.3
Commercial annual crops (irrigated)	7	7	4	5	6	1	4.5	34.5	6.9	4.6
Commercial annual crops (non-irrigated)	6.5	6.5	4	4.5	6	1	4	32.5	6.5	4.3
Subsistence crops	4	4	3	2	4	0.5	0.5	18	3.6	2.4
Tree plantations	0.5	1	0	0	4	0	0.5	6	1.2	0.8
Dense infestations of invasive alien plants	0.5	0	0	0	2	0	0	2.5	0.5	0.3
Quarrying (sand, stone, diamonds)	0	0	0	1	9	0	0.5	10.5	2.1	1.4
Coal mining	4	4	4	8	9	8	5	42	8.4	5.6
Ore mining	6	6	6	9	6	9	8	50	10.0	6.7
Eroded areas (& heavily degraded lands)	0	1	0	0	10	0	0	11	2.2	1.5
Urban Industrial/Commercial	7	7	7	5	4	6	5	41	8.2	5.5
Urban Informal	8	8	8	5	6	1	2	38	7.6	5.1
Urban Residential – high density	3	3	4	4	3	4	4	25	5.0	3.3
Urban Residential – low density	3	3	2	3	2	3	4	20	4.0	2.7
Urban Open Space	5	5	2	2	2	1	4	21	4.2	2.8
Livestock feedlots (cattle and pigs)	8	6	9	2	9	0	2	36	7.2	4.8
Chicken farms	9	4	8	2	2	0	8	33	6.6	4.4
Planted pastures (irrigated)	4	4	4	2	3	0	0	17	3.4	2.3
Infilling (incl. infrastructure)	0	0	0	2	2	0	1	5	1.0	n/a
Sediment deposits	0	2	1	0	10	0	0	13	2.6	n/a
Artificially wetter areas (e.g. seepage below dams)	2	1	0	1	0	0	0	4	0.8	n/a

A key consideration in applying the landuse – water quality spreadsheet is the area within which landuse is evaluated. This has been termed the "area of influence". It is important to only consider landuses that are located where they may actually influence the water quality of a wetland, bearing in mind that the spatial scale of analysis plays a vital role in the relationship between landuse and water quality (Gyawali *et al*. 2015).

In the methods developed by Malan *et al*. (2013) and Kotze (2016a, b), landuse within the entire catchment of a wetland is supposed to be evaluated in determining the impact of landuse on water quality. The ALARM tool for rivers (DWA, 2013) evaluates landuse at an even broader Quaternary catchment scale. A number of studies around the world have, however, shown that landuse should generally be considered at much finer scales when assessing its impact on the water quality of inland aquatic ecosystems. For example, in one of the few studies that have looked specifically at the influence of landscape extent (i.e. the "area of influence" that is taken into account) on the accuracy of landcover-based wetland assessments, in Alberta (Canada), Rooney *et al*. (2012) found that plant-based Index of Biotic Integrity (IBI) scores were best predicted using landcover data from 100 m buffers and bird-based IBI scores were best predicted using data extracted from 500 m buffers. This is supported, to some degree, by reviews on buffer zones for inland aquatic ecosystems (such as those by Macfarlane *et al*., 2009 and Beacon Environmental Ltd, 2012, and the many references cited therein), which show that the concentrations of most pollutants in diffuse surface runoff are reduced to acceptably low levels over very short distances (typically of the order of less than 100 m) if there is an effective natural buffer area around or adjacent to an aquatic ecosystem. On the other hand, in a recent study on the linkages between landuses and water quality in the U-tapao river basin in Thailand

(Gyawali *et al*., 2015), the relationship between landuse and river water quality was found to be strongest at the sub-watershed scale, compared to full-basin and buffer zone scales.

Studies on the spatial extent within which landuse has an effect on the water quality of lakes are somewhat inconclusive as to what the best unit of analysis is (e.g. Nielsen *et al*., 2012; Soranno *et al*., 2015). These studies have, however, highlighted the importance of taking into account regional variability and the degree of connectivity to inflowing streams when evaluating the influence of surrounding landuse on lake water quality.

A review of potentially relevant literature (partially summarised above), together with input solicited from water quality experts, were used to develop a pragmatic approach to determining the "area of influence" in the assessment of the impact of diffuse runoff. The proposed approach, for more detailed Level 1B and Level 2 assessments, is to evaluate the landuse within two main “areas of influence” (as shown in **Figure 9.6**): (1) a 200 m wide GIS buffer area around a wetland; and (2) the broader catchment of the wetland beyond the immediate wetland buffer, split into a 200 m wide GIS buffer area around the inflowing streams and the remaining portions of the topographical catchment of the wetland (minus the afore-mentioned GIS buffer areas). This represents a good compromise between using only the catchment or only a buffer area of a certain width around a wetland. The magnitude-of-impact scores for these individual "areas of influence" are then combined into an overall magnitude-of-impact score for the landuses surrounding a wetland, using HGM-specific rules (explained under **WQ Step 1D-2**). In the case of Level 1A assessments, the broader catchment beyond the immediate GIS buffer area around each wetland is not split into two separate “areas of influence”.

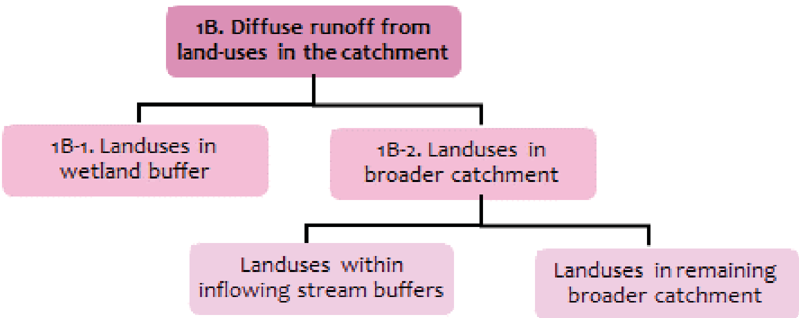


Figure 9.6. Conceptual diagram showing the sub-components considered in the assessment of the potential impact of diffuse runoff from landuses in the catchment of a wetland

Dealing with mining-related impacts on wetland water quality

Mining activities that pose a high risk of contamination to wetland water quality due largely to sub-surface impacts relating to Acid Mine Drainage, such as ore and coal mining, result in an impact on water quality that is disproportionately higher than the areal coverage of these landuses when they are located in a wetland and/or in the buffer or catchment of a wetland. There is presumably a strongly non-linear relationship between the areal extent of these types of mining landuse and water quality within the affected wetlands. In an attempt to account for this, for ore and coal mining (and for the more generic "mining – high and moderate contamination risk" categories in a Level 1A assessment), the "rules" given in **Table 9.3** have been built into the landuse – water quality spreadsheet.

Table 9.3. Built-in "rules" to account for the impact of ore and coal mining on wetland water quality in relation to the proportional extent of the landuse within each area of influence

Landcover category		Wetland	External areas of influence (wetland buffer, inflowing stream buffers, remaining catchment)
Level 1A	Level 1B / 2		
Mining – high contamination risk	Ore mining	Multiply % extent by 5, with maximum within-wetland Magnitude-of-Impact score (10) reached at 20% coverage	Multiply % extent by 3, with maximum Magnitude-of-Impact score for external areas (6.7) reached at 33% (one-third) coverage
Mining – mod. contamination risk	Coal mining	Multiply % extent by 5, with maximum within-wetland Magnitude-of-Impact score (8.4) reached at 20% coverage	Multiply % extent by 3, with maximum Magnitude-of-Impact score for external areas (5.6) reached at 33% (one-third) coverage

Rationale for "rules" in Table 9.3 (and Figure 9.7)

Any ore or coal mining activities within a wetland are likely to have a particularly detrimental impact on the water quality of the wetland, largely due to unaccounted for impacts relating to sub-surface flows of Acid Mine Drainage. To account for this, the extent of these landuse activities within the wetland is multiplied by 5 when deriving the magnitude-of-impact score, with the maximum constrained to the default intensity score for the relevant mining category. This allows the maximum intensity score to be reached with a lot less areal coverage (20%) than in the case of a linear relationship where the maximum is reached at 100% coverage. The extent of ore and coal mining in the external areas of influence is multiplied by 3, with the maximum constrained to the default intensity score for the occurrence of the relevant mining category in the external areas of influence surrounding a wetland. The maximum attainable magnitude-of-impact score, in these cases, is reached when one-third (33%) of the relevant external area of influence (i.e. wetland buffer, inflowing stream buffers, or remaining catchment) is occupied by moderate or high-risk mining landuses (i.e. ore or coal mining). These relationships are graphically illustrated in **Figure 9.7**, in comparison to the linear relationship that applies to most other landcover categories in the spreadsheet model that has been developed.

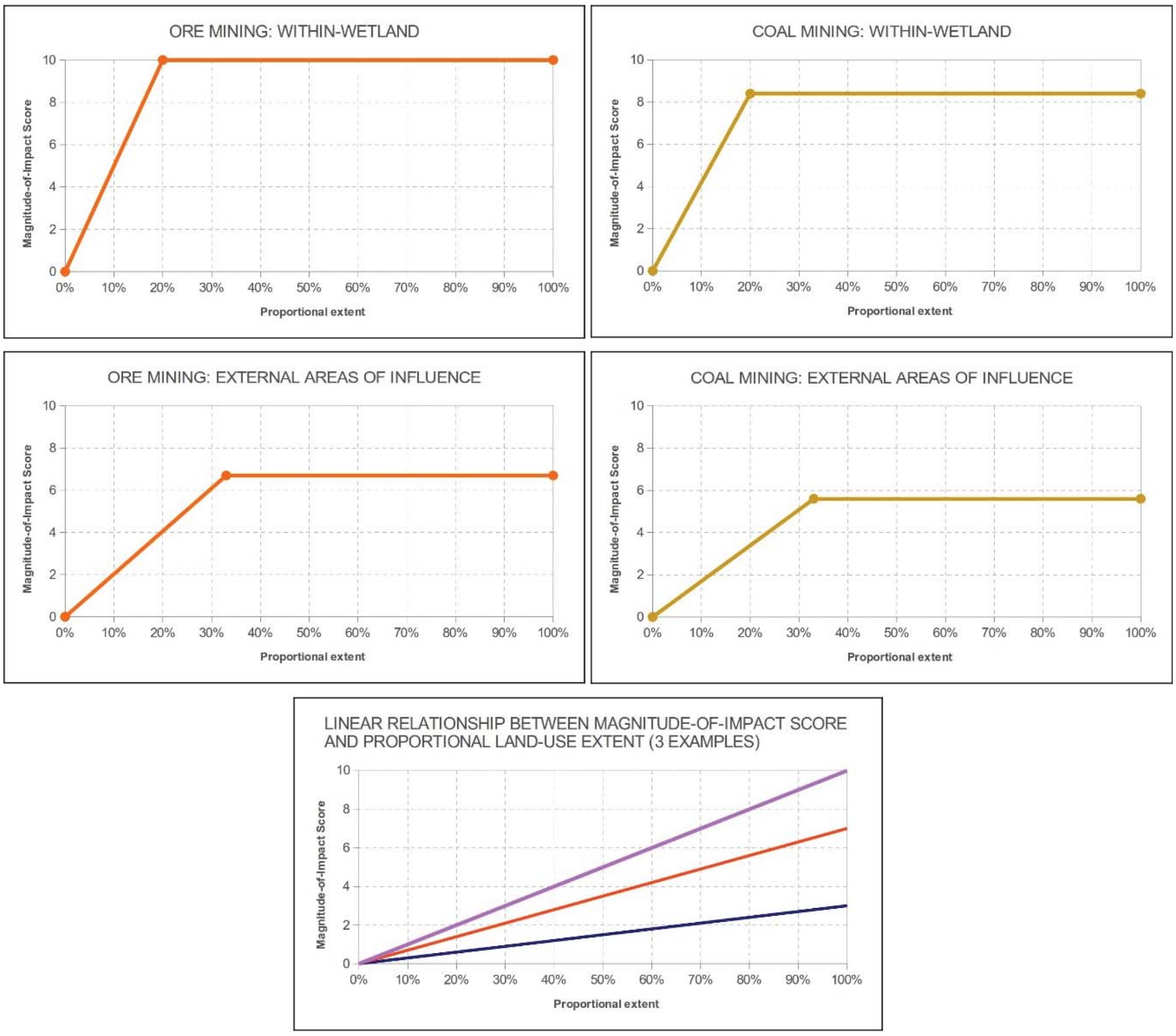


Figure 9.7. Conceptual graphs showing how the magnitude-of-impact score for ore mining (left) and coal mining (right) is derived for within-wetland landuses and landuses in the external areas of influence, in comparison to the linear relationship that is used for most other landuse types (bottom graph, showing three hypothetical examples with maximum intensity scores of 3, 7 and 10)

<u>WQ Step 1B-1</u>: Assess the potential impact of diffuse runoff from landuses in the wetland buffer (lateral inputs)

As explained above, one of the most important external areas of influence that are considered for the assessment of the water quality PES of a wetland in the tools that have been developed is the 200 m wide GIS buffer area upslope of the wetland (or around the whole wetland, including the down-slope areas in the case of a Level 1A assessment). Landuses in this area of influence can have a particularly significant impact on the water quality of a wetland.

WQ Step 1B-1a: Estimate proportional extent of landuses in the wetland buffer

Once the extent (in hectares) of each of the specified landcover types within the GIS buffer around a wetland has been recorded in the "Catchment landcover" worksheet (along with the extent of these landuses in the other external areas of influence), the spreadsheet tool will automatically derive a preliminary magnitude-of-impact score for the wetland buffer in the "EXT_Magnitude-separate" worksheet (hidden by default). This preliminary magnitude-of-impact score from landuse mapping is then automatically brought into the "Water Quality Module" worksheet in the case of a Level 2 assessment. For a Level 1 assessment, the preliminary score for the water quality impacts derived from landuses in the wetland buffer is incorporated into a formula (in the hidden "EXT_Magnitude-integrated" worksheet), which generates an overall score for external water quality impacts from the topographical catchment by also taking into account scores for water quality impacts from the broader catchment and (if relevant) the GIS buffers of inflowing streams.

WQ Step 1B-1b: Account for pollutant transport capacity of the wetland buffer

The transport capacity of the surrounding buffer area, and broader catchment, of a wetland is influenced by the hydrology, geology, soils and topography of the "area of influence", which means that these factors may affect the extent to which the landuses within the area of influence will impact upon wetland water quality (Fraterrigo and Downing, 2008). The characteristics of the vegetation within the buffer and broader catchment area of a wetland also plays an important role in the pollutant transport capacity of these external areas of influence. An attempt has been made to account for some of these factors in the Water Quality module, primarily for Level 2 assessments, largely by taking relevant criteria from the Buffer Zone Guidelines for wetlands (Macfarlane & Bredin, 2017a, b).

In particular, for the up-slope wetland buffer, consideration is given to the following factors (see **Table 9.4**):

1) the average slope of the GIS buffer area;
2) the inherent runoff potential (or permeability) of the soils;
3) the degree to which flows are concentrated in the GIS buffer;
4) the proportion of the GIS buffer area occupied by largely untransformed, vegetated land;
5) the location of largely untransformed, vegetated land in relation to the wetland; and
6) the structural characteristics of the dominant vegetation in the GIS buffer.

[Factors 4-6 relate to vegetation, while factors 1-3 are non-vegetation-related]

Most of this more detailed information (with the exception of the fifth factor listed above) can only be verified through fieldwork and, as such, can only be properly applied in a Level 2 assessment.

Detailed guidelines for selecting the relevant categories for the factors that need to be scored to determine the pollutant transport capacity of the wetland buffer can be found in the Practical Guide of the Buffer Zone Guidelines (Macfarlane & Bredin, 2017b). It is important to note that, when applying these criteria in WET-Health Version 2.0, categories/scores should be selected so as to represent the “average” or “dominant” characteristics of the wetland buffer area. The proportion of the wetland buffer that is occupied by largely untransformed, vegetated land is automatically calculated in the spreadsheet by summing the extent of "Natural / Minimally impacted", "Semi-natural", "Moderately degraded land" and "Urban Open Space" landcover types within the GIS buffer area, and working this out as a proportion of the total extent of land within the buffer. This proportion is automatically converted into a score between 0.5 and 1.5 (as shown in the relevant row of **Table 9.4**).

An overall score for the characteristics of the vegetation within the buffer area is derived by taking the average (mean) of the scores for the three vegetation-related factors. The overall score for the other (non-vegetation) factors contributing to the "pollutant transport capacity" of the GIS buffer surrounding a wetland is derived in a similar manner except that, if the score for the "concentration of flows within the buffer" is 1.25 (i.e. there are some major concentrated flow paths that will substantially reduce interception) or 1.5 (i.e. concentrated flow paths dominate), then this is taken as the overall score for the non-vegetation factors, instead of the average. This is because in these cases the flows passing through the wetland buffer are unlikely to be attenuated by the buffer, irrespective of its slope and soil permeability characteristics.

The mean of the overall score for the vegetation-related factors and the overall score for non-vegetation factors is taken as the overall "pollutant transport capacity of the wetland buffer". This will be a number between 0.6 and 1.5.

Table 9.4. Categories and associated scores for the factors used to determine an overall "pollutant transport capacity score" for the up-slope GIS buffer area around a wetland

Factors to be evaluated	Score				
A. Non-vegetation factors	0.5	0.75	1	1.25	1.5
A1. Average slope of the buffer		Gentle (<10%)	Moderate (>10-20%)	Steep (>20%)	
A2. Soil permeability within the buffer		High: High infiltration and permeability rates (deep, well-drained sands and gravels)	Moderate: Moderate infiltration rates, with permeability somewhat restricted (moderately fine soil textures)	Low: Slow infiltration rates with permeability significantly restricted by layers that impede downward movement of water (clay-dominated soils)	
A3. Concentration of flows within the buffer	No concentrated flow paths		Very few/minor concentrated flow paths	Some major concentrated flow paths (i.e. erosion gullies, drains) that will substantially reduce interception	Concentrated flow paths dominate
A. Overall score for non-vegetation factors: IF A3<=1, THEN Average (A1, A2, A3) ELSE IF A3>1, THEN A3					
B. Vegetation-related factors	0.5	0.75	1	1.25	1.5
B1. Proportion of 200m buffer occupied by largely untransformed, vegetated land (Natural / Minimally impacted, Semi-natural, Moderately degraded and Urban Open Space land classes)	>80%	60-80%	40-60%	20-40%	<20%
B2. Location of largely untransformed, vegetated land in relation to the wetland	Concentrated around the wetland		Equally distributed across the 200m buffer		Mostly located away from the wetland (distal upslope areas)
B3. Structural characteristics of the dominant vegetation in the buffer	Dominantly robust vegetation with high interception potential (e.g. dense stands of tall or tufted grass)		Dominantly moderately robust vegetation with fair interception potential (e.g. tufted grass stands but with lowered basal cover) OR less robust vegetation with good interception potential (e.g. kikuyu pasture)	Dominantly short vegetation (<5 cm) offering little resistance to flow (e.g. maintained lawns) OR more robust but sparse vegetation providing poor interception (e.g. trees/shrubs with poorly vegetated understorey, or degraded grasslands with very poor basal cover)	
B. Overall score for vegetation-related factors: Average (B1, B2, B3)					
Overall score for pollutant transport capacity of wetland buffer: Average (A, B)					

Rationale for scores in Table 9.4

The categories and associated scores for the factors used to generate a pollutant transport capacity "modifier score" for the GIS buffer around a wetland have been derived from the Buffer Zone Guidelines for wetlands in South Africa (Macfarlane & Bredin, 2017a, b), with scores calibrated to allow for the preliminary water quality impact score (based on landuse mapping alone) to be adjusted up (if the overall "buffer transport capacity" score is >1) or down (if the overall "buffer transport capacity" score is <1).

The rationale for taking the average slope of the wetland buffer area into account is that steeper slopes tend to be associated with faster runoff and less infiltration, leading to less attenuation of flows and the overland transport of more pollutants down-slope (and into wetlands) than in the case of more gentle slopes. The degree to which this effect occurs is, of course, strongly linked to the inherent runoff potential of the soils. Buffer areas dominated by deep, well-drained soils generally have high rates of permeability and lower runoff potential compared to fine-textured (clayey) soils with a low permeability (Macfarlane & Bredin, 2017a). As such, wetlands with buffer areas that are characterised by more permeable soils with higher infiltration rates, resulting in a lower inherent runoff potential, will typically experience more attenuation of pollutants from the surrounding areas than wetlands with more impermeable catchments and buffer areas. If there are concentrated flow paths within the buffer of a wetland, this would reduce the effectiveness of the buffer in attenuating runoff and reducing pollution input from the surrounding landuses. The impact of this factor would depend on the degree to which flows have been concentrated within the buffer area.

Wetlands that are surrounded by a band of largely untransformed, vegetated land in the immediate buffer area would experience better attenuation of runoff than wetlands surrounded by more degraded land or bare ground. In addition, the structural characteristics of the dominant vegetation in the buffer also plays a role, with more robust vegetation providing better attenuation of runoff and pollutants.

The preliminary magnitude-of-impact score for the GIS buffer around the wetland that was derived in WQ Step 1B-1a is automatically multiplied by the (averaged) overall pollutant transport capacity score for the wetland buffer, to derive a modified magnitude-of-impact score for the wetland buffer area. This modified score is constrained to a maximum of 10 (i.e. the maximum allowable impact intensity score).

WQ Step 1B-1c: Account for inherent sensitivity of wetland to lateral pollution inputs based on its shape

The sensitivity of a wetland to lateral pollution is, inherently, related to the perimeter-to-area ratio, which varies according to the shape of a wetland. The categories and associated scores for taking account of this criterion, which have also been derived from the Buffer Zone Guidelines for wetlands (Macfarlane & Bredin, 2017a, b), are presented in **Table 9.5**. This criterion is only factored into a Level 2 assessment.

Table 9.5. Categories and associated scores for deriving a modifier to account for the inherent sensitivity of a wetland to lateral pollution inputs based on its shape (perimeter-to-area ratio)

Score:	0.8	1	1.2
Perimeter to area ratio	Low (<500 m/ha)	Moderate (500 – 1500 m/ha)	High (>1500 m/ha)

Rationale for scores in Table 9.5

The greater the perimeter-to-area ratio of a wetland is, the greater is the likelihood that a relatively large proportion of the wetland could potentially be impacted upon by lateral pollution inputs. Long, thin wetlands are thus regarded as more susceptible to water quality impacts from surrounding landuses than round or oval systems that would be less affected by edge impacts.

The modifier that is derived to account for the inherent sensitivity of a wetland to lateral pollution inputs based on its shape is multiplied by the modified magnitude-of-impact score that was derived in **WQ Step 1B-1b** by factoring in the pollutant transport capacity of the wetland buffer. This results in a final magnitude-of-impact score for lateral inputs into the wetland from the buffer area, which is again constrained to a maximum value of 10.

Note that the inherent sensitivity of a wetland to external pollution inputs based on its size is dealt with in **WQ Step 1D-3**, and not here, because wetland size is relevant to the sensitivity of a wetland to inputs from *all* the external areas of influence (including groundwater and inputs from the broader catchment), not just the immediate GIS buffer area around the wetland. Sensitivity to lateral inputs based on wetland shape (perimeter-to-area ratio), however, is only relevant to lateral inputs associated with the immediate buffer around a wetland. Wetland size is also included as one of the factors in assessing the impact of point-source inputs discharging directly into a wetland (in **WQ Step 2D**), while the outflow drainage characteristics of a wetland (endorheic vs exorheic) are taken into account in the derivation of an adjusted overall Water Quality Impact Score (in **WQ Step 3B-1**).

<u>WQ Step 1B-2</u>: Assess the potential impact of diffuse runoff from landuses in the broader catchment

Beyond the 200 m wide GIS buffer area immediately adjacent to a wetland, in terms of water quality impacts from diffuse sources in the external areas of influence, consideration is also given, separately (at least for Level 1B and Level 2 assessments), to landuses within the buffers of streams flowing into the wetland and landuses in the broader catchment of the wetland (located beyond the wetland buffer and the buffers of the inflowing streams), as shown schematically in **Figure 9.8**. Landuses in the broader catchment beyond the wetland and stream buffers typically exert less influence on the water quality of a wetland than the landuses within the buffer areas, but these more distant landuses still have an impact on water quality that varies according to, *inter alia*, the wetland HGM type.

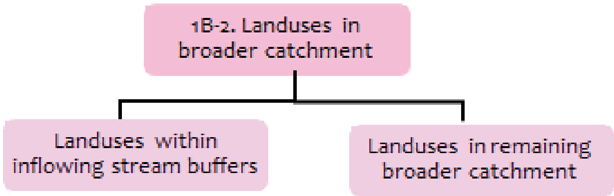


Figure 9.8. Conceptual diagram showing the sub-components considered in the assessment of the potential impact of diffuse runoff from landuses in the broader catchment of a wetland beyond the immediate wetland buffer

WQ Step 1B-2a: Estimate proportional extent of landuses in the buffers of inflowing streams and in the remaining broader catchment

As the initial part of Step 1B-2, for Level 1B and Level 2 assessments, the assessor is required to separately record the extent (in hectares) of each of the specified landcover types within the (200 m wide) GIS buffers of the inflowing streams and within the remaining catchment area of the wetland. This is done in the "Catchment landcover" worksheet. The relevant spreadsheet tools then automatically derive preliminary magnitude-of-impact scores for the GIS buffer area around the inflowing streams and the remaining broader catchment outside of the wetland buffer (in the "EXT_Magnitude-separate" worksheet, which is hidden by default). These preliminary magnitude-of-impact scores from landuse mapping are then automatically brought into the "Water Quality Module" worksheet in the case of a Level 2 assessment. For a Level 1B assessment, these preliminary scores for the water quality impacts derived from landuses in the broader catchment are incorporated into a formula (in the hidden "EXT_Magnitude-integrated" worksheet), which generates an overall score for external water quality impacts from the topographical catchment by also taking into account the score for water quality impacts from the buffer area of the wetland.

In the case of a Level 1A assessment, WQ Step 1B-2a simply involves recording the extents of the specified landcover types within each of the catchment areas considered in the assessment (without separately accounting for landuses in a GIS buffer area adjacent to inflowing streams), in the "CATCH_entry" worksheet of the spreadsheet tool developed for Level 1A assessments. The spreadsheet then automatically subtracts the landuse extents recorded for the wetland buffers from these values to derive the landuse extents in the broader catchment area beyond the wetland buffers (in the "CATCH_area" worksheet). These extents are, in turn, used to automatically derive, for each wetland, an overall magnitude-of-impact score for diffuse runoff from the catchment (in the "CATCH_mag_WQ" worksheet, which is hidden by default).

For Level 1 assessments, the following sub-step is skipped and the assessment process goes straight from Step 1B-2a to **WQ Step 1B-2c** in the case of Level 1B and to **WQ Step 1D-2** in the case of Level 1A.

WQ Step 1B-2b: Account for pollutant transport capacity of inflowing stream buffers and remaining broader catchment

During a Level 2 assessment, for assessing the impact of diffuse runoff from the inflowing stream buffers and remaining broader catchment, consideration is given to the average slope of the ground and the inherent runoff potential (or permeability) of the soils in deriving a pollutant transport capacity "modifier". For the inflowing stream buffers, the proportion of the GIS buffer that is occupied by largely untransformed, vegetated land is also factored in. The rationale for taking these factors into account is the same as that for the wetland buffer, as explained in **WQ Step 1B-1b** above. In the case of the inflowing stream buffers and remaining broader catchment, however, the scoring of the factors has been simplified so that they can be applied in a much coarser, broad-scale manner that is not dependent on field-based verification[22].

The categories and associated scores for taking account of the factors that are used to derive an overall "pollutant transport capacity" score for the inflowing stream buffers and remaining broader catchment are presented in **Table 9.6**. A national map of very coarse relief categories (high/moderate/low) has been produced through the current project to provide a preliminary estimate of the average slope of the catchment. For estimating the inherent runoff potential of the soils in the catchment, the "hydrological soil groups" delineated for localised catchments across South Africa through application of the Soil Conservation Services method for Southern Africa (SCS-SA, after Schulze *et al*., 1992) can be used to obtain an initial desktop-based categorisation. For the inflowing stream buffers, the proportion of the GIS buffer that is occupied by largely untransformed, vegetated land is automatically calculated by summing the extent of "Natural / Minimally impacted", "Semi-natural", "Moderately degraded land" and "Urban Open Space" landcover types within the GIS buffer area for inflowing streams, and working this out as a proportion of the total extent of land within the inflowing stream buffers. This proportion is automatically converted into a factor/score (ranging from 0.5 to 1.5) through application of the same "rules" applied in **WQ Step 1B-1b** for the wetland buffer.

Table 9.6. Categories and associated scores for the factors used to determine an overall "pollutant transport capacity score" for the GIS buffers around the inflowing streams of a wetland and the remaining broader catchment

Factors to be evaluated	**Score**				
A. Non-vegetation factors		**0.75**	**1**	**1.25**	
A1. Average slope of the catchment (Relief)		Gentle gradient (<=10%) ("Low" Relief category)	Moderate gradient (>10-20%) ("Moderate" Relief category)	Steep gradient (>20%) ("High" Relief category)	
A2. Inherent runoff potential of soils in the catchment (soil permeability)		Low runoff potential (SCS-SA categories A & A/B) High infiltration and permeability rates (deep, well-drained sands and gravels)	Moderate runoff potential (SCS-SA categories B, B/C & C) Moderate infiltration rates, with permeability somewhat restricted (moderately fine soil textures)	High runoff potential (SCS-SA categories C/D & D) Slow infiltration rates with permeability significantly restricted by layers that impede downward movement of water (clay-dominated soils)	
Overall pollution transport capacity score for remaining broader catchment (excluding inflowing stream buffer areas): = Average (A1, A2)					
B. Vegetation-related factors (Inflowing stream buffers)	**0.5**	**0.75**	**1**	**1.25**	**1.5**
B1. Proportion of 200m buffer occupied by largely untransformed, vegetated land (Natural / Minimally impacted, Semi-natural, Moderately degraded and Urban Open Space land classes)	>80%	60-80%	40-60%	20-40%	<20%
Overall pollution transport capacity score for inflowing stream buffers: = Average (A1, A2, B1)					

[22] For similar reasons, the more detailed criteria that are considered for the wetland buffer (i.e. concentration of flows in the buffer/catchment, location of untransformed land in relation to the feature, and structural characteristics of the dominant vegetation in the buffer/catchment) are not taken into account in the case of the inflowing stream buffers and the remaining broader catchment.

Rationale for scores in Table 9.6

The categories and associated scores for the factors used to generate a pollutant transport capacity "modifier" for the inflowing stream buffers and the remaining broader catchment of a wetland have been derived from the Buffer Zone Guidelines for wetlands in South Africa (Macfarlane & Bredin, 2017a, b). Scores have been re-calibrated to allow for the preliminary water quality impact score (based on landuse mapping alone) to be adjusted up (if the overall "pollutant transport capacity score" is >1) or down (if the overall "pollutant transport capacity score" is <1), instead of all being values between 0 and 1 that would only allow for downward adjustment of the impact score.

The mean of the scores for the average slope of the catchment, the inherent runoff potential of the soils in the catchment and the proportion of the inflowing stream buffers that is occupied by largely untransformed, vegetated land is taken as the overall "pollutant transport capacity score" for the inflowing stream buffers (this will be a number between 0.7 and 1.3). For the "pollutant transport capacity score" of the remaining broader catchment, the mean is simply taken of the scores for the average slope and the inherent runoff potential of the soils in the catchment (a number between 0.75 and 1.25), as shown in **Table 9.6**. The preliminary magnitude-of-impact scores for the catchment and the inflowing stream buffers that were derived in **WQ Step 1B-2a** are then automatically multiplied by these pollutant transport capacity scores, to derive modified magnitude-of-impact scores for these areas of influence. As in the case of the modified magnitude-of-impact score for the wetland buffer, these modified scores (which could range from 0 to 13) are constrained to a maximum value of 10 (i.e. the maximum allowable impact intensity score).

In WET-Health Version 2, a "pollutant transport capacity modifier" is only derived and applied for the inflowing stream buffers and remaining catchment, and for the wetland buffer, in a Level 2 assessment. It may be possible, however, to incorporate this into a Level 1B assessment (and maybe even Level 1A, in a more simplified manner). This could be explored in the future, as a possible further refinement to the suite of tools.

WQ Step 1B-2c: Integration of Impact Scores for diffuse runoff from the broader catchment

In the case of Level 1B and Level 2 assessments, an overall predicted impact score is derived for diffuse runoff from the broader catchment outside of the wetland buffer (including the inflowing stream buffers). Firstly, the magnitude-of-impact scores for runoff from landuses in the GIS buffers of the inflowing streams and the remaining broader catchment (outside of the 200 m wide GIS buffer around the wetland) are combined (as shown in **Figure 9.8**), after application of the relevant pollutant transport capacity modifiers in the case of a Level 2 assessment. For most HGM types, the overall score for the inflowing stream buffers is given a weighting of 75%, versus a weighting of 25% for the remaining broader catchment (i.e. the score for inflowing stream buffers contributes three times more than that for the remaining broader catchment). The rationale for this is that the water quality impact from diffuse runoff tends to be attenuated over relatively short distances of up to a few hundred metres (e.g. Macfarlane & Bredin, 2017a), and so the impact from landuses in the GIS buffer areas of the inflowing streams of a wetland is likely to be significantly greater than that of more distant landuses in the remaining catchment area beyond the immediate (200 m wide) GIS buffer around the wetland.

An exception to the above-mentioned rule is wetlands without any inflowing streams (e.g. a depression with no inflowing channels), for which the entire score for diffuse runoff from the broader catchment is attributed to landuses within the broader catchment area beyond the 200 m wide wetland buffer. Other exceptions, in terms of HGM types, are seeps and flats. These types of wetlands typically do not have inflowing streams under natural conditions but, in certain situations (often as a result of impacts) inflowing channels are present. To avoid the introduction of unnecessary complexity, the impact scores for the inflowing stream buffers and the remaining broader catchment are simply combined according to the relative proportion of land represented by these "areas of influence" for these two HGM types. For example, if the GIS buffer areas around the inflowing streams of a seep wetland cumulatively represent 20% of the total broader catchment area outside of a wetland and its immediate GIS buffer area, and the overall impact scores derived for diffuse runoff were 7 and 3 for the inflowing stream buffers and the remaining broader catchment area, respectively, then the calculation would be as follows: Overall impact score = (7.0x0.2) + (3.0x0.8) = 3.8.

The calculations for deriving an overall impact score for the predicted impact of diffuse runoff from the broader catchment beyond the immediate wetland buffer, as explained above, are automated in the spreadsheet tools that have been developed for Level 1B and Level 2 assessments. The score that is derived in this way is then compared to the score that is derived (in **WQ Step 1C**) for the predicted impact of point-source discharges into inflowing streams on wetland water quality, where relevant.

WQ Step 1C: Assess the potential impact of point-source discharges into inflowing streams

Once the potential impacts resulting from diffuse runoff from landuses in the catchment of the wetland have been taken into account (in **WQ Steps 1B-1 and 1B-2**), the influence of point sources of pollution discharging into the inflowing streams must be factored into the assessment of external wetland water quality impacts for a Level 2 assessment, where relevant[23]. In a Level 1B assessment, point-source pollution inputs can also be factored into the assessment as an optional extra, as stated previously (in **Section 5.2**). Point sources of pollution can often be of over-riding importance in terms of the water quality of a wetland, especially if discharging into a small and/or endorheic wetland (either directly or via inflowing streams). In **WQ Step 2B**, consideration is given to point source discharges directly into the wetland itself.

For the assessment of the impact of "external" point-source discharges from the broader catchment, the assessor must identify and characterise the main point-source effluent inputs entering inflowing streams for the river reaches situated within a distance of 5 km upstream of a wetland. The landuses that were mapped within the 200 m buffers of these stream reaches can be used as a guide as to where along the inflowing streams any point-source effluents are likely to be found. Such inputs are more likely to be present where there are urban landuse types adjacent to the inflowing streams, or livestock feedlots or chicken farms. The Department of Water & Sanitation (Resource Quality Information Services) and the Local Municipality should be contacted to find out if they have information about the location of outlets from Wastewater Treatment Works in the study area, as well as any data relating to the outflow volumes and water quality of the treated effluent that is being discharged. All *major* discharges into an inflowing stream (such as known WWTW outlets) should be considered in the assessment of point-source discharges, even if they enter the river more than 5 km upstream of the wetland.

Each of the main point-source inputs that are identified must be categorised into one of the following three pre-defined types of outlet:

- Treated sewage effluent;
- Industrial effluent; or
- Effluent from intensive livestock operations (e.g. chicken farms, piggeries, feedlots).

[23] This step will be irrelevant for wetlands that don’t have any inflowing streams and for wetlands with inflowing streams but no known point-source discharges into the inflowing streams.

For treated sewage effluent, where this type of point-source input is present, a distinction must be made between:

- Small-to-medium WWTW (<250 m^3/day as a guideline); or
- Large WWTW (≥250 m^3/day as a guideline).

A further four types of point-source effluent are taken into consideration for direct discharges into the wetland itself (in **WQ Step 2B**), namely:

- Overflowing sewer/manhole;
- Stormwater from informal settlements;
- Stormwater from commercial and residential areas; and
- Agricultural drains.

These additional effluent types are not taken into account for point-source discharges into the inflowing streams of a wetland, however, because it is very difficult to identify such inputs for at least 5 km of stream length for each inflowing stream. Furthermore, the impacts relating to stormwater inputs from the broader catchment should already be adequately catered for in the assessment of runoff-related impacts associated with landuses in the catchment (including the buffer areas of the inflowing streams). <u>If there are agricultural drains or overflowing sewers discharging into the inflowing streams of a wetland a short distance upstream of the wetland edge (as identified during a site visit), which could significantly influence the water quality of the wetland, these should be dealt with as point-source discharges directly into the wetland (in **WQ Step 2B**)</u>. This is because these inputs into the inflowing streams in close proximity to the edge of the wetland act in much the same way as a drain discharging directly into the wetland itself, and it simplifies the assessment process to complete it in this way.

Preliminary impact intensity scores have been assigned to the seven point-source pollution types that are considered in the WET-Health (Version 2) Water Quality module (see **Table 9.7**), using the same suite of water quality parameters that were considered for landuse impacts. The intensity scores, again, range from 0-10 and are an attempt to quantify the propensity of each effluent type to alter a particular water quality parameter from the reference range. The individual parameter-specific intensity scores have been summed for each effluent category, and these scores were normalised so that the category with the highest summed score ("overflowing sewer") was assigned a value of 10 (see comparison of normalised overall intensity scores in **Figure 9.9**).

Table 9.7. Default impact intensity scores associated with the pre-determined point-source types for the various water quality parameters that have been considered, showing the summed intensity scores and the final (normalised) intensity scores in the last two columns on the right

Outlet type (discharging into inflowing streams or directly into wetland)	Parameters							SUM	Normalised SUM
	Nutrients		COD/BOD	Salts	TSS	Toxics			
	N	P				Metals	Other		
Treated sewage effluent (small-med WWTW)	6	7	6	0	2	0	8	29	**6.9**
Treated sewage effluent (large WWTW)	6	7	6	0	2	0	8	29	**6.9**
Overflowing sewer/manhole	9	9	10	2	6	0	6	42	**10.0**
Industrial effluent	5	5	8	2	4	8	6	38	**9.0**
Effluent from intensive livestock operations	9	7	8	0	3	0	8	35	**8.3**
Stormwater - Informal	8	8	9	0	6	2	8	41	**9.8**
Stormwater - Residential/Commercial	3	3	3	0	4	4	4	21	**5.0**
Agricultural drain/s	6	3	2	8	5	0	5	29	**6.9**

*<u>NOTE</u>: outlet types in italics are only considered for direct discharges into the wetland itself (in **WQ Step 2B**), and not for point-source discharges into inflowing streams.

Rationale for scores in Table 9.7 (and Figure 9.9)

The parameter-specific intensity scores for each effluent type were generated by a team of water quality specialists, based largely on their knowledge of the relevant literature and the findings of their own research. Organic pollution sources associated with untreated (raw) sewage were rated to be the most intensive, specifically overflowing (surcharging) sewers and stormwater runoff from informal settlements that typically contains raw sewage. These effluent types are considered to typically have high levels of at least four of the parameters that were taken into account (i.e. N and P nutrient concentrations, BOD/COD, and potentially toxic un-ionised ammonia). Industrial effluent and effluent from intensive livestock operations were also assigned relatively high overall scores, due to the high levels of oxygen demand (COD/BOD) and non-metal toxic contaminants typically associated with these point-source pollution types, often compounded by relatively high heavy metal concentrations in the case of industrial effluents and high nutrient levels in the case of effluent from intensive livestock operations. One of the main toxic parameters of concern for the effluent from livestock operations is un-ionised ammonia (NH3). Relative to the other effluent types under consideration, stormwater discharges from residential and commercial areas were rated to typically have the least impact on wetland water quality due to most of the parameters being closer to the reference range than they generally are for the other types of point-source pollution input.

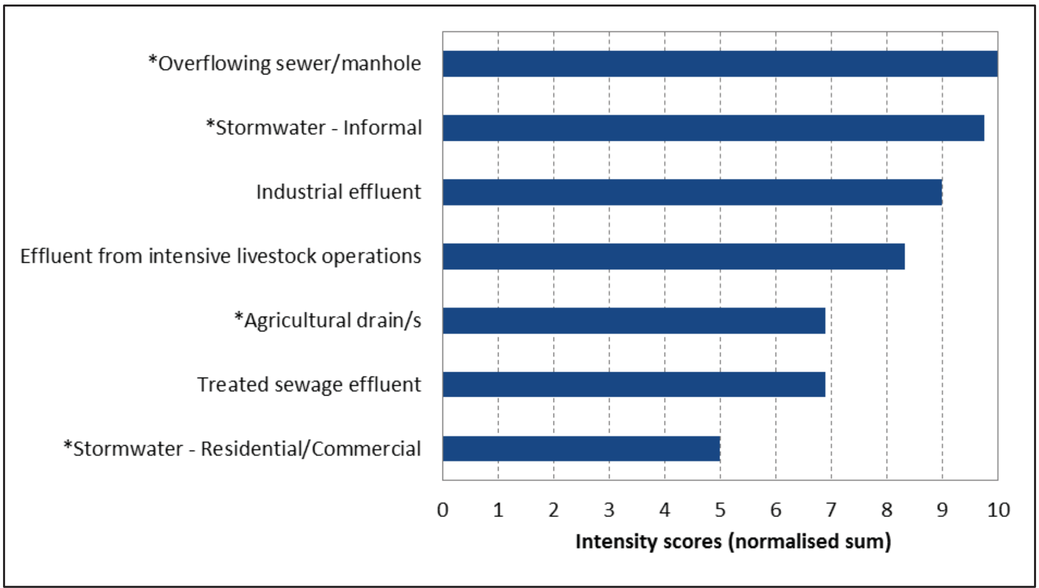


Figure 9.9. Pre-assigned water quality intensity scores (normalised sum) for the seven types of point source pollution that are taken into account in a "Level 2" assessment or (optionally) in a "Level 1B" assessment

[*Effluent types marked with an asterisk are only considered for direct discharges into the wetland itself (in **WQ Step 2B**), and not for point-source discharges into inflowing streams]

For each point-source discharge that is identified for the inflowing stream reaches within 5 km of a wetland (or further upstream for major known discharges), when conducting a Level 2 assessment, the following information must be recorded in the relevant spreadsheet:

- The effluent type must be categorised into one of the three relevant outlet types (as listed above);
- The relative discharge volume must be categorised as high / medium / low volume; and
- The distance upstream of the wetland must be categorised into one of five categories.

The relevant worksheet allows for the capturing of this information for five point-source discharges into the inflowing streams of the wetland that is being assessed. The worksheet also automatically calculates the MAR/ha for the relevant Quaternary catchment by dividing the MAR by the total extent of the Quaternary catchment. This provides an easily obtainable relative indication of how "wet" the catchment area is that the wetland is located in, which is important because point source discharges are typically likely to be more detrimental to the water quality of a wetland in drier areas where natural river flows would generally be low. The categories and associated scores for the discharge volume, the distance upstream and the MAR/ha are given in **Table 9.8**. This table also shows how these scores are used, together, to modify the default impact intensity score for the relevant effluent type so as to derive an overall impact score for each point-source pollution discharge into inflowing streams that is identified by the assessor.

Table 9.8. Categories and associated scores for evaluating the relative volume of point-source discharges into the inflowing streams of a wetland, the distance upstream from the wetland and the MAR/ha of the relevant Quaternary catchment

Multipliers for point-source discharges into inflowing streams: Level 2 assessment					
A. <u>Loading factor</u>:	**Score**				
	0.6		**0.8**		**1.0**
A1. Discharge volume	Low (<50 m^3/day)	-	Medium (50-250 m^3/day)	-	High (>250 m^3/day)
B. <u>Dilution factors</u>:	**Score**				
	0.3	**0.5**	**0.7**	**0.9**	**1.0**
B1. Distance upstream	>5 km	3-5 km	1-3 km	200 m-1 km	<200 m
B2. MAR/ha (m^3/ha) for Quaternary catchment	>1000	500-1000	100-500	50-100	<=50
A: Initial load = [Impact intensity score for effluent type (Table 9.7 & Figure 9.9)] * [A1] **B: Dilution multiplier = Average of [B1] & [B2]**					
Final Impact Score (per point source) = [Initial load (A)] * [Dilution multiplier (B)]					

NOTE: Table also shows how multipliers are derived and applied to determine final Impact Score for each point-source input into inflowing streams

Rationale for scores in Table 9.8

The variables and associated scores in Table 9.8 serve to moderate the impact intensity scores for point source discharges into inflowing streams, unless the effluent is being discharged at a high volume (>250 cubic metres per day), a short distance (<200 m) upstream of the wetland, and in a "dry" catchment (with an MAR of <50 cubic metres per hectare). In all other cases, the impact of the point-source discharge on the water quality of the wetland will be less severe than this "worst-case scenario" and the preliminary impact intensity score (as shown in **Figure 9.9**) will be moderated by a factor of between 0.18 to 0.95, depending on the discharge volume, the distance upstream of the wetland that the effluent is being discharged into the inflowing stream and the MAR/ha of the relevant Quaternary catchment.

The way the scoring has been set up is to first provide an estimate of the loading (by multiplying the relevant impact intensity score by a "loading factor" based on the categorised discharge volume of the effluent). This "initial load" score is then multiplied by a "dilution multiplier" that is calculated by taking the average of the scores for the two "dilution factors" that are considered (i.e. distance upstream and the MAR/ha of the relevant Quaternary catchment). This scoring system was developed through a process of trial-and-error in the application of various permutations during the case study testing that was undertaken, in an attempt to devise a method for factoring in point-source pollution that is scientifically robust yet not too complex for the user of the "tool" to apply.

To cater for the relatively common scenario where the assessor does not know what the discharge volume of a point-source discharge is, the spreadsheet tool automatically assigns a default discharge score/category based on the type of effluent that is selected, using the following "rules":

- High discharge volume of >250 m^3/day ["loading score" = 1.0] is assigned to "Treated sewage effluent (large WWTW)";
- Medium discharge volume of 50-250 m^3/day ["loading score" = 0.8] is assigned to "Treated sewage effluent (small-med WWTW)"; and
- Low discharge volume of <50 m^3/day ["loading score" = 0.6] is assigned to "Industrial effluent" and "Effluent from intensive livestock operations".

Where the discharge volume of the selected effluent type is known, these default scores/categories can and should be overridden with the correct score/category by the assessor in the relevant worksheet.

In the case of a Level 1B assessment, where point-source inputs into the inflowing streams that enter a wetland can be factored into the assessment as an additional option, the scoring process has been simplified. This has been done in an attempt to encourage users to include this aspect in these largely desktop-based assessments. Besides only catering for the consideration of two point-source discharges (versus five in the case of a Level 2 assessment), the discharge volume does not need to be categorised in a Level 1B assessment because this is automated following the above-mentioned “rules” without the option to override the result. Furthermore, the number of categories for the distance upstream from the wetland to the point-source input have been reduced to three (i.e. >5 km, 1-5 km, and <1 km with associated “dilution scores” of 0.3, 0.7 and 0.9, respectively), versus five categories in the case of a Level 2 assessment (see **Table 9.8**).

The overall impact scores per point-source discharge that are derived through the assessment process explained above are automatically added together in the relevant spreadsheets, using a cumulative summing algorithm (explained in **Box 5.1**). This produces an overall magnitude-of-impact score for all the point source effluents identified to be discharging into the inflowing streams of a wetland.

WQ Step 1D: Derive a score for the overall impact of external surface water inputs on wetland water quality

The scores that were calculated for diffuse surface water runoff from the various components making up the catchment area surrounding a wetland (in **WQ Step 1B**) and the overall score that was derived for point-source inputs into the inflowing streams of the wetland (in **WQ Step 1C**) are all brought together in WQ Step 1D, to derive an integrated magnitude-of-impact score for external surface water inputs. This involves, firstly, calculating an overall magnitude-of-impact impact score for surface water inputs from the broader catchment beyond the wetland buffer (Step 1D-1) and then deriving an integrated magnitude-of-impact score for the change in water quality associated with surface flows from the entire upslope catchment of the wetland (Step 1D-2). Thereafter, the sensitivity of the wetland to external pollution inputs, based on its size, is taken into account (Step 1D-3), before deriving a final magnitude-of-impact score for all surface water inputs from the upslope catchment (Step 1D-4) that accounts for the relative importance of surface water inputs compared to inputs from the regional aquifer.

WQ Step 1D-1: Integration of Water Quality Impact Scores for the broader catchment

The overall impact score for the input of point-source pollution into inflowing streams that was derived for wetlands that have inflowing streams in **WQ Step 1C**, above, is compared to the overall impact score that was derived for diffuse runoff from the broader catchment beyond the immediate wetland buffer in **WQ Step 1B-2**. The maximum of these two scores is taken as the final magnitude-of-impact score for surface water inputs from the broader catchment (excluding the GIS buffer area around the wetland), as shown schematically in **Figure 9.10**. This calculation, which is not applicable for Level 1A assessments where point-source inputs are not considered, is automated in the spreadsheet tools that have been developed for Level 2 and Level 1B assessments. The impact score for diffuse surface water runoff from the GIS buffer area immediately adjacent to the wetland (referred to as "lateral inputs") is factored in during the next step in the assessment process.

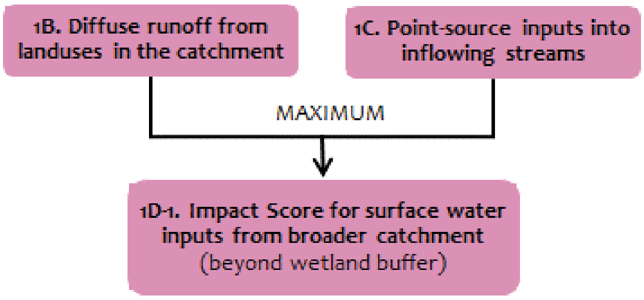


Figure 9.10. Conceptual diagram showing how the final magnitude-of-impact score for surface water inputs from the broader catchment is derived

Initially, in earlier revisions of WET-Health Version 2.0, the impact scores for diffuse runoff from the broader catchment and point-source inputs into inflowing streams were integrated using the cumulative summing algorithm explained in **Box 5.1**. Through the case-study testing that was undertaken, however, it was found that this approach tended to produce an over-inflated integrated impact score, particularly when at least one of the scores represented a large impact. The use of the average of the two scores, on the other hand, was found to produce scores that were too low in situations where one of the input scores is significantly higher than the other one. In the end, it was concluded that taking the maximum of the two scores more consistently produces an overall result is reflective of the actual impact. It also makes intuitive sense that the greater of the two impacts will, in most cases, have an overriding effect on the water quality associated with external inputs from the broader catchment. The way in which scores are combined in all the modules of the revised version of WET-Health is, however, an aspect that requires further testing and consideration. Once the suite of tools that have been developed as part of the current project have been applied more widely by a diversity of users and across a wider range of scenarios, it will be possible to determine whether any revisions are needed to the way in which various scores are combined in Version 2.0 of the assessment method.

WQ Step 1D-2: Derive an integrated magnitude-of-impact score for external surface water inputs

Here, the final magnitude-of-impact scores for the wetland buffer (representing "lateral inputs", as calculated in **WQ Step 1B-1**) and the broader catchment of the wetland (calculated in **WQ Step 1B-2a** for a Level 1A assessment and in **WQ Step 1D-1** for Level 1B and Level 2 assessments) are automatically combined to derive an integrated magnitude-of-impact score for the change in wetland water quality associated with surface flows from the external catchment (see **Figure 9.11**, below).

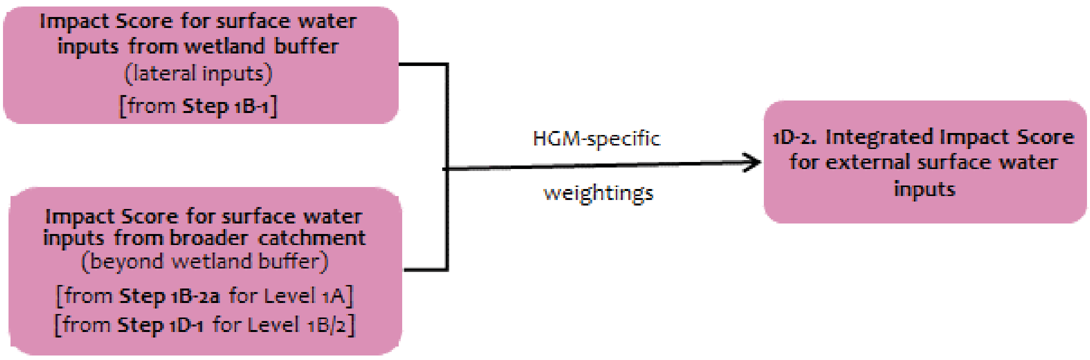


Figure 9.11. Conceptual diagram showing how an integrated magnitude-of-impact score for the change in wetland water quality associated with surface flows from the external catchment is derived

The input scores are combined using HGM-specific weightings, which in the case of Level 1B and Level 2 assessments are based on the assumed relative importance of landuses within the three external "areas of influence" that are considered for these assessments (as outlined in **Table 9.9**). The spreadsheet tools that have been developed for Level 1B and Level 2 assessments automatically determine from the landuse extent data entered into the "Inflowing stream buffers" column of the "Catchment landcover" worksheet whether a depression (endorheic or exorheic) has any channelled inflows so they can be appropriately classified into HGM sub-types (i.e. “DEP-endo-in” and “DEP-exo-in”). All the other HGM types and sub-types are entered by the assessor in the “Wetland attributes” worksheet of the relevant spreadsheet, as explained previously.

Table 9.9. The relative weightings for the three external "areas of influence" in a Level 1B or Level 2 assessment (wetland buffer, inflowing stream buffers, and remaining catchment), which are used to derive an overall score for the potential impact of surface runoff from these areas of influence on the water quality of different types of wetlands (classified by HGM type and sub-type#)

HGM type (and sub-type)		Weighting (%)		
		Wetland buffer (200 m)	Inflowing stream buffers	Remaining catchment (minus buffers)
Floodplain wetland (FP)		10	67.5	22.5
Channelled valley-bottom wetland (CVB)	**CVB-chan**	30	52.5	17.5
	CVB-lat	70	22.5	7.5
Unchannelled valley-bottom wetland (**UVB**)		30	52.5	17.5
SEEP		80	20	
Depression (DEP)	**DEP-endo-in**	80	15	5
	DEP-exo-in	80	15	5
	DEP-endo	80	0	20
	DEP-exo	80	0	20
FLAT		80	20	

CVB-chan = CVB wetland dominated by water inputs from the channel; CVB-lat = CVB wetland dominated by lateral inputs; DEP-endo = endorheic depression without channelled inflow; DEP-endo-in = endorheic depression with channelled inflow; DEP-exo = exorheic depression without channelled inflow; DEP-exo-in = exorheic depression with channelled inflow.

Rationale for scores in Table 9.9

The weightings in Table 9.9 are an attempt to account for differences in the way in which water and sediment moves into different wetland HGM types from the external areas surrounding a wetland. This, in turn, affects the degree to which runoff from the different areas of influence can alter the water quality of a wetland. Lateral inputs from the immediate GIS buffer of the wetland are given the highest weighing (80%) for depressions, flats and seeps because it is assumed that these types of wetland receive far more significant surface water and sediment inputs from the areas around the margin of the wetland than from the more distant portions of the catchment. The 200 m wide wetland buffer has also been given a relatively high weighting (70%) for channelled valley-bottom wetlands that are driven primarily by lateral inputs (CVB-lat) because, by definition, the inputs from the immediate GIS buffer are a lot more important than those from the overtopping of the channel or the more distant portions of the catchment. For channelled valley-bottom wetlands dominated by water inputs from the through-flowing channel (CVB-chan) and unchannelled valley-bottom wetlands, it is presumed that water and sediment inputs from the more distant portions of the catchment are more important than those from the immediate buffer, explaining the weighting of 30% given to the buffer for these HGM types. Floodplain wetlands are presumed to be driven primarily by water and sediment inputs from inflowing streams and overtopping of the channels flowing through the wetland, thus being assigned a low weighting of 10% for the immediate wetland buffer. For depressions without inflowing channels (DEP-endo and DEP-exo), the inflowing stream buffers are obviously given a weighting of zero, leaving a weighting of 20% for the remaining catchment. For seeps and flats, an overall weighting of 20% is given to the external areas outside of the immediate (200 m) wetland buffer, based on the assumption that most wetlands of these types don’t have inflowing streams but they are present in some cases. For all the other wetland HGM sub-types, the overall weighting for the external areas outside of the immediate wetland buffer is split between the inflowing stream buffers and the remaining broader catchment in a ratio of 3:1. As explained previously, this is due to the water and sediment inputs from the GIS buffers adjacent to the inflowing streams typically being of far greater importance than the more distant portions of the remaining catchment in terms of wetland water quality.

For Level 1A assessments, the HGM sub-types would not have been classified. In addition, the inflowing streams would not have been mapped and buffered, and the true topographical catchment of a wetland would not have been delineated. Due to these limitations for such broad-scale, desktop-based assessments, a simplified HGM-specific weighting system is used to automatically derive the preliminary overall magnitude-of-impact score for water quality (see **Table 9.10**). For depressions, an assumption is made that they are endorheic. This provides a "worst case scenario" for assessing potential pollution of the wetland, which is considered to appropriate for a less detailed, desktop-based assessment.

Table 9.10. The relative weightings for the two external "areas of influence" in a Level 1A assessment (wetland buffer and broader catchment), which are used to derive an overall score for the potential impact of landuses in these areas of influence on the water quality of different types of wetlands (classified by HGM type)

HGM type	Relative weightings	
	Broader catchment (EXT-Catch)	Wetland buffer (EXT-Buff)
Floodplain wetland (**FP**)	80	20
Channelled valley-bottom wetland (**CVB**)	50	50
Unchannelled valley-bottom wetland (**UVB**)		
SEEP	20	80
Depression (**DEP**)		
FLAT		

Rationale for scores in Table 9.10

When conducting a Level 1A assessment, besides using less refined HGM types, the true topographical catchments of the wetlands that are being assessed are not usually delineated. Instead, a "pseudo-catchment" such as a Quaternary catchment or a Sub-Quaternary Catchment is used as a proxy for the true catchment. This typically results in portions of the area taken as the "catchment" of a wetland being located outside of the true catchment of the wetland, where the landuse can have no effect on the water quality of the wetland through surface runoff. To ensure that the landuses in the more distant (often irrelevant) parts of the pseudo-catchment do not skew the results that are generated, the weightings for the broader catchment have been reduced for a Level 1A assessment, in comparison to the weightings for a Level 1B or Level 2 assessment. For example, the broader catchment has been given a weighting of 80% for floodplain wetlands and 50% for unchannelled valley-bottom wetlands, versus 90% and 70%, respectively, for a Level 1B/2 assessment. For channelled valley-bottom wetlands, equal weightings (of 50%) have been being given to the immediate buffer and the broader catchment in the case of a Level 1A assessment because it is not known whether the channelled valley-bottom wetland being assessed is driven primarily by channel overtopping or by lateral inputs (since HGM sub-types are not distinguished at this level of assessment). The weightings for depressions, seeps and flats, in the case of a Level 1 assessment, are the same as those used for a Level 1B/2 assessment.

<u>WQ Step 1D-3</u>: Account for inherent sensitivity of wetland to external pollution inputs based on its size

Large (typically deeper) wetlands have a greater inherent buffer capacity and are, therefore, less likely to be affected by changes in pollution inputs from external sources than small (typically shallower) wetlands, where moderate changes in pollutant inputs could have more of a substantial impact on the water quality of the wetland (Macfarlane & Bredin, 2017a, b). For a Level 2 assessment, therefore, a modified magnitude-of-impact score is automatically generated for external water inputs by multiplying the integrated score (as derived in **WQ Step 1D-2**) by a factor relating to the size of the wetland, according to the multiplier scores presented in **Table 9.11**.

Table 9.11. Categories and associated scores for deriving a modifier to account for the inherent sensitivity of a wetland to external pollution inputs based on its size (areal extent)

Score:	**0.8**	**0.9**	**1**	**1.1**	**1.2**
Size of the wetland (surface area)	Large (>200 ha)	Intermediate to large (>50 – 200 ha)	Intermediate (>10 – 50 ha)	Small to intermediate (>1 – 10 ha)	Small (≤1 ha)

Rationale for scores in Table 9.11

The scores in this table are based on the aerial extent of the wetland, although in reality the dilution capacity of a wetland is more directly related to the total volume of water stored in the wetland. It is, however, a lot easier to determine the surface area of a wetland than it is to determine the water storage volume, and there is a tendency for wetlands with a greater surface area to have a larger storage volume. The application of the scores allows for a moderation of the water quality impact from external pollution inputs in the case of larger wetlands (>50 ha in aerial extent), versus a magnification of the impact for smaller wetlands (<10 ha in aerial extent). If a wetland is being assessed that is known to have a large volume despite having a relatively small surface area (e.g. because it is particularly deep), or vice-versa, the assessor should adjust the score recorded for this factor accordingly.

WQ Step 1D-4: Derive a final magnitude-of-impact score for external surface water inputs

The modified magnitude-of-impact score, factoring in the size of the wetland (as derived in **WQ Step 1D-3**), is automatically multiplied by a factor indicating the importance of surface water inputs from the catchment relative to inputs from the regional aquifer (as derived in **WQ Step 1A**). This generates a final magnitude-of-impact score for surface water inputs from the upslope catchment in a Level 2 assessment. For a Level 1B assessment, the integrated magnitude-of-impact score (from **WQ Step 1D-2**) is used in this calculation, instead of the modified magnitude-of-impact score (which is only generated for Level 2 assessments in **WQ Step 1D-3**). The formula for the calculation, for both Level 1B and Level 2 assessments, is as follows:

[FINAL IMPACT SCORE] for external surface water inputs =
[INTEGRATED IMPACT SCORE (modified for Level 2)] X (1 – [AQUIFER-CONNECTIVITY FACTOR])

In the case of a Level 1A assessment, the importance of surface water inputs from the catchment relative to inputs from the regional aquifer is not factored in, so the integrated magnitude-of-impact score generated in **WQ Step 1D-2** is the final impact score for external water inputs.

WQ Step 1E: Derive a combined Impact Score for all external water inputs

The last part of WQ Step 1, for assessments at Levels 1B and 2, is the derivation of a combined water quality impact score for surface water and groundwater inputs. This automated step (schematically illustrated in **Figure 9.4**) simply involves the adding of the final weighted score for impacts associated with regional aquifer (as derived in **WQ Step 1A**) to the final weighted score for impacts associated with surface water inputs from the upslope catchment (as derived in **WQ Step 1D-4**). The result is an overall impact score for the external impacts on wetland water quality. As the contribution of the regional aquifer to wetland water quality impacts is not considered in the case of Level 1A assessments, this step is not relevant and (as mentioned above) the overall impact score is taken as the integrated magnitude-of-impact score for the change in wetland water quality associated with surface flows from the external catchment that was derived in **WQ Step 1D-2**.

It is important to recognise that, with the completion of Step 1 in the assessment process for the Water Quality module, an assessment has been made of the water quality impacts resulting from external (surface and groundwater) inputs only. Water quality impacts resulting from within-wetland activities have not been taken into account in this set of steps, specifically the impact of within-wetland landuses and the impact of point-source discharges directly into a wetland. These impacts are taken into account in **WQ Step 2**.

WQ Step 2: Assess the potential impact of within-wetland activities on wetland water quality

The within-wetland activities that are assessed, in terms of their impact on wetland water quality, are landuses within the wetland itself (Step 2A) and point-source discharges directly into the wetland (Step 2B), as shown schematically in **Figure 9.12** (below).

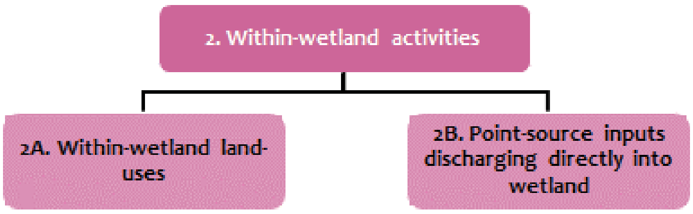


Figure 9.12. Conceptual diagram showing the secondary components included in the assessment of the potential impact of within-wetland activities on wetland water quality

WQ Step 2A: Assess the potential impact of within-wetland landuses on wetland water quality

In this step, the assessor is simply required to record the extent (in hectares) of each of the specified landcover types that have been mapped within each wetland to be assessed, in the "Wetland landcover" worksheet of the spreadsheets for Level 1B and Level 2 assessments, and in the “WET_entry” worksheet of the Level 1A spreadsheet. The relevant spreadsheet tool then automatically derives a preliminary magnitude-of-impact score for within-wetland landuses, in the "WET_Magnitude" worksheet (hidden by default), by multiplying the proportional extent of each landuse category within each wetland by the pre-assigned impact intensity scores for the various landcover categories (as illustrated in **Figure 9.13**). The adjustments for ore and coal mining, which were explained under Step 1B (see **WQ Step 1B**, in particular **Table 9.3** and **Figure 9.7**), are factored into these calculations.

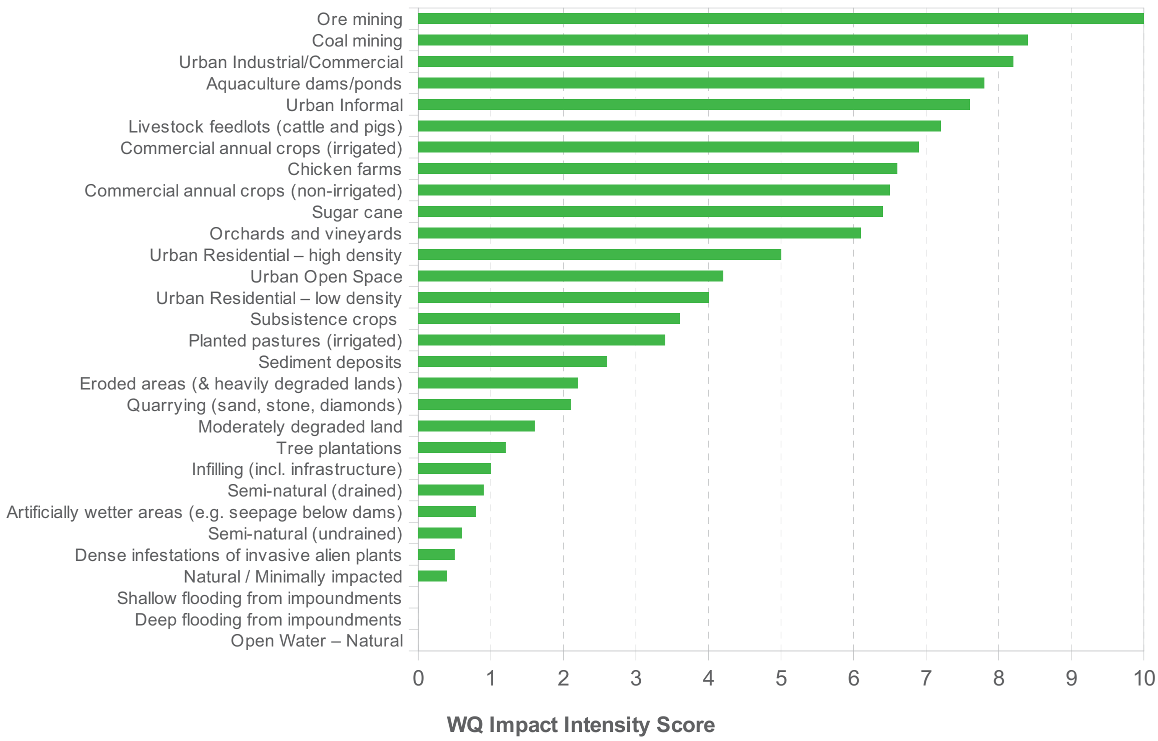


Figure 9.13. Pre-assigned water quality intensity scores (normalised sum) for the landcover categories considered within a wetland in "Level 1B" and "Level 2" assessments

Rationale for scores in Figure 9.13

As explained in the introduction to **WQ Step 1B**, the default water quality impact intensity scores that have been derived for landuses within a wetland represent what is considered to be the maximum impact that runoff from each of the listed landuses can have on the water quality of a wetland, on a scale of 0-10 relative to the other landuses (see **Table 9.2** and rationale provided for the scores in the note below **Figure 9.5**, in particular). These "worst-case scenario" scores for each of the listed landuse categories would be obtained if the entire wetland was occupied by the relevant landuse type. Additional explanations for the default within-wetland Water Quality Impact Intensity scores that have been assigned to the predefined landcover categories are provided in **Section 5.3[A]**.

WQ Step 2B: Assess the potential impact of point-source inputs discharging directly into the wetland

Once the potential impact of within-wetland landuses has been taken into account, the influence of point sources of pollution discharging directly into a wetland must be factored into the assessment of wetland water quality for a Level 2 assessment. The option is also available (but not compulsory) to take point-source inputs into account in a Level 1B assessment. Point-source pollution can often be of over-riding importance, especially if it is discharging directly into a small and/or endorheic wetland. The assessor is required to identify all point-sources of pollution that discharge directly into a wetland (via a pipe or other conduit), which can only be done properly by conducting a site visit to the wetland except for known or major inputs such as a WWTW discharging into a wetland.

The impact intensity scores that have been assigned to the seven types of point-source pollution that are considered for direct discharges of effluent into a wetland are presented in **Table 9.7** and **Figure 9.9** (under **WQ Step 1C**: Assess the potential impact of point-source discharges into inflowing streams).

For each point-source that is identified and verified to be discharging directly into a wetland (which typically requires a site visit), when conducting a Level 2 assessment, the following information must be recorded in the relevant spreadsheet:

- The effluent must be categorised into one of the seven relevant outlet types;
- The relative discharge volume must be categorised as high / medium / low volume; and
- An estimate of the proportion of the wetland that is affected by the input of the effluent must be made, using the five categories provided (see **Box 9.1**).

The relevant worksheet allows for the capturing of this information for up to five point-source discharges into a wetland. The worksheet automatically categorises the wetland size class, using the within-wetland landuse extent data that were entered in WQ Step 2A. This provides an easily obtainable relative indication of the dilution capacity of the wetland (which is, ultimately, dependent on the volume of water in the wetland[24]). The categories and associated scores for the discharge volume, the wetland size class and the proportion of the wetland affected are given in **Table 9.12**, below. This table also shows how these scores are used, together, to modify the default impact intensity score for the relevant effluent type so as to derive an overall impact score for each point-source pollution input identified by the assessor to be discharging directly into a wetland.

Table 9.12. Categories and associated scores for evaluating the relative volume of point-source discharges directly into a wetland, the size class of the wetland and the proportion of the wetland affected by a particular point-source discharge

Multipliers for point-source discharges directly into wetland: Level 2 assessment					
A. Loading factors:	**Score**				
	0.8		**0.9**		**1.0**
A1. Discharge volume	Low (<50 m³/day)	-	Medium (50-250 m³/day)	-	High (>250 m³/day)
B. Dilution factors:	**Score**				
	0.6	**0.7**	**0.8**	**0.9**	**1.0**
B1. Wetland size class	Large (>200 ha)	Med-Large (50-200 ha)	Medium (10-50 ha)	Small (1-10 ha)	Very small (<1 ha)
	0.1	**0.25**	**0.5**	**0.75**	**1.0**
B2. Proportion of wetland affected	Very small (<10%)	Small (10-40%)	Moderate (40-60%)	Large (60-90%)	Very large (>90%)
A: Initial load = [Impact intensity score for effluent type (Table 9.7 & Figure 9.9)] * [A1] **B: Dilution multiplier = Average of [B1] & [B2]**					
Final Impact Score (per point source) = [Initial load (A)] * [Dilution multiplier (B)]					

NOTE: Table also shows how multipliers are derived and applied to determine final Impact Score for each point-source input discharging directly into a wetland.

Rationale for scores in Table 9.12

The variables and associated scores in Table 9.12 serve to moderate the impact intensity scores for point source discharges directly into a wetland, unless the effluent is being discharged at a high volume (>250 cubic metres per day) into a very small wetland (<1 ha in size) and is affecting a very large proportion (>90%) of the wetland. In all other cases, the impact of the point-source discharge on the water quality of the wetland will be less severe than this "worst-case scenario" and the preliminary impact intensity score (as shown in **Figure 9.9**) will be moderated by a factor of between just under 0.3 and 0.9. Except for situations where a small proportion of a

[24] As explained previously, in the discussion relating to accounting for the inherent sensitivity of a wetland to external pollution inputs based on its size for external surface water inputs (under **WQ Step 1D-3**), the aerial extent of a wetland can be used as a coarse proxy for the total volume because there is generally a relatively strong positive correlation between these two variables.

wetland is affected, the moderating multipliers generated for point-source inputs discharging directly into a wetland are generally not as “severe” as those for point-source inputs into the inflowing streams of a wetland because discharges entering directly into the wetland will typically have a greater impact on the water quality of the wetland than those entering upstream.

The way the scoring has been set up, as in the case of point-source pollution inputs into inflowing streams, is to first provide an estimate of the loading (by multiplying the relevant impact intensity score by a “loading factor” based on the categorised discharge volume of the effluent), and then multiply this “initial load” score by a “dilution multiplier” (which is calculated by taking the average of the scores for the two “dilution factors” that are considered). As explained previously, this scoring system was developed through a process of trial-and-error in the application of various permutations during the case study testing that was undertaken, in an attempt to devise a method for factoring in point-source pollution that is scientifically robust yet not too complex for the user of the “tool” to apply.

Box 9.1. A note about estimating the proportion of a wetland affected by the discharge of a point-source pollution input directly into the wetland

As part of **WQ Step 2B** (Assess the impact of point-source inputs discharging directly into the wetland), at least for a Level 2 assessment and certain Level 1B assessments, the assessor must estimate and categorise the proportion of a wetland affected by each direct point-source input that is identified to be present. This is not an automated process and requires the assessor to apply their mind to the particular situation being assessed. In some cases, this will be relatively easy. For example, if there is a point-source discharge such as a residential stormwater outlet entering a valley-bottom wetland near the downstream extremity of the wetland, it should be clear that a small (10-40%) or very small (<10%) proportion of the wetland is being affected, depending on exactly how far upstream from the end of the wetland the effluent enters relative to the total length of the wetland.

In other cases, however, it may not be so simple and may require more investigation on the part of the assessor. For example, if a point-source input (such as an industrial effluent outlet) discharges directly into an endorheic depression (or any other wetland without a strong unidirectional movement of water), the “plume of effect” could extend a substantial distance from the inlet point due to diffusion, often affecting the entire wetland (especially for small endorheic systems). In much larger wetlands, even if they are endorheic and/or don’t have a strong unidirectional movement of water through them, a point-source input discharging directly into the wetland is less likely to affect the entire system. Here, the assessor will need to use their own discretion and knowledge of the system to estimate the proportion of the wetland that is likely to be affected. It is important to remember that these estimates do not need to be precise, only requiring the assessor to determine which of the five (or three) categories is most appropriate.

Irrespective of whether the situation being assessed is simple or complex, it is important to remember that the *entire extent of the wetland* (and not just the portions containing flowing or standing water) must be considered when estimating the proportion affected by point-source inputs. This means that even the portions of wetland that do not consist of channels or open bodies of water must be included as part of the wetland, such as the vegetated wetland areas situated adjacent to a through-flowing channel in the case of a channelled valley-bottom wetland system. If this is not done correctly, and only the portions of wetland containing flowing or standing water are considered, the assessor will significantly over-estimate the proportion of wetland affected by direct point-source inputs.

To cater for the relatively common scenario where the assessor does not know what the discharge volume of a point-source discharge is, the spreadsheet tool automatically assigns a default discharge score/category based on the type of effluent that is selected, using the following “rules”:

- High discharge volume of >250 m^3/day [“loading score” = 1.0] is assigned to “Treated sewage effluent (large WWTW)”;
- Medium discharge volume of 50-250 m^3/day [“loading score” = 0.9] is assigned to “Treated sewage effluent (small-med WWTW)”; and
- Low discharge volume of <50 m^3/day [“loading score” = 0.8] is assigned to all other point-source types.

Where the discharge volume of the selected effluent type is known, these default scores/categories can and should be overridden with the correct score/category by the assessor in the relevant worksheet.

In the case of a Level 1B assessment, where point-source inputs discharging directly into a wetland can be factored into the assessment as an additional option, the scoring process has been simplified as it has been for point-source inputs into the inflowing streams of a wetland. Again, besides only catering for the consideration of two point-source discharges (versus five in the case of a Level 2 assessment), the discharge volume does not need to be categorised in a Level 1B assessment because this is automated following the above-mentioned "rules" without the option to override the result. Furthermore, the number of categories for the proportion of the wetland affected by a particular point-source input have been reduced to three (i.e. small: <25%; moderate: 25-70%; large: >70%, with associated "dilution scores" of 0.2, 0.6 and 0.9, respectively), versus five categories in the case of a Level 2 assessment (see **Table 9.12**).

The overall impact scores per point-source discharge that are derived through the assessment process explained above are automatically added together in the relevant spreadsheets, using the cumulative summing algorithm explained in **Box 5.1** (as is the case for point-source inputs into the inflowing streams of a wetland). This produces an overall magnitude-of-impact score for all the point source effluents identified to be discharging directly into a wetland.

WQ Step 2C: Derive a combined Impact Score for within-wetland activities

A final magnitude-of-impact score for within-wetland activities is derived by taking the maximum value of the impact score for landuses within the wetland and the overall impact score for point-source discharges directly into the wetland (if relevant), as shown schematically in **Figure 9.14** (below). This calculation is automated in the spreadsheet tools that have been developed.

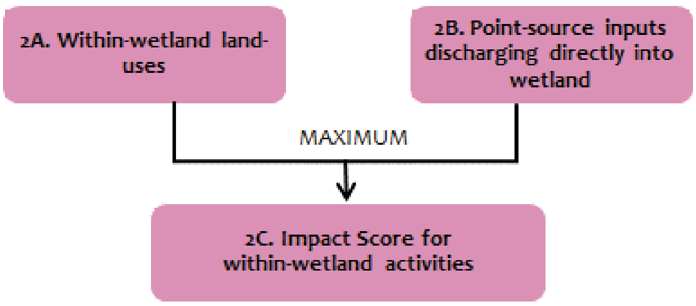


Figure 9.14. Conceptual diagram showing how a final magnitude-of-impact score for within-wetland activities is derived

Initially, in earlier revisions of WET-Health Version 2.0, the impact scores for within-wetland landuses and point-source inputs discharging directly into a wetland were integrated using the cumulative summing algorithm explained in **Box 5.1**. Through the case-study testing that was undertaken, however, it was found that this approach tended to produce an over-inflated integrated impact score, particularly when at least one of the scores represented a large impact. The use of the average of the two scores, on the other hand, was found to produce scores that were too low in situations where one of the input scores is significantly higher than the other one. As in the case of integrating the impact scores for diffuse runoff from the broader catchment and point-source inputs into inflowing streams (**WQ Step 1D-1**), it was concluded that taking the maximum of the two scores more consistently produces an overall result is reflective of the actual impact. As explained previously, however, the way in which scores are combined in all the modules of the revised version of WET-Health is an aspect that requires further testing and consideration.

WQ Step 3: Derive overall PES Score and Ecological Category for Water Quality

The derivation of an overall PES Score and Ecological Category for water quality, as the penultimate step in the assessment process, involves the following (see **Figure 9.15**):

(1) Combining the impact scores for external water inputs and within-wetland activities (Step 3A);

(2) Accounting for endorheic drainage and the impact of reduced water inputs (Step 3B); and

(3) Converting the final water quality impact score into a PES Score and assigning an Ecological Category (Step 3C).

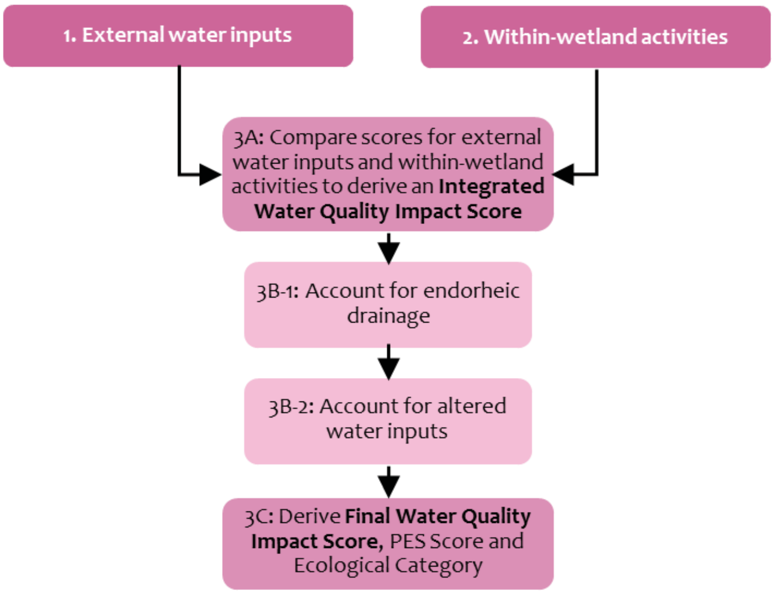


Figure 9.15. Conceptual diagram showing the sub-steps followed in deriving an overall PES Score and Ecological Category for wetland water quality, once the scores for external water inputs and within-wetland activities have been determined

WQ Step 3A: Compare scores for external water inputs and within-wetland activities to derive an Integrated Water Quality Impact Score

The final magnitude-of-impact-score for within-wetland activities (as derived in **WQ Step 2**) is compared to the overall magnitude-of-impact score for external inputs (as derived in **WQ Step 1**), and the maximum of these two scores is taken as the Integrated Water Quality Impact Score.

The same method of deriving an Integrated Water Quality Impact Score is used for all levels of assessment (i.e. Levels 1A, 1B and 2), although there are additional steps for deriving the input scores at each successive level of assessment. In the case of a Level 1A assessment, the integrated impact score derived in this step is taken as the Final Water Quality Impact Score. For assessment at Levels 1B and 2, however, endorheic drainage and the impact of reduced water inputs are accounted for in an additional step (**WQ Step 3B**), before deriving a Final Impact Score.

Initially, in earlier revisions of WET-Health Version 2.0, the overall magnitude-of-impact scores for within-wetland activities and external inputs were integrated using the cumulative summing algorithm explained in **Box 5.1**. Through the case-study testing that was undertaken, however, it was found that this approach tended to produce an over-inflated integrated impact score, particularly when at least one of the scores represented a large impact. The use of the average of the two scores, on the other hand, was found to produce scores that were too low in situations where one of the input scores is significantly higher than the other one. It was, in the end, concluded that taking the maximum of the two scores more consistently produces an overall result is reflective of the actual impact. As explained previously, however, it is important to note that the way in which scores are combined in all the modules of the revised version of WET-Health is an aspect that does require further testing and consideration.

WQ Step 3B: Account for endorheic drainage and the impact of reduced water inputs

For Level 1B and Level 2 assessments, once an Integrated Water Quality Impact Score has been derived (in **WQ Step 3A**), the outflow drainage characteristics of the wetland (endorheic versus exorheic) are accounted for in **WQ Step 3B-1** and the impact of reduced water inputs in **WQ Step 3B-2**. These additional steps are not carried out in the case of a Level 1A assessment.

WQ Step 3B-1: Account for endorheic drainage

In an endorheic (inward-draining or "non-flushing") wetland system, by definition, water only leaves through evaporation and vertical infiltration (Ollis *et al*., 2013). This typically results in an increased concentration of pollutants (and of dissolved salts, in general) in such systems over time, compared to exorheic (outward-draining or "flushing") systems. An attempt has been made to account for this in the Water Quality module, specifically for endorheic depressions (the only HGM type that is truly endorheic).

For Level 1B and Level 2 assessments in which the selected refined HGM type is "Depression without flushing" (i.e. an endorheic depression), the Integrated Water Quality Impact Score (as derived in **WQ Step 3A**) is simply multiplied by a factor of 1.2 (with the maximum score constrained to 10) to account for the accumulation of pollutants that typically occurs in these inward-draining systems.

WQ Step 3B-2: Account for altered water inputs

Water quality has a close, but complex, relationship with water quantity and changes to the hydrological regime of an aquatic ecosystem. The nature of the relationship depends strongly on the location and characteristics of the individual catchment, and the type of aquatic ecosystem (Sinclair Knight Merz, 2013). Despite these complexities, which are further complicated by variations in the quality of the inflowing water, a *decrease* in the inflow quantity to a wetland typically results in an increase in the concentration of pollutants within the wetland. An increase in the concentration of pollutants within a wetland leads to a concomitant shift in the water quality of the wetland from its natural reference range in terms of most of the water quality parameters of potential concern.

The relationship between water quantity and quality is less clear for an *increase* in the inflow quantity to a wetland because it is so dependent on the inflowing water quality. For example, the change in water quality of a wetland receiving an increased quantity of highly polluted water would be very different to that of the same wetland receiving a similar increase in the quantity of inflowing water but with near-natural water quality (Malan & Day, 2012).

An attempt has been made to factor in the potential impact of decreased inflows into the PES assessment of wetland water quality, in a very simplified manner. This is done by taking a fraction of the score for the extent to which the inflow quantity into a wetland has been decreased, which is obtained from **Hydro Step 2A**, and multiplying the Integrated Water Quality Impact Score (derived in **WQ Step 3A**) by this this modifier. The water inputs modifier only applies to negative values (i.e. a reduction in the inflow quantity), and it is constrained to a factor of 1.25 (by dividing the absolute value of the relevant score from the Hydrology module by 40) to avoid over-inflating the influence of this modifier on the final score.

WQ Step 3B-3: Derive an Adjusted Water Quality Impact Score

The modifiers for endorheic drainage and reduced water inputs are both, in turn, multiplied by the Integrated Water Quality Impact Score (from **WQ Step 3A**), to derive an Adjusted Water Quality Impact Score (constrained to a maximum value of 10) for Level 1B and Level 2 assessments. The maximum value of the multiplier that could be applied to the Integrated Water Quality Impact Score, taking both modifiers into account, is 1.5 (= 1.2 x 1.25).

WQ Step 3C: Derive Final Water Quality Impact Score, PES Score and Ecological Category

The Final Water Quality Impact Score is taken as the Integrated Water Quality Impact Score from **WQ Step 3A** for Level 1A assessments, and as the Adjusted Water Quality Impact Score from **WQ Step 3B** in the case of Level 1B and Level 2 assessments. This impact score, which has a maximum value of 10, is converted into a PES Score by simply subtracting it from 10. The relevant Ecological Category (A-F) is then automatically determined from this score, following the pre-defined ranges for the different categories as presented in **Table 3.2** (see **Section 3.4**).

In the case of Level 1A assessments, the completion of Step 3C is typically the end of the PES assessment process for wetland water quality. For Level 1B and Level 2 assessments, however, the assessor is still required to review the outputs and derive a Revised Final PES Score and associated Ecological Category for water quality (in **WQ Step 4**). In addition, as part of the final step, an assessment must be provided of the anticipated trajectory of change in the water quality of the wetland.

WQ Step 4: Review outputs, derive Revised Final PES Score for water quality and assess anticipated trajectory of change

In the final step of the assessment process, at least in the case of Level 1B and 2 assessments, the assessor is provided an opportunity to review and revise the final PES scores for water quality, and to determine the anticipated trajectory of change in the water quality of a wetland.

WQ Step 4A: Review the predicted degree to which individual water quality parameters have changed relative to the presumed natural reference state

In addition to calculating a Final Water Quality Impact Score, the spreadsheet tool that has been developed for Level 2 assessments also (in the background) automatically generates impact scores for the individual water quality parameters that have been incorporated into the model for surface water inputs[25]. As explained previously (in the introduction to **WQ Step 1B** and under **WQ Step 1C**), the pre-specified water quality parameters included in WET-Health Version 2.0, for both diffuse and point sources of pollution to surface waters, are ***nutrients (N and P), BOD/COD, dissolved salts (TDS), suspended sediments, heavy metals and other toxics***. The parameter-specific impact scores that are generated represent the relative amount that each of these parameters contributes towards the

[25] This is only done for Level 2 assessments. Although it is theoretically possible to generate parameter-specific impact scores for Level 1B assessments where point-source inputs have been taken into account, this additional detail and complexity is considered to be inappropriate for these less intensive assessments.

overall magnitude-of-impact scores derived in the Water Quality module, excluding scores relating to changes in the water quality of the regional aquifer[26].

The integrated impact scores that are generated for individual water quality parameters are derived by following the same procedures and "rules" that are followed in the derivation of overall Water Quality PES scores, as far as possible, except that the parameter-specific default impact intensity scores are used, instead of the overall (summed and normalised) scores. In essence, the default landuse-related impact intensity score for each parameter (as presented in **Table 9.2**) is multiplied by the relative extent of each landuse type within the wetland and in each of the external areas of influence to derive a set of parameter-specific scores for diffuse pollution[27]. To derive parameter-specific scores for point-source pollution, the default intensity scores for the different types of point-source effluent (as presented in **Table 9.7**) are multiplied by the relevant "loading factors" and "dilution factors" from the assessment of overall impacts. These scores are then combined, for each parameter, using the same "rules" that are applied when combining scores in the overall assessment of water quality PES, to derive a set of parameter-specific integrated impact scores for surface water impacts.

As in the case of the impact scores for overall water quality, the parameter-specific integrated impact scores also have a maximum value of ten. These scores are presented in the Water Quality Module worksheet of the spreadsheet developed for Level 2 assessments, under "STEP 4: REVIEW THE PREDICTED DEGREE TO WHICH THE SPECIFIED WATER QUALITY PARAMETERS OF POTENTIAL CONCERN HAVE CHANGED WITHIN THE WETLAND". An indication of the predicted degree to which each water quality parameter has changed relative to the presumed natural reference range, based on the scores, is also provided, using the following categories and criteria:

- *High degree of change* (**H**): Integrated score >=8
- *Medium-to-high degree of change* (**M-H**): Integrated score = 6-7.9
- *Medium degree of change* (**M**): Integrated score = 5-5.9
- *Low-to-medium degree of change* (**L-M**): Integrated score = 4-4.9
- *Low degree of change* (**L**): Integrated score = 2-3.9
- *Very low degree of change* (**VL**): Integrated score = 0-1.9

The categories above are also presented, for each parameter, in the "Review" worksheet of the spreadsheet tool for Level 2 assessments (see example of output in **Figure 9.16**). This serves as a useful point of reference against which water quality data for the wetland (if available) can be compared. In particular, for those parameters for which water quality data are available (preferably collected over a long term, as opposed to once-off measurements), the predictions of the model can be evaluated. For example, if the model predicts that the degree of change for nutrients (N and P) is low and there are long-term nutrient measurements available for the wetland that show the wetland is consistently in a eutrophic-to-hypertrophic state (i.e. highly nutrient enriched relative to the natural state), then this indicates that the predictions of the model are inaccurate. In such a case, the assessor should first go back and re-evaluate the scores and answers they initially provided in the assessment to see if changing some of these produces results that bring the predictions closer to what the measurements

[26] The simplistic way in which impacts on groundwater quality have, at this stage, been incorporated into the assessment of overall wetland water quality PES in WET-Health Version 2.0 does not incorporate the consideration of individual water quality parameters. This is an aspect that should be considered for future revisions of the method, through the involvement of groundwater water quality specialists.

[27] When deriving parameter-specific impact scores for landuse-related impacts, the same default impact intensity scores are used as the starting point for both within-wetland impacts and impacts relating to the external areas of influence. The summed magnitude-of-impact scores (generated after multiplying the default intensity scores by the relative extent of each landuse type) are then divided by 1.5 in the case of the external areas of influence. This is done to achieve a similar ratio between scores for within-wetland and the external areas of influence as is used for the assessment of overall impacts, which is not obtained if the individual (parameter-specific) default impact intensity scores for all the different landuse types are first divided by this factor before multiplying by the relative extent of each landuse type.

suggest as the true situation. If there is still a discrepancy between the predicted results and what the water quality measurements indicate (which suggests that some of the assumptions built into the model may be incorrect), then changes to the relevant scores can be made in the "Review" worksheet, using the available data as justification for these adjustments.

Besides providing an indication of the degree to which each parameter is predicted to have changed from the presumed natural reference state, the categories listed above also provide an indication of which water quality parameters are likely to be of most concern for the wetland. Parameters rated to have a High (H), Medium-to-high (M-H) or even Medium (M) degree of change from the reference range, in particular, are likely to be of most concern in relation to the water quality of the wetland. These are the parameters that should (as a minimum) be included in any water quality monitoring initiatives for a wetland, although parameters that are not identified as being of present concern should also be monitored to check that they are not increasing to levels where they do become of concern. In the example of an output presented in **Figure 9.16**, no water quality parameters were predicted to have changed to a high degree from the presumed reference state but it was predicted that there had been a low-to-medium degree of change in TSS and the concentration of non-metal toxic compounds. These variables would then be of more concern than the others, possibly requiring monitoring, but should not be particularly problematic for present-day water quality based on the modelled present ecological condition of the wetland. A contrasting example would be a wetland for which it is predicted that there has been a high degree of change in the concentrations of N, P and COD/BOD relative to the natural reference state. These three variables, suggesting severe organic pollution, would then clearly be of major concern to the present-day water quality of the wetland.

PREDICTED DEGREE TO WHICH EACH WATER QUALITY PARAMETER HAS CHANGED FROM THE NATURAL REFERENCE RANGE FOR THE WETLAND:		
Nutrients	N	L
	P	L
COD/BOD		L
Salts		VL
TSS		L-M
Toxics	Metals	L
	Other	L-M
Groundwater unlikely to have a major influence on wetland water quality, so the above predictions are more likely to be reliable		
No water quality data available for wetland. Parameter-specific predictions (above) can only be reviewed if water quality data are available as a point of comparison.		

Figure 9.16. An example of the output of the parameter-specific predictions automatically generated in the "Review" worksheet of a Level 2 assessment

[In this example, the contribution from groundwater relative to surface water was insignificant (so the predictions are more reliable) and it was recorded in the "Wetland Questions" worksheet that no water quality data are available for the wetland]

The output that is produced for the predicted degree to which each water quality parameter has changed from the presumed natural reference range for the wetland, as presented in the "Review" worksheet of the spreadsheet tool for a Level 2 assessment (e.g. see **Figure 9.16**), includes an indication of the reliability of the predictions based on the likelihood of a connection to an underlying regional aquifer. More specifically, if the Wetland PES assessment indicates that the relative contribution from an underlying regional aquifer is likely to be 60% or more, compared to surface water inputs, then a message will be auto-generated stating that the parameter-specific predictions in the output are likely to be unreliable. The reason for the lack of reliability in these scenarios is that the integrated parameter-specific scores do not factor in groundwater in the current version of the tool, as explained previously.

The output that is produced also includes an auto-generated message relating to the availability of water quality data for the wetland, based on the answer given by the assessor in the "Wetland Questions" worksheet to the question, "*Are water quality data available for the wetland?*" If the answer is yes, then the following message is given below the table of predicted changes to individual water quality parameters: *Compare available water quality data for the wetland with the above predictions about WQ parameters likely to be of particular concern for the wetland (as highlighted in red and orange) in relation to the other parameters considered*.

It is important to bear in mind that the determination of the predicted degree to which individual water quality parameters have changed relative to the natural reference state is done in a rather simplistic and rudimentary manner at this stage. The results that the preliminary calculations generate have also only received limited testing during the current project, as the focus of testing was on the main outputs of the model relating to overall Water Quality PES. When the Level 2 assessment tool is applied, therefore, these outputs should be treated with some caution and users should attempt to formulate ways in which improvements could be made to this aspect in future revisions of the tool.

WQ Step 4B: Derive Revised Final Impact Score, PES Score and Ecological Category for water quality

For both Level 1B and Level 2 assessments (but not for Level 1A), WET-Health Version 2.0 provides the assessor with an opportunity to review the summarised Water Quality PES scores and to adjust/revise (with motivation) any of the output scores that are considered to be problematic or incorrect. The procedure is explained, for all modules, in **Section 11.1**.

WQ Step 4C: Assess anticipated trajectory of change for Water Quality PES

Once all the required tasks have been completed for deriving a finalised (revised) PES Score and Ecological Category for water quality, as explained in the preceding sections of this chapter, the assessor must provide an assessment of the anticipated trajectory of change in the water quality of the wetland, at least for WET-Health (Version 2.0) assessments at Level 1B or 2. An explanation of this process is given, for all modules, in **Section 12.1**.

10. VEGETATION MODULE

10.1. Introduction

Wetland vegetation has compositional and structural characteristics that provide specialized habitats for a range of important wetland dependant species. Wetland vegetation may also provide a range of locally important goods for local communities such as reeds for weaving, and contribute to regulatory services such as flood attenuation and nutrient retention. It is therefore important to assess vegetation health.

10.1.1. Conceptual Framework

The Present State of the vegetation is evaluated based on the degree to which current vegetation composition has deviated from perceived natural or reference conditions. Assessing this deviation is based primarily on what "should not be there" (e.g. invasive alien species or a high abundance of ruderal (weedy) species) rather than on the composition of indigenous plants that "should be there".

Undertaking an assessment for an entire HGM unit may prove difficult in situations where vegetation is highly variable as a result of different parts of the HGM unit being subject to different disturbances (cultivation, dams, etc.). The evaluation is therefore simplified by defining and assessing the condition of vegetation in "disturbance units" which represent areas where the vegetation has been subject to similar type/s and level/s of human impact (**Section 6.1.1**).

10.1.2. Overview of the steps to be followed in the hydrology assessment process

An overview of the steps involved in the vegetation assessment process are outlined in **Figure 10.1** below. This starts with some precursory steps as outlined in **Section 5** and then involves an evaluation of wetland attributes in each assessment unit based on understanding of the general structure and composition of wetland vegetation in the area. The Present Ecological State of wetland vegetation is then based on a weighted average of all disturbance units.

Precursory steps:

- Mapping of wetland
- Classification of wetlands by HGM type
- Calculate the extent of landcover classes in the wetland
- Delineation of disturbance units

↓

Step 1: Familiarization with the general structure and composition of wetland vegetation in the area

↓

Step 2: Briefly describe the vegetation in each disturbance unit

↓

Step 3: Assess the intensity of impact on the vegetation in each disturbance unit

↓

Step 4: Determine the Present Ecological State based on a weighted average of all disturbance units

Figure 10.1. An outline of the steps involved in the vegetation module

10.2. The Vegetation assessment process

Veg Step 1: Familiarisation with the general structure and composition of wetland vegetation in the area

In order to evaluate changes in vegetation, it is important for the assessor to have a reasonable regional appreciation of the appearance and composition of wetland vegetation under natural conditions. It is also useful to appreciate the response of vegetation to disturbance. Where assessors are not familiar with the vegetation in a particular region they need to familiarize themselves with wetlands in the area before undertaking this assessment. It is important to note, however, that this methodology does not require the assessor to be able to identify all wetland plant species. Rather, the assessor should have a feel for general wetland vegetation characteristics and must be able to identify the alien species, ruderal (weedy) species and common indigenous species, including those that are naturally dominant and those that are invasive or ruderal ("pioneer/weedy species"). Such information can be obtained by undertaking brief field visits to a range of wetlands within the region or working together with a person with a good knowledge of the vegetation of the area. Bromilow (1995) is a useful reference book for identifying alien and ruderal plants and DWAF (2005) and Van Ginkel *et al*. (2010) provide assistance with the identification of indigenous wetland plants.

At this point it is important to note that certain wetland types, e.g. Kalahari salt pans, are entirely lacking in vegetation in their natural reference condition. For the purposes of conducting a WET-Health assessment, a wetland which has less than 5% coverage of vegetation in its natural reference state is taken to be naturally non-vegetated. When such wetlands are assessed, the vegetation module should simply be omitted. In the spreadsheet that has been developed for a Level 2 assessment, this is catered for by the inclusion of a "wetland question" as to whether the wetland is presumed to have less than 5% coverage of vegetation in its natural reference state. If an answer of "Yes" is selected, the Vegetation Impact Score is automatically recorded as "N/A" in the Summary worksheet and an alternative equation is used to calculate the Overall Wetland PES score, only taking into account the Impact Scores for Hydrology, Geomorphology and Water Quality.

Veg Step 2: Briefly describe the vegetation in each disturbance unit

Identification and mapping of disturbance units is described in detail in **Section 6** as one of the upfront steps of the overall method, which precede the four individual modules. From **Section 6.1.1** it can be seen that vegetation plays a key role in identifying and mapping the disturbance units and in the example given in **Figure 6.1** it was seen how the presence of scattered invasive alien plants served as the main basis for distinguishing between two different disturbance units. Thus, it can be appreciated that a key first part of the vegetation assessment has already been set in place with the upfront identification and mapping of disturbance units, which then provide the units within which the remaining steps of the vegetation module are carried out.

Based on walking through representative sections of each of the disturbance units (identified using the methods described in **Section 6.1.1**) very briefly describe each unit, recording what appear to be the two or so most abundant species in each disturbance unit (**Table 10.1**). If a more comprehensive list of plant species in the disturbance units is available then this would increase confidence in the assessment, but is not a pre-requisite for a Level 2 assessment. Where a high confidence assessment is required (e.g. for a Comprehensive Reserve Determination process) users are encouraged to undertake quantitative sample-based assessments. This would entail a detailed assessment and description of species compositions under the current and natural or reference conditions. Suitable approaches would include transect or quadrat assessments designed to specifically enumerate the composition of wetland vegetation at appropriate sites. Additional guidance is also provided for preparing an inventory of invasive alien plants where such an assessment is required to inform management actions (**Box 10.1**).

Table 10.1. Description of the disturbance units within the wetland shown in Figure 6.1

Disturbance unit	Landcover category (Level 2)	Description
DU#1	Commercial annual crops (non-irrigated)	Commercial annual crops (non-irrigated) with no artificial drains. No indigenous vegetation present
DU#2	Commercial annual crops (non-irrigated)	Commercial annual crops (non-irrigated) with no artificial drains. No indigenous vegetation present
DU#3	Natural / Minimally impacted	Natural vegetation used for livestock grazing, with very limited invasive alien plants and dominated by the native hydric species *Cyperus latifolius* and *Ischaemum fasciculatum.*
DU#4	Natural / Minimally impacted	Natural vegetation used for livestock grazing, with scattered invasive alien plants (*Rubus cuniifolius*: American bramble) and dominated by the native hydric species *Cyperus latifolius*
DU#5	Dense infestations of invasive alien plants	Dense infestation of the invasive alien tree, *Acacia mearnsii* (Black wattle) with limited indigenous plants occurring mainly in breaks in the wattle canopy

Box 10.1. Assessing the incidence of invasive alien plants

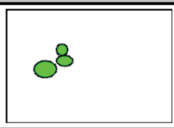
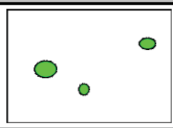
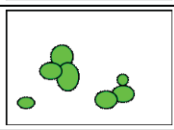
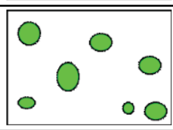
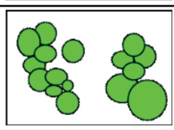
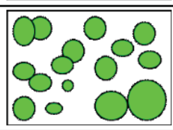
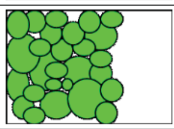
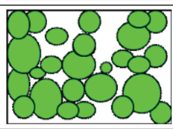
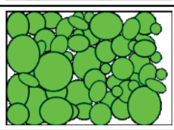
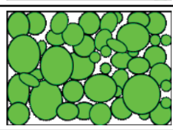
Invasive alien plants are one of the key impacts to wetland vegetation, and if not controlled can rapidly increase in extent over time. Whilst not a requirement of this assessment, there may be merit in recording the presence of invasive alien plants present in each disturbance unit to inform management actions. The template provided in Table 1 can be used to list and estimate the approximate aerial of invasive alien plants in each disturbance unit. Table 2 also provides a useful reference point for carrying out a visual assessment of this nature. Scoring of threat of further invasion, is another important aspect to consider and, if rated, should be referred back to when assessing the trajectory of change for wetland vegetation.

Table 1. Information on invasive alien species to be recorded for each disturbance unit, with the example given of the wetland appearing in Figure 6.1

Dist. Unit	List the invasive alien species present	Aerial extent of invasion (%)	Suspected factors contributing to increased abundance	Threat of further invasion (Low, Medium, High)
1	-	-	-	-
2	-	-	-	-
3	*Rubus cuniifolius*	1%		Medium
4	*Rubus cuniifolius*	15%	Historical disturbance	High
5	*Acacia mearnsii, Rubus cuniifolius*	85%	Historical disturbance and planting	High

Note: Where a detailed weed control strategy must be developed, this table may be expanded to include separate extent estimates for each species present.

Table 2: Classes to assist scoring the aerial cover of invasive alien plants in the disturbance unit.

Diagrams of contiguous situation	Diagrams of highly clumped situation	Diagrams of a loosely clumped situation	Extent range
			1-5%
			6-25%
			26-50%
			51-75%
			75 – 100 %

Veg Step 3: Assess the intensity of impact on vegetation in each disturbance unit

Before assessing intensity of impact on the vegetation, begin by referring to any description that may have been given of the natural reference state of the wetland (**Section 3.2**). This will help to identify wetlands that are particularly challenging from the perspective of assessing vegetation condition. Some examples might include wetland areas that are geomorphologically naturally very dynamic and characterized by the periodic deposition of deep sediment as part of a natural cut and fill cycle, as described Pulley *et al*. (2018). In such wetlands it may be natural to find a very high abundance of ruderal (weedy) species shortly after a major sediment deposition event, which then subsequently decline in abundance through the intervening period.

Now refer to the descriptions of the disturbance units under assessment (**Table 10.1**) and to **Table 10.2**, which provides an indication of the impact scores typically associated with different landcover classes. **Table 10.2** also provides an indication of some specific factors to look out for in assigning an intensity of impact score for each disturbance class.

Next, compare vegetation characteristics to those you would expect in a reference site. **Table 10.3** is then used to allocate an intensity of impact score that reflects the degree to which each disturbance class deviates from the reference conditions.

Table 10.2. Typical intensity of impact scores for disturbance classes that can be used to inform the vegetation assessment

Disturbance class	Typical intensity scores	Specific factors to consider when assigning the score
Infrastructure	10	N/A
Mining and other excavation	9-10	Mining, particularly for coal and ore, generally results in the total removal of all vegetation, Therefore an impact intensity of less than 10 is rare but may occur where small patches of vegetation remain,
Deep flooding by dams	10	N/A
Shallow flooding by dams	5	The impact on vegetation may be less intense where the dams are shallow and emergent plant species are able to persist. The impacts on vegetation depend on the periodicity of flooding and the extent to which seasonal drying out of dam margin occurs
Cultivation	9-10	Impact to wetland vegetation is determined largely by disturbance interval. Drains can also dry out these areas, reducing the likelihood of wetland species persisting in them.
Commercial plantations and woodlots	9-10	Commercial plantations generally result in a gradual suppression of wetland vegetation as indigenous plants become shaded out by commercial species. Pines tend to have a more detrimental impact on wetland vegetation than wattle, gum or poplar due to the slow decaying litter layer that builds up under such plantations.
Planted pastures	9-10	Small scale patches that can be readily colonized by indigenous vegetation are more likely to have at least a little indigenous vegetation present than large, contiguous cultivated patches
Perennial pastures	4-10	The degree of change is largely dependent on the duration between disturbance events and how long ago the area was tilled. The longer the interval between tillage events, and the further back in time the area was tilled, the lower the impact score.
Dense Alien vegetation patches.	7-9	Degree of change is determined largely by the class of plants and their aerial cover. The longer these plants have persisted, the greater the potential impact on wetland vegetation.
Urban open space	7-10	Dependent on the degree of maintenance and species introduced.
Excess sediment deposition & infilling	7-10	The longer the time since the past disturbance (e.g. from cultivation) and the smaller the extent to which the natural hydrology has been altered, the greater the opportunity provided for recovery towards the natural vegetation, unless the area becomes dominated by aggressive invasive alien plants. In addition, the wetter the area was naturally, the more readily it generally recovers to its natural vegetation, as the excessive wetness generally exerts an overriding influence on the other factors.
Eroded areas	3-9	
Semi-natural vegetation, including old abandoned lands	4-8	
Seepage below dams	1-5	The greater the changes in water balance in the wetland area below the dam, the greater the potential change in vegetation characteristics. Historically temporary wetland zones will therefore be more severely affected than seasonal / permanent wetland zones.
Minimal human disturbances	0-3	Many of South Africa's wetlands evolved under burning and grazing by indigenous grazers, and are well adapted to moderate grazing intensities. A change in wetland vegetation does become apparent under heavy grazing pressure where a decrease in basal cover may even trigger significant erosion. Exclusion of grazing and fire may also have a negative consequence through shading out of grazing tolerant wetland species.

Table 10.3. Present Ecological State categories used to define health of wetland vegetation

Description	Impact Score	PES Category
Vegetation composition appears natural.	0-0.9	A
A very minor change to vegetation composition is evident at the site, e.g. the abundance of ruderal/pioneer species is slightly higher than natural.	1-1.9	B
The natural vegetation composition has been moderately altered but introduced alien and/or increased ruderal/pioneer species are still clearly less abundant than native species characteristic of the natural species composition.	2-3.9	C
The natural vegetation composition has been largely altered and introduced alien and/or increased ruderal/pioneer species occur in approximately equal abundance to the characteristic indigenous wetland species.	4-5.9	D
The natural vegetation composition has been substantially altered but some characteristic species remain, although the vegetation consists mainly of introduced, alien and/or ruderal/pioneer species.	6-7.9	E
.The natural vegetation composition has been totally or almost totally altered, and if any characteristic species still remain, their extent is very low.	8-10	F

Veg Step 4: Determine the present vegetation state of the HGM Unit

The magnitude of impact score is now calculated for each disturbance unit based on intensity and extent (e.g. **Table 10.4**). Impact scores are then summed to obtain an overall magnitude of impact score for the HGM unit (bottom row of **Table 10.4**). This is the Present Vegetation State for the HGM unit. In the example given in **Table 10.4**, the overall magnitude of impact of the HGM unit is 4.6, which represents a Present Ecological State category of D, as defined in **Table 10.3**.

Table 10.4. Example of the calculation of the HGM magnitude of impact score based on an area weighted magnitude of impact score for each disturbance class

Disturbance unit	Description	Extent (%)	Vegetation Impact Intensity Score (0-10)	Magnitude of impact score*
DU#1	Commercial annual crops (non-irrigated) with no artificial drains. No indigenous vegetation present	9%	10	0.9
DU#2	Commercial annual crops (non-irrigated) with no artificial drains. No indigenous vegetation present	10%	10	1.0
DU#3	Natural vegetation used for livestock grazing, with very limited invasive alien plants and dominated by the native hydric species *Cyperus latifolius* and *Ischaemum fasciculatum.*	49%	2	1.0
DU#4	Natural vegetation used for livestock grazing, with scattered invasive alien plants (*Rubus cuniifolius*: American bramble) and dominated by the native hydric species *Cyperus latifolius*	19%	3	0.6
DU#5	Dense infestation of the invasive alien tree, *Acacia mearnsii* (Black wattle) with limited indigenous plants occurring mainly in breaks in the wattle canopy	15%	7	1.1
			HGM Magnitude of impact score**	4.6

* Magnitude of impact score is calculated as extent / 100 x intensity of impact

** Overall magnitude of impact score for the HGM unit = sum of magnitude scores for each disturbance class.

11. REVIEW AND INTEGRATION OF FINAL SCORES

11.1. Review and adjustment of impact scores

Once a Level 1B or Level 2 assessment has been completed, the relevant spreadsheet tools provide the assessor with an opportunity to review the output scores for the various aspects that have been evaluated, and to refine some of these scores if deemed necessary. A "Review" tab/worksheet has been incorporated into the relevant spreadsheets for this purpose. The Review worksheet for a Level 1B assessment has less variables to review and adjust than that for a Level 2 assessment, with the latter requiring the review and adjustment of scores to be carried out at a Disturbance Unit (versus whole wetland) level for certain variables (e.g. compare the example of the Hydrology section of the Review worksheet for a Level 1B assessment in **Figure 11.1** with that for a Level 2 assessment in **Figure 11.2**). It is important to fill in the rationale for any changes that are made and to rate the confidence of the revised scores, and the relevant worksheet provides space to do this.

The review of results and provision of an opportunity to adjust certain scores was introduced into WET-Health Version 2 in recognition of the fact that not all scenarios can be catered for in the assessment tools, and to cater for situations where the underlying assumptions of the model are not entirely valid. Scores should only be adjusted by experienced wetland assessment practitioners, however, and well-reasoned justification (with a confidence rating) should be provided for all adjustments that are made.

11.2. Integration of PES scores

Once the PES scores for the individual modules have been determined, the scores are combined into an Overall Wetland PES Score using the following simple formulae:

For vegetated wetlands*

IF PES Score for HYDROLOGY is in Ecological Category A / B / C / D	Wetland-PES = ([Hydro-PES]*3 + [Geo-PES]*2 + [WQ-PES]*2 + [Veg-PES]*2)/9
IF PES Score for HYDROLOGY is in Ecological Category E / F	Wetland-PES = ([Hydro-PES]*6 + [Geo-PES]*2 + [WQ-PES]*2 + [Veg-PES]*2)/12

*All wetlands are assumed to be naturally vegetated in Level 1A and 1B assessments

For non-vegetated wetlands (Level 2 assessments only)

IF PES Score for HYDROLOGY is in Ecological Category A / B / C / D	Wetland-PES = ([Hydro-PES]*3 + [Geo-PES]*2 + [WQ-PES]*2)/7
IF PES Score for HYDROLOGY is in Ecological Category E / F	Wetland-PES = ([Hydro-PES]*6 + [Geo-PES]*2 + [WQ-PES]*2)/10

These formulae are considered to be equally applicable to all HGM types because the differences between HGM types have already been taken into account in the derivation of component PES scores within each of the modules. The reason for having two different formulae, depending on the Ecological Category for Hydrology PES, is because it is presumed that a critical threshold is reached when the hydrological functioning of a wetland is so severely impacted, which would have an overriding influence on the overall ecological condition of the wetland. The weighting for Hydro-PES is doubled when this threshold is reached.

It should be noted that the formulae given above are used to derive an Overall Wetland PES Score for Level 2 assessments as well as for Level 1 (A and B) assessments. The Overall Wetland PES Score and associated Ecological Category are automatically derived in the spreadsheet tools that have been developed for WET-Health Version 2.

Level 1B: Review & Finalisation of PES Scores

An opportunity is provided here for users to refine selected impact scores based on further field indicators and expert opinion. Such changes must be appropriately justified by providing a clear rationale for the changes made. Any refinements made here are used to refine the final outcomes of the assessment, as reflected in the "Level 1B (Summary)" Tab. It is important to note that the "Trajectory of Change" is also assessed for each component in this tab.

	Modelled Score	Refined Score (select)	Rationale for changes (fill in where modelled score was refined)	Final Scores
HYDROLOGY				
Changes in the quantity & pattern of water inputs				
Changes in the quantity of water inputs from the wetlands catchment				
Regional Aquifer				
Relative contribution of groundwater inputs from regional aquifer	*20%*			*20%*
Lowering of the regional aquifer	-3.0			-3.0
Altered contribution from regional aquifer	*-0.6*			*-0.6*
Topographically defined catchment				
Relative contribution of surface water inputs from the topographical catchment	*80%*			*80%*
Change in water inputs	-2.1			-2.1
Altered contribution from topographical catchment	*-1.7*			*-1.7*
Overall change in quantity of water inputs	**2.3**			**2.3**
Changes in the pattern of water inputs				
Change in flood peaks	2.0	-2.0	Less change	-2.0
Adjusted Peak Flow Score	**1.4**			**0.8**
Change in seasonality	**1.6**	1.0	Less change	1.0
Overall changes in water inputs				
Overall change in water inputs	**2.3**			**2.3**
Alteration of water distribution & retention patterns within the wetland				
Change in water distribution & retention	**3.2**			**3.2**
Overall Hydrology Impact Score	**4.7**			**4.7**
Trajectory Class	**Slight deterioration**			
	↓			
Confidence (refined scores)	High			

Figure 11.1. An extract of the Review worksheet for a Level 1B assessment, showing the scores for the Hydrology component

Level 2: Review & Finalisation of PES Scores

An opportunity is provided here for users to refine selected impact scores based on expert opinion. Such changes must be appropriately justified by providing a clear rationale for the changes made. Any refinements made here are used to refine the final outcomes of the assessment, as reflected in the "Level 2 (Summary)" Tab. It is important to note that the "Trajectory of Change" is also assessed for each component in this tab.

	Modelled Score	Refined Score (select)	Rationale for changes (fill in where modelled score was refined)	Final Scores
HYDROLOGY				
CHANGES IN THE QUANTITY & PATTERN OF WATER INPUTS				
Altered contribution of water inputs from the regional aquifer	0.00	-1.5		-1.50
Altered contribution from topographical catchment	-3.97	-3.0		-3.00
Overall change in the quantity of water inputs	3.97			4.50
Change in floodpeaks	0.48	1.0		1.00
Change in seasonality of water inputs	0.00			0.00
Overall change in water inputs	3.97			4.50
Alteration Class	Moderate			Large
ALTERATION OF NATURAL WATER DISTRIBUTION AND RETENTION PATTERNS WITHIN THE WETLAND				
Stream channel modification	Enter refined scores for each relevant Disturbance Unit (to the right), if necessary, and then provide rationale for alteration of scores here			
Drains and erosion gullies	Enter refined scores for each relevant Disturbance Unit (to the right), if necessary, and then provide rationale for alteration of scores here			
Deposition, infilling & excavation	Enter refined scores for each relevant Disturbance Unit (to the right), if necessary, and then provide rationale for alteration of scores here			
Altered surface roughness	Enter refined scores for each relevant Disturbance Unit (to the right), if necessary, and then provide rationale for alteration of scores here			
Direct water lossses	Enter refined scores for each relevant Disturbance Unit (to the right), if necessary, and then provide rationale for alteration of scores here			
				Combined Intensity Score
Overall change in water distribution & retention patterns	2.50			3.14
Alteration Class	Moderate			Moderate
PRESENT HYDROLOGICAL STATE OF THE WETLAND				
Catchment Impact Score	3.97			4.50
Within-wetland Impact Score	2.50			3.14
Hydrology Impact Score	5.48			6.23
Alteration Class	Large			Serious
PES Score (%)	45%			38%
Ecological Category	D			E
TRAJECTORY OF CHANGE OF WETLAND HYDROLOGY				
Trajectory Class	Slight deterioration			
	↓			
Confidence (refined scores)	Medium			

	DU#1		DU#2	
Stream channel modification	0.00		0.00	
Drains and erosion gullies	0.00		-3.17	-2.00
Deposition, infilling & excavation	0.00		-1.00	
Altered surface roughness	-1.70	-2.50	0.00	
Direct water lossses	0.00		-6.80	
Combined Intensity Score	-1.70	-2.50	-8.03	-2.00
	1.4	2.1	0.7	0.6

Figure 11.2. An extract of the Review worksheet for a Level 2 assessment, showing the scores for the Hydrology component

12. ASSESSMENT OF ANTICPATED TRAJECTORY OF CHANGE AND PRESENTATION OF OVERALL RESULTS

For all four modules of WET-Health Version 2, an assessment must be made of the anticipated trajectory of change in wetland PES when completing an assessment at Level 1B and Level 2 (but not for a broad-scale desktop-based assessment at Level 1A). This enables the final results to be presented in a way that provides an indication of both the present ecological condition of a wetland and the anticipated trajectory of change.

12.1. Assessment of anticipated trajectory of change

The PES of the four components of wetland "health" – namely hydrology, geomorphology, water quality and vegetation – provide a current snapshot, which in itself is an extremely useful measure. However, if considered alone, it does not indicate where the state of these components appears to be heading in the future. It may be, for example, that a particular wetland is facing a likely rapid increase in invasive alien plants, which in the near future will significantly lower the vegetation and hydrology integrity scores. Alternatively, for another wetland, it may be that cultivation of the system was recently abandoned and a recovery of the vegetation component is expected so that an improvement in this component is anticipated in the near future.

The anticipated trajectory of change is determined qualitatively using five categories of likely change, which are described based on the direction and degree of anticipated change in the next 5 years (as shown in **Table 12.1**). Results of these assessments are recorded, separately for each module/component, in the "Review" tab of the relevant spreadsheet (as shown, for Hydrology, in the examples presented in **Figures 11.1 & 11.2**).

Table 12.1. Trajectory classes, description of each class and designated symbols used to evaluate Trajectory of Change of the four components of wetland health

Trajectory Class	Description	Symbol
Improve markedly	Likely to improve substantially over the next 5 years	↑↑
Improve	Likely to improve slightly over the next 5 years	↑
Remain stable	Likely to remain stable over the next 5 years	→
Deteriorate slightly	Likely to deteriorate slightly over the next 5 years	↓
Deteriorate markedly	Likely to deteriorate substantially	↓↓

As is the case with the current state, future changes to the health of a wetland may arise from upstream in the catchment of the wetland or from within the wetland itself. Both of these sources of change, therefore, need to be considered when selecting the appropriate trajectory class. Also, as highlighted in **Section 3.4**, the four components of wetland health, are closely linked. Thus, when considering future changes likely to take place that affect each of the four components, it is important to consider the potential changes that could result in the other three components.

When assessing the trajectory of change, a key factor to consider for all components is the anticipated landuse change in the wetland and its upstream catchment, which may, for example, be in an area where rapid urban expansion is taking place. In addition, a number of factors specific to the respective components of wetland health should be considered (as explained in **Table 12.2**).

Table 12.2. A few key aspects to consider when scoring the trajectory of change for the respective components of wetland health

Trajectory Class	A few key features
Hydrology	• Anticipated anthropogenic erosion, which may potentially have a draining effect on the wetland. • Anticipated change in tree plantations or invasive alien trees which would alter the volumes of water inputs.
Geomorphology	• The inherent vulnerability of the wetland to erosion. • Anthropogenic lowering of the base level, which is likely to trigger erosion during high flow events. • Changes in catchment landuses, particularly urban developments that are likely to increase runoff (and increase erosion risk) and activities that are known to radically change sediment inputs (e.g. dams or mines). • Risks of ground fires related to reduced water inputs from the catchment.
Water quality	• Intensification of landuses in the catchment. • Anticipated new point sources of pollution.
Vegetation	• Anticipated increase / decrease in invasive alien plants generally.

12.2. Presentation of overall results

Once trajectory of change has been scored, the overall health score is presented for each of the four components of "wetland health" by jointly representing the PES and likely trajectory of change (e.g. see hypothetical example in **Table 12.3**). This provides a useful overall picture of the health of the wetland assessment unit. From the example given in **Table 12.3**, it can be seen that geomorphology is the least impacted of the four components of this hypothetical wetland assessment unit and that this component of wetland PES is likely to remain in a similar state in the near future, while vegetation is the most impacted of the four components and likely to be subject to further deterioration in the future.

Table 12.3. Summary of the overall health of a hypothetical wetland assessment unit

Hydrology	Geomorphology	Water quality	Vegetation
C↓	B→	C→	D↓

The final outcomes of the assessment are comprehensively summarised in a final summary page of the spreadsheet tools that have been developed for WET-Health Version 2. Examples of these summaries are provided in this report for assessments at Level 1A (**Figure 5.2** in Chapter 5), Level 1B (**Figure 5.3** in Chapter 5) and Level 2 (**Figure 12.1**, below). For all levels of assessment, the summaries present the final Impact Score, PES Score and Ecological Category for each of the four components of wetland PES, as well as the combined Impact Score, PES Score and Ecological Category derived by integrating the component scores (using the formulae explained in **Section 11.2**). All the summary worksheets also show the "hectare equivalents" represented by each wetland assessment unit, which is derived by multiplying the Combined PES Score (as a percentage) by the total extent of the wetland. Finally, for all levels of assessment, the summary worksheet includes an automatically generated confidence rating for the PES results that have been derived for each wetland assessment unit. In addition, in the case of a Level 1B and Level 2 assessment, both the unadjusted (modelled) results and the final (adjusted) results are presented in the summary page, together with the confidence ratings for the revised results and the anticipated trajectory of change symbol derived for each of the four components of wetland PES.

WET-Health Level 2 assessment:
PES Summary

This worksheet provides an overall summary of the WET-Health Assessment that can be used for reporting purposes

	Wetland PES Summary			
Wetland name	**HYPOTHETICAL EXAMPLE**			
Assessment Unit	**UNIT A**			
HGM type	Depression without flushing			
Areal extent (Ha)	6.0 Ha			
Unadjusted (modelled) Scores				
PES Assessment	**Hydrology**	**Geomorphology**	**Water Quality**	**Vegetation**
Impact Score	5.5	1.0	7.3	4.0
PES Score (%)	45%	90%	27%	60%
Ecological Category	D	A	E	D
Combined Impact Score	4.5			
Combined PES Score (%)	55%			
Combined Ecological Category	D			
Hectare Equivalents	3.3 Ha			
Confidence (modelled results)	MODERATE-TO-HIGH: Field-based assessment including information about the regional aquifer			
Final (adjusted) Scores				
PES Assessment	**Hydrology**	**Geomorphology**	**Water Quality**	**Vegetation**
Impact Score	6.2	1.0	7.3	4.0
PES Score (%)	38%	90%	27%	60%
Ecological Category	E	A	E	D
Trajectory of change	↓	→	↑	↓↓
Confidence (revised results)	Medium	High	Low	High
Combined Impact Score	5.2			
Combined PES Score (%)	48%			
Combined Ecological Category	D			
Hectare Equivalents	2.9 Ha			

Figure 12.1. Example of the summary that is automatically generated in the tool for a Level 2 assessment

13. CONCLUSIONS AND RECOMMENDATIONS

13.1. Conclusions

WET-Health Version 2.0 consists of a series of three tools developed to assess the Present Ecological State (PES) or "ecological health" of wetland ecosystems of different hydrogeomorphic types at three different levels of detail/resolution. This refined suite of tools builds on previous methods for the assessment of the PES of wetland ecosystems in South Africa, including WET-Health Version 1 (Macfarlane *et al*., 2008) and Wetland-IHI (DWAF, 2007). The three tools were developed through extensive engagement with key stakeholders to clarify user requirements for different types of wetlands and levels of PES assessment, and have been tested across a variety of wetland hydrogeomorphic types and landuse contexts. Thus, the development of WET-Health Version 2.0 has achieved the main project aim of integrating the existing Wetland PES assessment tools into a single suite of tools which are in line with user requirements and which address the shortcomings of the previous methods.

Whilst WET-Health Version 2.0 has a similar structure to the original version, it has been comprehensively revised, incorporating elements of the Wetland IHI method (after DWAF, 2007) and previous work undertaken (mostly by Malan & Day, 2012, Malan *et al*., 2013 and Kotze, 2016a, b) to infer impacts on wetlands based on landcover types in a wetland and its catchment. Some key changes made to the method, in going from Version 1 to Version 2.0, include:

- A stronger emphasis on landcover information and the mapping of landuses, particularly for desktop assessments;
- The explicit provision of two desktop-based levels of assessment (i.e. Levels 1A and 1B), with the spreadsheet for Level 1A purposefully designed to cater for the assessment of multiple wetlands (up to 2 000) at a time for broad-scale applications;
- More focussed integration of differences in wetland type, and an expansion of the method to specifically cater for wetland types not previously accommodated;
- A comprehensive revision of the geomorphology module, which now clearly differentiates between impacts to geomorphic structure and impacts to geomorphic processes;
- The addition of a water quality module, which was not included in the previous version;
- An overhaul of the spreadsheets, with the inclusion of additional drop-down boxes for the selection of options and many more automated calculations, in an attempt to make the spreadsheets more user-friendly;
- Restructuring of the spreadsheet for a Level 2 assessment to facilitate more rapid data entry and avoid duplication, by grouping the indicators that need to be considered into a list of "catchment questions" and a list of "wetland-related questions", instead of grouping the indicators by module as before;
- Integration of new research and information to refine scoring guidelines.

The development of the elements listed above should contribute significantly to the generation of new knowledge relating to the ecological condition of wetlands in South Africa. This knowledge represents both the knowledge distilled into the tools themselves, as well as how the tools are anticipated to better equip practitioners and scientists in the future to add more effectively to the pool of knowledge relating to the present ecological condition of South Africa's wetlands.

13.2. Recommendations

The development of the refined suite of tools making up WET-Health Version 2.0 is thought to represent a significant advancement in the practice of wetland assessment in South Africa. At the same time, however, it is important to emphasise that some assumptions of the revised method remain largely untested and should be validated and refined through further research and testing. As such, it is recommended that research on factors affecting the various components of wetland condition should be actively encouraged and be used to provide recommendations for further refinements to the method. Application of the method in other countries should also be actively encouraged, since the underlying principles and associated scoring system are likely to be valid, particularly in other temperate regions.

It is strongly recommended that a User Manual should be produced for WET-Health Version 2, to accompany and support the Technical Guide that has been produced in the current report. The development of the User Manual should be undertaken through a process that includes consultation with assessors who have applied the refined suite of tools, to obtain feedback about the tools, and minor additional refinements to the tools to improve them and address any issues that are identified. A similar process was followed in the development of the final versions of the Technical Manual and Practical Guide of the Buffer Zone Guidelines for Rivers, Wetlands and Estuaries in South Africa (Macfarlane & Bredin, 2017a, b). The User Manual that is produced for WET-Health Version 2 should contain more guidance on application of the tools in GIS, including specific guidance relating to the use of FOSS options for GIS such as Quantum GIS (QGIS) to complete the required tasks.

Finally, it is also strongly recommended that training material is developed and a series of training courses are rolled out across the country for WET-Health Version 2, once the User Manual has been produced. This will greatly facilitate the proper application of the tools, and should lead to more robust wetland PES assessments in South Africa with better consistency between assessors.

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APPENDICES

LIST OF APPENDICES:

Appendix A: Developing a conceptual description of how the water enters, passes through and leaves a wetland

Compiled by: Donovan Kotze, Eddie Riddell, Piet-Louis Grundling and Althea Grundling

Background and aim of the guidelines

In responding to the need to better describe the reference condition of a wetland, guidelines have been developed to assist in undertaking a conceptual description of how the water enters, passes through[1] and leaves the wetland in its natural reference state. Acreman and Miller (2006) also recommend such a conceptual description as a first step for the hydrological impact assessment of a wetland. Moreover, a conceptual model is always the most appropriate step before undertaking a more quantitative analysis of a hydrological system (Wainwright and Mulligan, 2004). These guidelines contribute to the hydrology module of the suite of tools currently being developed for assessing the Present Ecological State of wetlands. In addition, they contribute to the water quality module, e.g. determining whether a depression has any outflows or not has profound implications for the degree to which toxicants/pollutants might react (precipitate, evaporate, decompose, etc.) and accumulate in the wetland.

The wetland HGM (hydrogeomorphic) types presented by Ollis et al. (2013) are all described in terms of typical inputs, through-flows and outputs associated with each of the HGM types in the classification. However, as will be elaborated upon later in the document, several of the HGM types, notably depressions and channelled valley bottoms, encompass a considerable range of possibilities in terms of inputs, through-flows and outputs. This limits the generalizations which can be drawn on HGM type alone.

Conceptual hydrological flow models per HGM wetland types were developed by Gary Marneweck as an Appendix to Maherry et al. (2016) and which build on those described by Marneweck and Batchelor (2002). These models, which are potentially useful for the hydrological characterization of wetlands and for assessing hydrological impacts on wetlands, focus on the source of water supplying a type, and provide several sub-types of the HGM types given by Ollis et al. (2013). For example, six different types of seepage slope wetlands are identified based on the different sources of water maintaining the wetland, including, amongst others: Hillslope seepage – interflow, Hillslope seepage – regional groundwater, Hillslope seepage – rainfed. Unfortunately, however, Maherry et al. (2016) do not provide any guidance to assist in identifying these types, e.g. what indicators can one use to determine if a hillslope seep is fed primarily by interflow rather than regional groundwater? This is a key challenge which needs to be addressed.

The aim of the document is to provide the following.

- Step-wise guidelines for describing, at a coarse level, how the water enters, passes through and exits the wetland. This is based on identifying the wetland's HGM type, its climatic setting, its broad hydrogeological type setting (see Objective below), and level of wetness (i.e. permanent, seasonal or temporary).
- A description of broad hydrogeological type settings, which are based on the primary lithology. The settings attempt to group broadly similar hydrogeological characteristics that control aquifer discharge regimes linked to ecosystems, particularly wetlands. The different settings, which are mapped nationally, provide a preliminary basis on which to draw inferences in terms of groundwater-surface water linkages of wetlands.

[1] Encompassed in the concept of how water passes through the wetland is that of storage of water in the wetland

It is important to emphasize that the conceptual model arising from the application of these guidelines is generally based on limited information, mainly relating to the broad climatic and geological and hydrogeomorphological setting of the site. Therefore the model is of a relatively low resolution/confidence. If a higher resolution/confidence is required then additional information will be needed, especially relating to soil in the wetland and its contributing hillslopes, and the hydropedology guidelines of Job and le Roux (2018) are recommended for using this soil information to assist in identifying the predominant recharge areas and spatially and temporally variable sub-surface flow paths to the wetland.

A procedure for describing the dominant flowpaths in a wetland and its catchment

Water inputs

Although direct rainfall is an important water source for wetlands generally, the mean annual precipitation of South Africa is less than half of the global average for continental areas and the potential evapotranspiration is generally far greater than rainfall (Ellery et al., 2009). Thus in South Africa, inflows, including both surface and sub-surface, are generally also critical sources of water that contribute to a prolonged hydroperiod, essential in maintaining a wetland and its characteristic hydrological processes.

The starting point for identifying hydrological inflows to the wetland is to identify its topographically-defined catchment. For most wetlands, the wetland's hydrological supply area is contained within its topographically-defined catchment. However, in certain situations the wetland is likely to be supplied from beyond its topographically-defined catchment. The two most prominent of these situations are: (1) coastal plain areas characterized by generally shallow regional groundwater levels, or (2) within Karst terrain areas[2].

In South Africa, coastal plains consist of low relief, undulating landscapes usually comprising predominantly high permeability sandy materials but also including less permeable materials (e.g. unfractured calcrete or subsoil clay) either occurring as lenses within the sand or dominating the sediment in large portions of the landscape (Grundling, 2014a and b). Karst terrain areas are underlain by limestone or dolomite and evolve through the dissolution of the bedrock, resulting in an efficient underground drainage system consisting of fissures, conduits and caves (Meyer, 2012).

For many wetlands in situation (1) and (2), the wetland is potentially connected with the regional aquifer[3] and the hydrological supply area of these wetlands may extend a considerable distance beyond the wetland's topographically defined catchment (see Wetland B in Figure A1). The unconfined and high transmissivity of the extensive sandy sediments generally provide unimpeded drainage conditions characteristic of coastal plain areas (Kelbe et al., 2015). In karst landscapes, the fissures,

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[2] It is recognized that additional situations may also occur where the hydrological supply area extends beyond topographically-defined catchment (e.g. in some valley-bottom wetlands which intersect the regional fractured rock aquifer). However, for the purposes of this assessment it will not be possible to identify these.

[3] Although South African water legislation does not define the term groundwater, it defines an aquifer as "A geological formation which has structures or textures that hold water or permit appreciable water movement through them." Appreciable water is usually taken to be enough water to supply a well or borehole and Colvin et al. (2007) characterizes "appreciable" as meaning that there is sufficient water to sustain a dependent ecosystem even though the quality may not meet the standards set for human needs. A primary aquifer refers to an aquifer in which water moves through the primary openings of the geological formation, which are the openings that were formed at the same time as the formation of the sedimentary deposit or rock that contains the openings (Colvin et al., 2007). A Secondary aquifer refers to an aquifer in which water moves through the secondary openings of the geological formation, which are the openings which were formed by processes that affected the rocks after they were formed, e.g. when the rocks were subject to faulting (Colvin et al., 2007).

conduits and caves characteristic of the underlying rock result in the regional aquifer being very strongly connected across the landscape (Meyer, 2012). In contrast, other wetlands on the coastal plain or in karst terrain may be perched above the regional aquifer on a layer/lens of relatively impermeable material (an aquitard) (Grundling, 2014) and maintained by interflow from within the wetland's topographically defined catchment (see Wetland A in Figure A1).

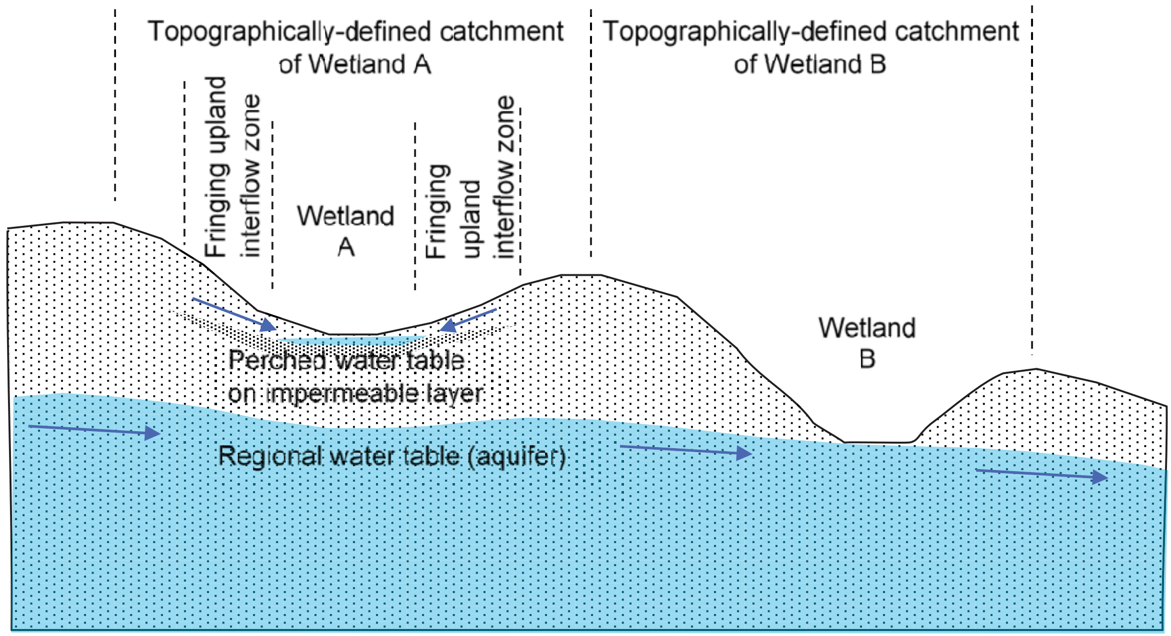

Figure A1: Two hydrologically contrasting wetlands on a coastal plain comprising predominantly permeable sandy deposits. Wetland A is perched on an aquitard location above the regional aquifer and maintained by interflow from the hillslopes in its topographically-defined catchment and Wetland B is in contact with the regional aquifer, which supplies the wetland from well beyond the wetland's topographically-defined catchment.

In coastal plains and karst landscapes, wetland areas connected with the regional landscape are usually those wetlands occupying the lowest-lying areas in the local landscape, as can be appreciated from Figure A1. In addition, such areas are often (but certainly not always) characterized by stable water levels, due to continuous through flow from the regional aquifer (Grundling et al., 2016). Based on preliminary evidence such as that presented by Grundling (2014a) it appears that wetlands perched above the regional aquifer are typically not located in the lowest lying areas in the local landscape and are generally subject to greater water table fluctuations than those connected with the regional aquifer.

For wetlands not on the coastal plain or in karst terrains, it is assumed that wetlands are generally not in contact with the regional aquifer, especially those wetlands located in the headwaters. For example, a detailed long term hydrological investigation by Riddell et al. (2013) of a headwater wetland, the Manalana wetland in Bushbuckridge, showed that the upper hillslope component of the wetland (piezometers W1 and W2) were fed primarily by direct precipitation and shallow-sub surface interflow through predominantly sandy sediment perched on a clay-rich lens. This hillslope area of the wetland was disconnected from the deeper groundwater, which therefore had a negligible contribution to the wetland area's water budget. Similar findings were reported by McCartney and Neal (1999) for another headwater wetland, in this case in the Zimbabwe highlands.

While a distinction has been drawn above between wetlands which are connected to the regional aquifer/deep groundwater and perched wetlands which are not, it is important to acknowledge that some perched wetlands may be infrequently connected with the regional aquifer in wet years, and as the regional aquifer subsides, the aquitards described above allow water to persist for longer at the local wetland site than would otherwise be the case (Kelbe et al., 2016). It is important to also note that so far in the document an aquitard has been described in terms of impeding the movement of water down through the profile, resulting in a perched water table. However, an aquitard can also act to confine a regional aquifer located below.

Having identified which wetlands are likely to be connected to the regional aquifer/deep groundwater and which are not, the next question to be addressed relates to the particular environmental sensitivities of these two contrasting situations. From Figure A1 it can be appreciated that wetlands supplied from the regional aquifer (e.g. Wetland B) are likely to be far more sensitive to an artificial lowering of the regional aquifer (e.g. as a result of high levels of groundwater abstraction or regionally extensive eucalypt plantations) than naturally disconnected wetlands such as Wetland A perched above the regional aquifer. It may even be that such impacts are located entirely outside of the of the wetland's topographically defined catchment. In contrast, as noted by Kelbe et al. (2016), and can be appreciated from Figure A1, naturally disconnected wetlands (e.g. Wetland A) are more susceptible to anthropogenic stressors (e.g. plantations) specifically within their local topographically-defined catchments than is the case for connected wetlands (e.g. wetland B). However, these perched/disconnected wetlands are much more resilient to a lowering of the regional water table. Acreman and Miller (2006) describe how wetlands which are perched above the aquifer, e.g. where a wetland is underlain by a continuous thick layer of impermeable estuarine clay, are unlikely to be impacted by abstraction from any nearby aquifer.

In a rapid assessment, some wetlands are likely to be able to be reliably identified as separated from an underlying regional aquifer, i.e. perched, based on available information, such as that described by Grundling (2014a and b) which is referred to earlier. However, Acreman and Miller (2006) draw attention to those situations where it will be very difficult to determine if a wetland is separated from an underlying aquifer, e.g. where underlying sediments are thin, irregular and of varying permeability. Such situations would require the collection of site-specific data and detailed assessments (Acreman and Miller, 2006). This would clearly be far beyond the scope of any rapid assessment method. Where such high levels of uncertainty exist, it is probably best to treat the wetland as sensitive to both regional aquifer draw down and local impacts from land-uses in the upslope catchment.

For those wetlands with the hydrological supply area contained within the topographically-defined catchment (which applies to most inland wetlands in South Africa), it is helpful to draw the distinction between: (1) the local upslope catchment which supplies water to the wetland predominantly via diffuse lateral surface and sub-surface inputs from the adjacent hillslope and sometimes also via small (first order) tributaries; and (2) the upstream catchment which feeds the wetland longitudinally via the main stream/s entering the wetland (Figure A2). If a wetland had a small catchment (i.e. <50 ha) then it would generally comprise only (1) but wetlands with larger catchments would tend to have both (1) and (2), but their relative contributions would varying depending on the particular topography, climate, etc..

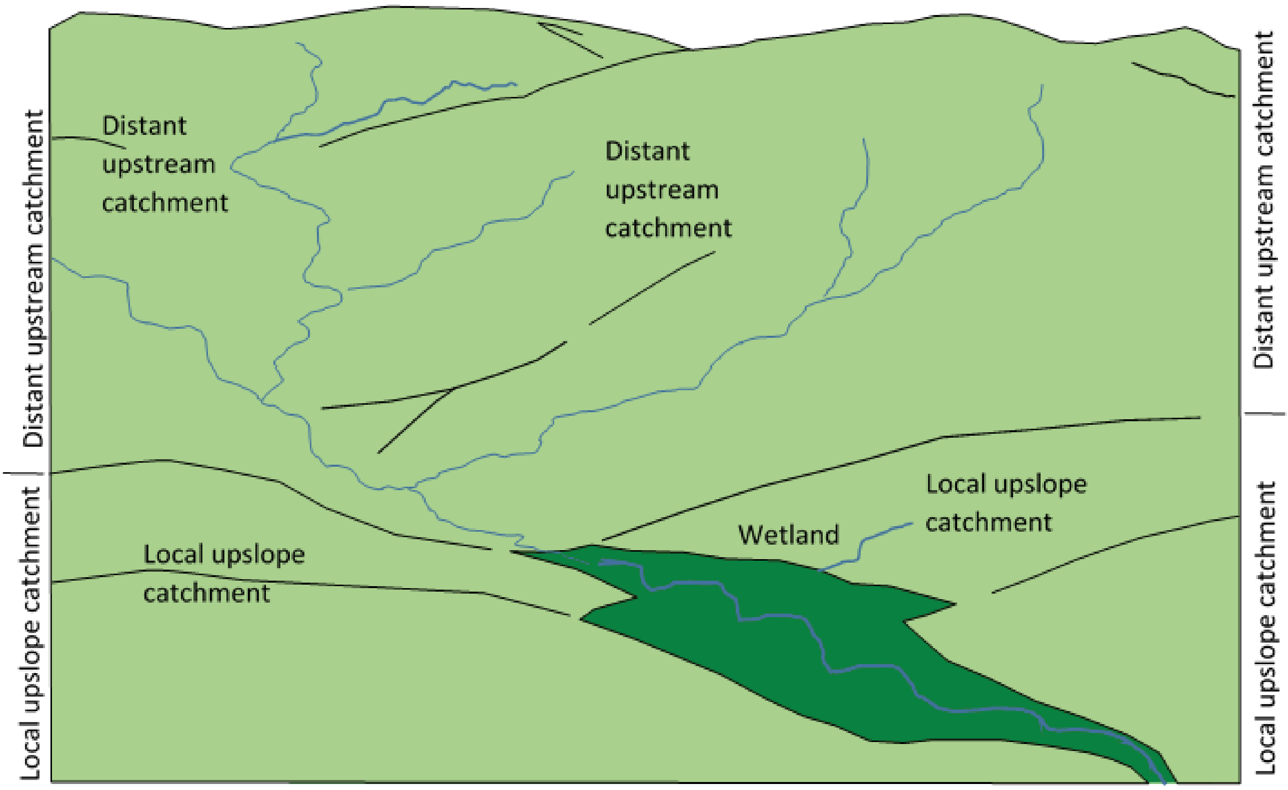

Figure A2: A wetland and its local upslope catchment and distant upstream catchment

Whether a wetland is maintained predominantly by its local upslope catchment vs. inflow from the distant upstream catchment is reasonably well covered by the HGM classification:

- For floodplain wetland areas, which are characterized by periodic flooding of the valley floor when the main channel exceeds its capacity, it is generally the inflows from the upstream catchment which predominate, especially where the local climate is dry. Even so, floodplains vary greatly in terms of the frequency and extent of flooding from the channel, and for some this may be very infrequent and therefore inputs from the local upslope catchment may be very important.
- Most hillslope seepages are lacking in a distant upstream catchment and therefore inflows will be dominated by the local upslope catchment.
- Most depressions are in a similar position to hillslope seepages, i.e. dominated by inputs from the local upslope catchment, but some depressions have a distant upstream catchment and an inflowing stream, and the proportion of the upstream catchment supplying this stream relative to the local upslope catchment will determine which predominates.
- Unchannelled valley bottom wetland areas are characterized by the inflowing stream spreading out diffusely through the wetland once it enters the wetland, and therefore the distant upstream catchment generally predominates. However, lateral inputs from the local upslope catchment may also be important, and where the stream order is very low (i.e. a first order stream) there is very little or no upstream catchment and the local upslope catchment will predominate.

Channelled valley bottom wetland areas tend to be more difficult to generalize about than the other HGM types unless in the unusual case that the stream order is very low there is very little or no upstream catchment. The remaining channelled valley bottom wetland areas, which are fed by a distant upstream catchment, vary greatly in terms of whether they are maintained by the local upslope catchment vs. inflow from the distant upstream catchment. At one extreme are situations where the water level in the main channel is high relative to the valley floor and flooding occurs frequently out of the channel and across the valley bottom and evidence of lateral inputs are limited. At the other extreme, the water level in the main channel is relatively low and flooding of the valley bottom by the main channel is very infrequent/absent and there is evidence of lateral inflows corresponding with the wettest portions of the valley bottom (Figure A3) or extensive lateral seepage into the outer margins of the valley bottom.

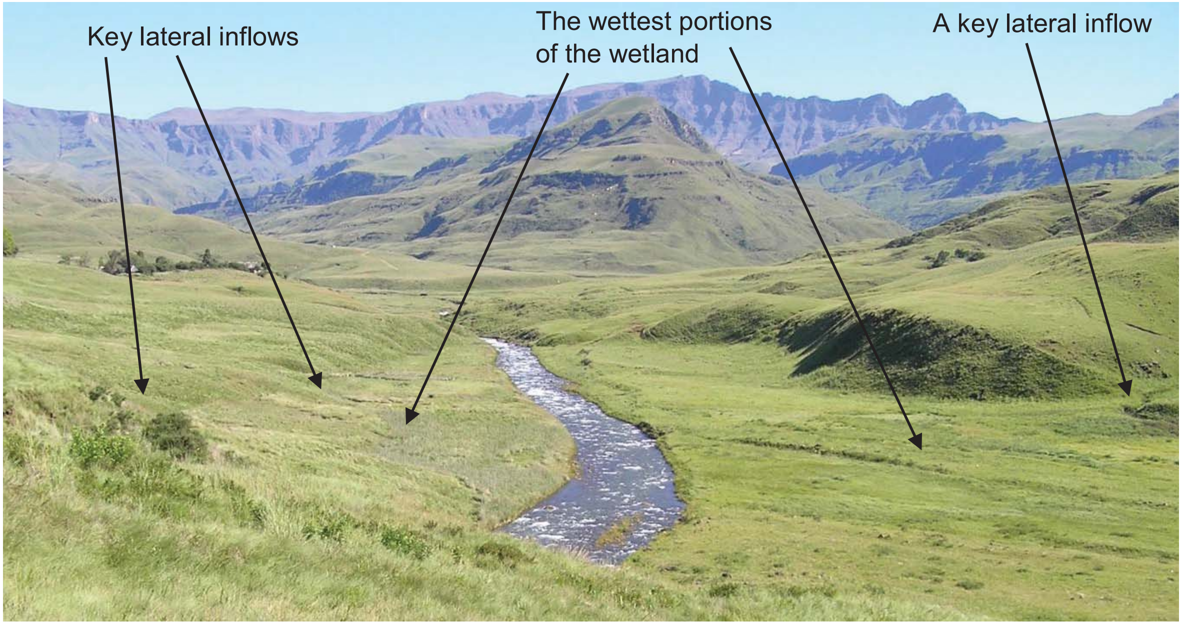

Figure A3: An example of a channelled valley bottom wetland area in Loteni Game Reserve maintained predominantly by lateral inflows from local hillslope sources.

A further factor amplifying the contribution of the distant upstream catchment to a wetland is where this catchment extends (usually along an orographic precipitation gradient) into a much wetter climate than that which occurs locally. For example, the three major inland delta wetlands of Africa, namely the Okavango Delta, the Sudd and the Niger Inland Delta, are supplied predominantly from the humid tropical highlands of their respective distant upstream catchments where precipitation levels are much higher than their local semi-arid climates (McCarthy, 1993; McCarthy, 2006). Similarly, in the San Luis valley floor in Colorado, where despite extremely low mean annual precipitation on the extensive valley floor (<200 mm at the centre of the floor), abundant surface and ground water flows into the floor from adjacent high mountains with high precipitation, which supports extensive wetlands, including some with sustained saturation levels (Sanderson and Cooper, 2008). An analogous South African example is the Papenkuils wetland in the Breede catchment, one of the Western Cape's largest inland wetlands, where the locally the mean annual precipitation on the Breede River valley floor is <300 mm but its distant upstream catchment extends into mountainous areas where it is >1000 mm. Inflows to the Papenkuils wetland are dominated by the Breede and Holsloot Rivers which are supplied by these mountainous areas.

Although beyond the scope of most rapid assessments, it is anticipated that obtaining information on soil morphology in the wetland's local upslope catchment will be a valuable source of evidence for how water is delivered to the wetland from its local upslope catchment. Existing information on soil forms can be used. However, a limitation of soil forms is that depth is seldom described below 1.2 m, and therefore it is preferable to undertake fieldwork in order to sample to greater depths. The soil horizon immediately above auger refusal is generally the most informative, as is elaborated upon in more detail by Job and le Roux (2018), and this will often require auguring to depths >2 m.

There is a growing body of literature around the topic of hydropedology (e.g. Van Tol et al., 2013a and b) which provide the basis for drawing inferences on water movement down a hillslope based on soil profile features, e.g. an abrupt transition between the E horizon and the underlying B horizon generally indicates a higher tendency for sub-surface lateral flows (Van Tol et al., 2013a). However, it is recognized that surveying soils in order to identify soil forms is very time consuming. Therefore the best use possible needs to be made of available information, in particular that contained in the land type surveys (e.g. Land Type Survey Staff, 1986). A Water Research Commission project (WRC Project K5/2461) is currently underway which will provide specific guidance in terms of hydropedological and landform interpretations for wetlands, which can be referred to. The guidelines of Job and le Roux (2019) from this project provide a hydrological response classification of South African soil forms, which can be used together with information on the soil forms in the wetland's catchment (e.g. derived from the land type information) as an aid to determine the relative extent of different hydrological response types (i.e. recharge, shallow interflow, deep interflow and response) in the wetland's catchment and within specific hillslopes contained within the catchment. Thus, this classification provides a practical means of translating existing soil unit information into hydrological response unit information (Job and le Roux, 2018).

How the water moves through the wetland

How the water moves through the wetland is fairly well covered by the HGM classification: for most HGM types, water moves through the wetland in a characteristic way. Hillslope seepage wetlands are almost all characterized by the sub-surface seepage of water through the wetland in the direction of the hillslope. Unchannelled valley bottoms are characterized by the movement of both high and low flows through the wetland in a diffuse pattern across a wide front (a large wetted perimeter, when the stream and wetland are viewed in cross-section). Depressions are all characterized by closed surface drainage responsible for the detention of water, although, as discussed later, they may vary in terms of how the water leaves the wetland. However, channelled valley bottoms generally encompass a greater diversity than most other HGM types in terms of movement of water through the wetland, influenced in particular by how water enters the wetland. If the predominant inputs are from the adjacent hillslopes of the local catchment then the predominant movement is laterally (i.e. at right angles to the channel). However, if the predominant inputs are from the channel itself during high flow periods then the predominant movement is likely to be in the direction of the main channel.

How the water exits the wetland

Given the high potential evaporation rates in South Africa, total evaporation (ET, evaporation plus transpiration, more commonly called evapotranspiration) can generally be taken as an important water exit route for wetlands generally, especially when they occur in dryland landscapes in arid to sub-humid regions of South Africa. In some cases this can be a major proportion of the wetland water budget, especially during the dry season in both summer (e.g. Riddell et al., 2013; Grundling et al., 2015) and winter rainfall areas (e.g. Parsons and Vermeulen, 2017). For some wetlands this is the only exit route, but for most wetlands surface and/or sub-surface flows are also important exit routes.

It would seem logical to expect vegetated areas within wetlands to exhibit greater total evaporation than areas of open water, and this was typically found in the early literature on the subject. Although with reduced uncertainty in modern determinations of ET processes the modern scientific understanding is these two wetland regions exhibit similar total evaporation (Mohamed et al., 2012; Abtew & Melesse, 2013). Whilst it is extremely important, a cautionary approach is required when conceptualising the extent that different regions of a wetland will have on the ET removal from the water budget, especially when the wetland vegetation types are not too dissimilar e.g. herbaceous species such as *Phragmites australis* versus *Typha capensis*. However, it has been noted that there can be distinct differences in transpiration when wetland contains a woody canopy leading to much greater ET losses from that wetland region than the surrounding herbaceous canopy, such as the swamp forests of the coastal plain (e.g. Clulow et al., 2012; Grundling et al., 2015). In similar cases, such as these, one could conceptualise distinct ET differences across the wetland environment. Moreover one will need to consider other dynamics such as dormancy, such as in the Western Cape where the reed collar around Groenvlei remained dormant during winter (Parsons and Vermeulen, 2017). Meanwhile reeds continued to actively transpire during winter in other systems (e.g. Riddell et al., 2013).

There are however other factors to consider in the conceptualisation of ET processes in wetlands in terms of their orientation and distribution in the landscape. These being termed the oasis and clothes line effects (Drexler, 2004). The oasis effect applies to wetlands with surrounding landscapes with a greater vapour pressure deficit (low humidity) such as bare soil or dry seasonal grasslands, leading to greater ET from the wetland environment. Meanwhile, clothes line effects describe long narrow wetlands such as riparian areas and wetland fringes that tend to have higher ET rates than large expanses of wetlands with greater area-to-perimeter ratios.

There are of course other mechanisms that allow water to leave a wetland and this is fairly well covered by the HGM classification. For valley bottom and floodplain wetlands this is generally via a stream channel while for hillslope seepage wetlands this is either via a stream channel or via hillslope seepage. In the majority of depressions, water exit is largely confined to evaporative loss. However, in some depressions, water also exits by surface and/or subsurface flows (i.e. the depression is subject to some degree of flushing). An example would be the depression wetlands which have sustained contact with the regional aquifer such as the Groenvlei wetland which has no surface flows exiting the wetland but sub-surface water enters and exits this wetland through the Eden Primary Aquifer (Parsons and Vermeulen, 2017). In terms of the water budget calculated by Parsons and Vermeulen (2017) inputs comprised direct rainfall (71.6%) and groundwater inflow along the western and northern boundaries of the lake (28.4%) balanced by evaporation from open water and the reed fringe (83.1%) and groundwater outflow along the southern boundary (16.9%).

Wetland B in Figure A1 and Groenvlei represent examples of depressions linked with a coastal aquifer and would be considered to be flushed by the sustained outflow of sub-surface water from such systems. However, the majority of depressions in South Africa are not linked with a coastal aquifer. Guidance is required in determining whether the remaining depressions are subject to flushing, for which neither Ollis et al. (2013) nor Maherry et al. (2016) provide any guidance.

Batchelor (2011) suggests that pans (depressions) can, on the basis of their salinity profiles, be classified into the following five types, which vary according to their "leakiness":

- Free draining, seasonal to temporary, fresh: Na <5 mg/l (in the water)
- Occasionally flushing, seasonal to temporary, intermediate salinity: Na 5-80 mg/l
- Occasionally flushing, seasonal to temporary, saline
- No flushing, seasonal to temporary, saline: Na >900 mg/l
- Groundwater linked, permanent, Na variable

However, based on feedback from Prof. Jenny Day (pers comm. 2017), the general rule of thumb is unlikely to be widely applicable across South Africa, with Na levels being strongly affected by seasonal and inter-annual variability and additional site factors, e.g. the geology of the catchment supplying the wetland. Nevertheless, if account is taken of the timing of sampling and information is available for the local area (e.g. the geology includes sediments of marine origin known to have inherently high Na levels) then any measurements of Na or of electrical conductivity (very readily measured in the field) could be interpreted accordingly along with other sources of evidence. Understandably this would require a high level of field experience and familiarity with the local area.

For those depressions not connected to an extensive regional aquifer, in the absence of any physicochemical measurements taken in a depression, a very coarse general assumption could be made that the lower the rainfall, the lower the probability that a depression is leaky.

Reference back to the conceptual description when assessing the impact intensity of different stressors

The intention is for the conceptual description of the wetland's hydrology (inputs, storage, throughflow, exits) to be used to assist in inferring the intensity of impact of different land-uses in the upslope/upstream catchment. This will require pointing out the particular vulnerabilities and resiliencies of the different situations (Figure A5). For example, land-use activities generally associated with reduced runoff (e.g. plantation forestry) occurring in the local upslope areas within a wetland's topographically-defined catchment are likely to impact most severely on a wetland supplied by its topographically defined catchment alone. In contrast, a wetland connected to the regional aquifer and therefore supplied from a wider area, would generally be most vulnerable to impacts taking place at a broader scale.

The first question posed in Figure A4, namely whether the wetland is supplied from beyond its topographically-defined catchment through its connection to an extensive regional aquifer, is difficult to answer for a non-specialist and without data. Therefore the hydrology module of the Wetland PES tool generalizes based primarily on the broad hydrogeological type setting of the wetland (see following section, in particular Table A2). The question of whether a wetland is perched above to the regional aquifer rather than being connected to the regional aquifer is dealt in the section above on "Water inputs, in particular in the text following Figure A1. The question of whether inflows to the wetland are primarily from the distant upstream catchment vs. local upslope catchment is also dealt with in the section on "Water inputs" above, in particular in the text following Figure A2. The last question of whether a wetland fed predominantly by its upstream catchment is dependent on bank overspill can be inferred from the HGM type of the wetland. Floodplains and channelled valley bottoms are dependent on this overspill but unchannelled valley bottoms lack a channel and are therefore not dependent on bank overspill.

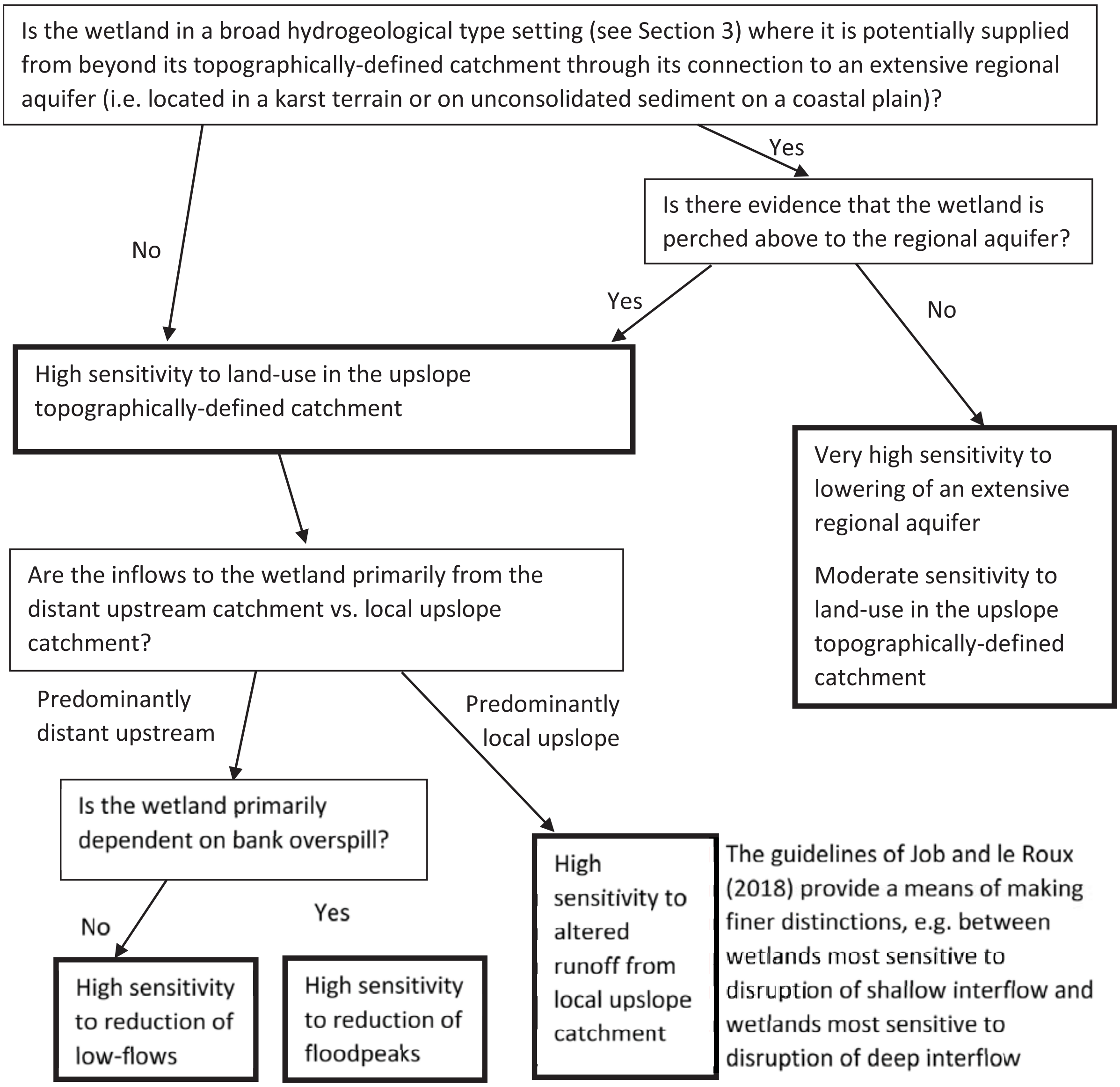

Figure A4: A decision tree for screening the hydrological sensitivity of a wetland to catchment impacts.

The main aquifer types in South Africa and their links with wetlands

An overview of the types

A very useful introduction to aquifer dependent ecosystems in South Africa is provided by Colvin et al. (2007). As the first step in classifying the main aquifer types in South Africa, Colvin et al. (2007) recommend that this be based on the aquifer properties of the main lithology (rock type) of the different rock strata. Six main aquifer types were categorised at a national scale by Colvin et al. (2007) based on the primary lithology at a 1:1 million scale (Figure A5). These categories group broadly similar hydrogeological characteristics that control aquifer discharge regimes linked to ecosystems.

Colvin et al. (2007) sub-divided one of the six classes, namely Unconsolidated deposits, into three sub-classes, namely Alluvial, Inland aeolian (Kalahari) and Coastal plain (Table A1). A few further sub-divisions were undertaken, in particular to distinguish two further classes with particularly pronounced distinguishing characteristics, e.g. Karst landscapes were distinguished from other Carbonate Terrains (Table A2).

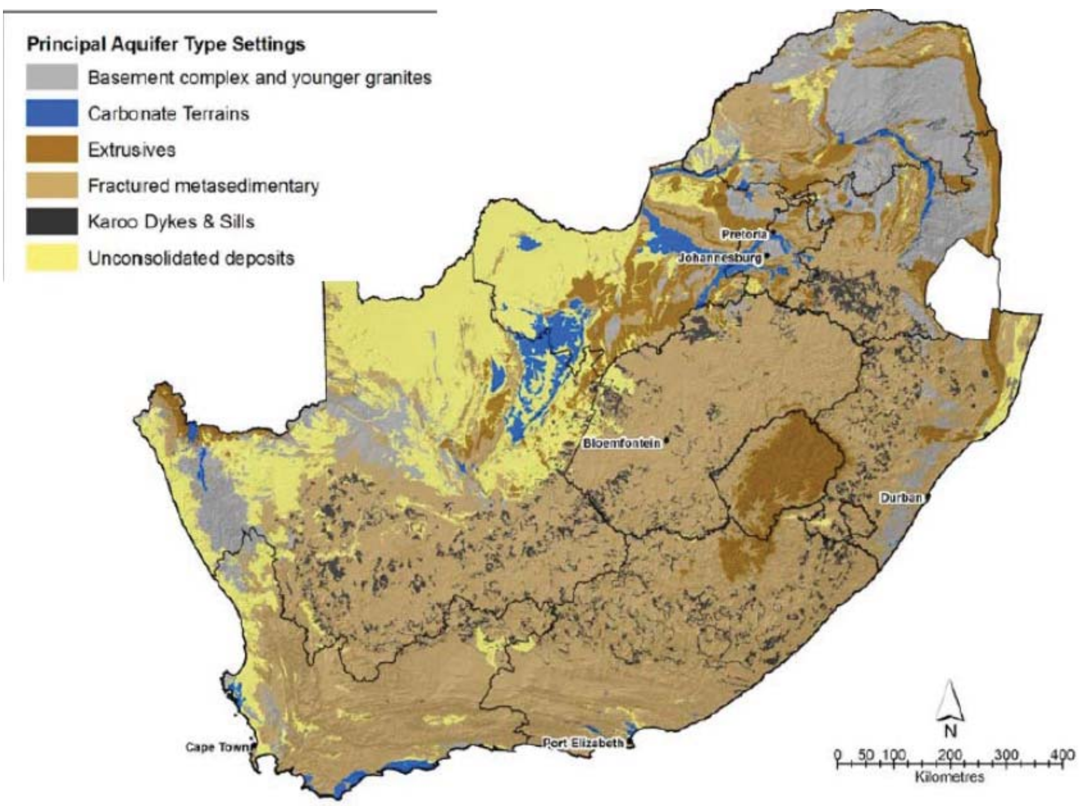

Figure A5: Map of main aquifer types based on primary lithology. (Source data – Council for Geoscience 1: 1000 000 lithology) (from Colvin et al., 2007).

Table A1: Typesettings for Aquifer Dependent Ecosystems in South Africa based on aquifer types and habitat types, with an indication of the probability[1] of occurrence

Aquifer Dependent Ecosystems Type-settings

Habitat types	Secondary Aquifer types					Primary Aquifer types		
	Karoo Dykes & Sills	Basement & younger granites	Extrusives	Carbonate	Fractured Meta-sediments	Alluvial	Inland aeolian (Kalahari)	Coastal plain
In-aquifer	Unlikely	Unlikely	Unlikely	Known	Unlikely	Probable	Unlikely	Probable
Spring	Known	Known	Known	Known	Known	Known	Unlikely	Probable
Riverine aquatic	Probable	Probable	Probable	Known	Probable	Known	Unlikely	Known
Riparian	Probable	Probable	Probable	Known	Probable	Known	Unlikely	Known
Wetland/seep	Known	Known	Known	Known	Known	Known	Unlikely	Known
Terrestrial	Probable	Probable	Probable	Probable	Probable	Probable	Known	Known
Estuarine/coastal	Unlikely	Unlikely	Unlikely	Known	Known	Known	Unlikely	Known

Known | Probable | Unlikely

[1]The probability of occurrence is defined as: Known = there are known occurrences of these ecosystem types in this setting; Probable = these types are likely to occur there but no data are available to confirm that; and Unlikely = these ecosystem types are unlikely to occur

Table A2: A preliminary broad-scale classification of aquifer types in South Africa based on lithology (modified from Colvin et al., 2007)

Primary aquifer types (Unconsolidated deposits)	Coastal plain	
	Inland aeolian (Kalahari)	
	Alluvial	
Secondary aquifer types	Carbonate terrains	Karst landscapes
		Other
	Extrusive	
	Fractured meta-sedimentary	Table Mountain Group
		Karoo Supergroup with dolerite dykes and sills
		Karoo Supergroup without dolerite dykes and sills
		Other, including Waterberg, Soutpansberg and Transvaal Supergroup
	Basement complex and younger granites	

Having identified within which of the 11 broad-scale aquifer type settings given in Table A2 a wetland is located, some initial inferences can then be drawn in terms of hydrogeological characteristics that control aquifer discharge regimes to the wetland (Table A3), particularly when viewed in conjunction with HGM type. As indicated previously, these inferences are at a broad scale and of low confidence. However, they can be refined with the addition of local information, including the soil types in the wetland and its upslope catchment and the degree of wetness in the wetland. For example, if under natural conditions a depression wetland in a coastal plain remains permanently flooded and is located in a topographic low point within the local landscape then this would suggest that the wetland is in contact with the regional aquifer.

Table A3: A preliminary identification of the likelihood of aquifer-wetland connections for aquifer types in South Africa

Aquifer type	Likelihood of connection[1]		Additional notes
	Deep/regional[2]	Shallow/perched/local	
Coastal plain primary aquifer	High	Moderate	See sub-section below on "The coastal plain primary aquifer"
Inland aeolian (Kalahari) primary aquifer	Very low	Low	Some perched wetlands on localized carbonate areas.
Alluvial primary aquifer	Moderate	Moderate	While much of the alluvial primary aquifer is within reach of deep rooted riparian trees, it is often too deep to be reflected as wetland conditions
Karst landscapes	High	Moderate	See sub-section below on "Karst landscapes"
Other carbonate terrains	Low to moderate	High	This covers all carbonate terrains (both inland and coastal) other than Karst landscapes.
Extrusives	Low	High	This includes numerous and extensive valley bottoms/floodplains on the rhyolite/basaltic plains in the Lowveld and Springbok flats.
Table Mountain Group	Moderate to high	High	See sub-section below on "Table Mountain Group (TMG) aquifer"
Karoo Supergroup with dolerite dykes and sills	Moderate	Moderate	See sub-section below on "Karoo Supergroup, including dolerite dykes and sills"
Karoo Supergroup without dolerite dykes and sills	Low	Low	In higher rainfall areas, potentially along geological contact zones.
Other Fractured meta-sedimentary	Moderate	Low?	Includes artesian and warm water springs associated with fault/contact zones.
Basement complex and younger granites	Low to Moderate	High	Seep zones on slope changes (concave).

[1]The rationale for the scores in Table A3 is given in the sub-sections to follow on the individual aquifer types

[2]A deep aquifer may not be regional in the proper sense, particularly where the topography is broken

The remainder of this section will focus on the two types given above with a high likelihood of connection to the deep/regional aquifer, namely the coastal plain primary aquifer and Karst landscapes. As discussed earlier, this serves as an aid to identifying those "special case" wetlands where the hydrological supply area might extend beyond the topographically defined catchment of the wetland. The remainder of this section will also cover two additional types, namely the Table Mountain Group and the Karoo Supergroup in order to illustrate some of the contrasting situations found in the different types. Unfortunately the scope of the project does not allow for the rest of the types to be described here, but it is hoped that this can be done in the future.

The coastal plain primary aquifer

In South Africa, coastal plains are not extensive, and much of the coastal plain area of South Africa is located within a few key areas. Coastal plains are generally characterized by a primary aquifer which lies close to the ground surface, but not uniformly close. Given the topographic relief of coastal plains, wetlands typically occur where the coastal aquifer intersects the lower-lying areas, and such areas are sustained by the regional aquifer. However, wetlands may also occur above and completely disconnected from the coastal aquifer. For example, Grundling (2014) notes the occurrence in the Maputaland coastal plain[4] of wetlands perched above the regional aquifer, in particular temporary depressions such as the Kwamsomi Pan (shown as Z62 in Figure A6), which lies on an upland plain parallel to the Muzi Swamps wetland system (Grundling, 2014). The soil profiles of such perched wetlands are characterized by aquitards caused by high clay content, buried ferricrete or paleo-peat layers (Grundling, 2014). For example, Botha and Porat (2007) note that where the clay-enriched Kosi Bay Formation weathering profiles are exposed, the near-surface water table is perched, resulting in extensive wetland areas (including the Kwamsomi Pan referred to above) in the catchment areas of Lake Sibaya and the Kosi lakes. Kelbe et al. (2016) suggest further the presence of these perched temporary wetlands above the regional water table may be important for depression-focused recharge, which in part provides water to wetlands at lower elevations such as the peat-dominated Muzi wetlands and Kosi Bay swamp forests.

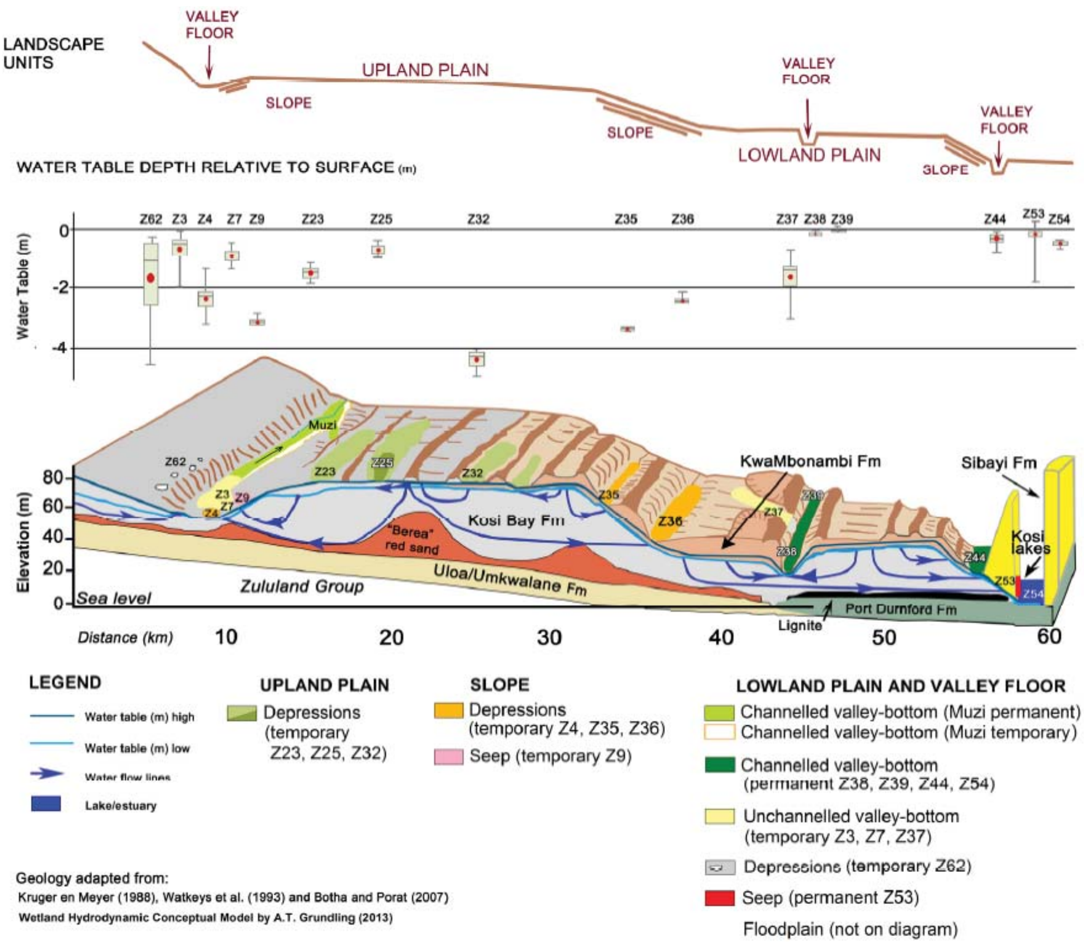

Figure A6: Wetland Hydrodynamic Conceptual Model. Schematic illustration of wetland types identified and their respective position in the landscape (from Grundling, 2014). Note: a distinction is not made in the figure between perched water tables and the regional aquifer surface.

[4] The Maputaland coastal plain contains many interdune or topographic lows in contact with regional aquifer and supports one of the highest extents of wetland in South Africa and 60% of South Africa's known peatlands (Grundling et al., 1998; Grundling, 2014).

As indicated in the section about "A procedure for describing the dominant flowpaths in a wetland and its catchment", the lowest lying and wettest areas are generally most likely to be linked to the regional aquifer. For further assistance in identifying whether linked to the regional aquifer or perched above it, reference should be made to existing studies on the coastal plain in question. For example, a regional groundwater model has been developed for the Maputaland Coastal plain by Kelbe et al. (2016) that extrapolates the depth to water table based on the regional topography, geomorphology, climatology and lithology, coupled with information on wetland distribution and character. For the Cape Flats, useful reference can be made to a model developed by Adelana et al. (2010) based on information drawn from an extensive network of boreholes and profile descriptions. Aquitards have been mapped by Adelana et al. (2010) along extensive transects traversing this coastal plain (Figure A7). Several further studies exist for some of the smaller coastal plain areas, e.g. Parsons (2009; 2017) for the Sedgefield area of the southern Cape.

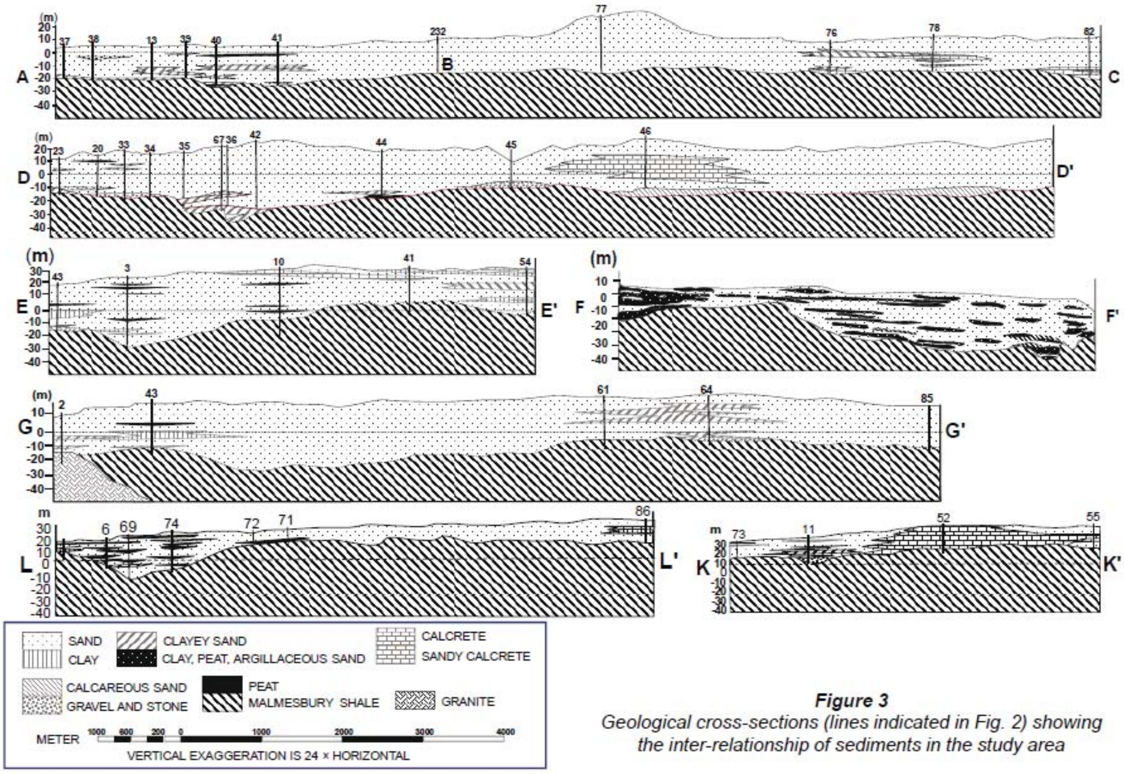

Figure A7: Geological cross sections in the Cape Flats (from Adelana et al. ,2010).

Karst landscapes

The term karst is primarily associated with terrains underlain by limestone or dolomite and refers to a distinctive terrain and landforms that evolve through the dissolution of the bedrock and where an efficient underground drainage system consisting of fissures enlarged by solution, conduits and caves develop with time (International Association of Hydrogeologists, Karst Commission, 1999; Meyer, 2014).

The primary karst terrain in South Africa falls within Groundwater Region 10, which is underlain by dolomite and stretches from Delmas and Springs, east and southeast of Johannesburg respectively, to the Botswana border north of Mafikeng, an east-west distance of just over 300 km. The area is characterized by low topographic relief and gently undulating plains especially towards the western part of the region.

Some streams and rivers (e.g. the Molopo River) originate at or are sustained by springs and baseflow from the dolomite formations. However, large areas within the region lack surface drainage systems, which is a common feature in areas underlain by dolomitic rocks. The flow regime of the South African karst terrains, and therefore the occurrence of wetlands within these areas, is largely controlled by dykes which act as barriers to groundwater flow and which compartmentalise the carbonates as shown in the schematic cross-section (Figure A8) (Colvin et al., 2007; Meyer, 2014).

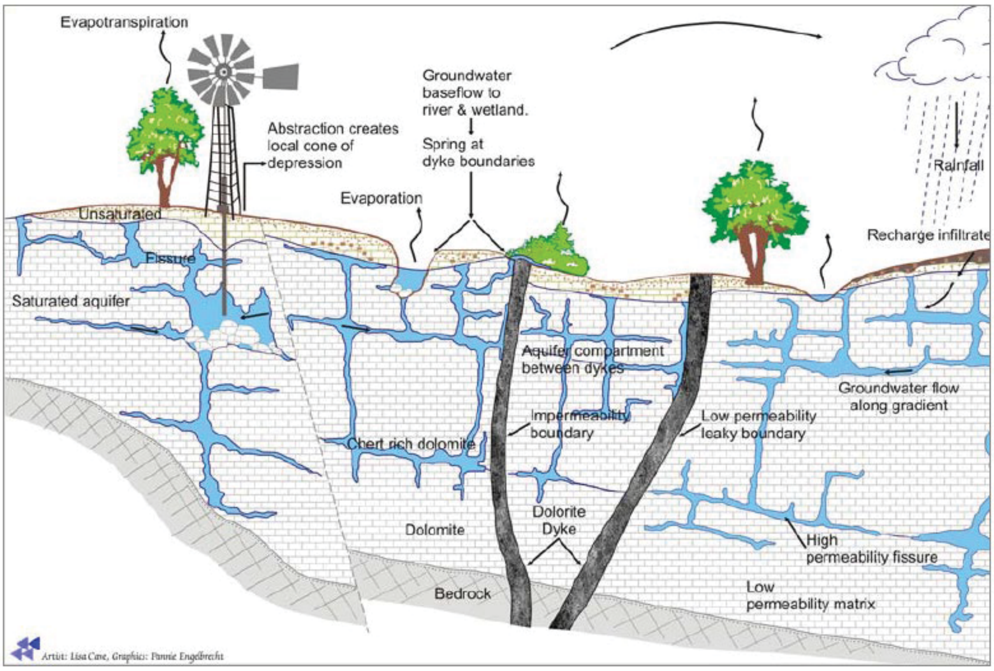

Figure A8: Schematic cross-section of the dolomitic aquifer of North-West Province, South Africa (from Colvin et al., 2007).

Within Region 10 the more prominent dykes are often referred to under specific names, for example the Pretoria, Irene, Olifantsfontein and Sterkfontein dykes. These dykes are generally considered to be mostly impermeable or having a low permeability, and act as barriers to groundwater flow within Groundwater Region 10. As a result Region 10 can be subdivided into numerous groundwater compartments (Meyer, 2014). Close to surface these dykes are usually weathered and groundwater flow across dykes does occur, while at depth the dykes are considered to be essentially impermeable. However, Bredenkamp (2002, as cited by Meyer, 2014) suggests that fracturing at depth due to tectonic activity does occur thereby allowing some trans-compartmental flow, and not necessarily creating a no-flow boundary.

Table Mountain Group (TMG) aquifer

As the rocks in the Table Mountain Group (TMG) generally have low primary porosities, they generally only become good aquifers when fractured (De Beer, 2002). Thus, the aquifer potential of the TMG rocks, as influenced by the degree of fracturing, varies across the TMG, and the most favourable targets are faults and strongly folded strata (De Beer, 2002).

Groundwater discharge to the surface environment is characteristic of TMG catchments (Colvin et al., 2009). These catchments are typically mountainous with orographic rainfall, high permeability and discharge occurring from multiple flow paths. Colvin et al. (2009) distinguish between (a) rapid recharge-discharge response areas in the higher-lying, unsaturated and unconfined parts of the Peninsula and Skurweberg aquifers resulting in seasonal and interflow contribution to springs, wetlands and seeps; and (b) higher storage and longer flow paths in the lower-lying unconfined and confined parts of this multiple-aquifer system, resulting in a smoothed recharge response and prolonged, often constant discharge (Colvin et al., 2009).

Similarly Meyer (2002) distinguished between (a) “Shallow circulating” (perched) springs/seeps issuing from a network of joints, small fractures, contact zones of weathered mantle and bedrocks that are seasonally controlled and generally cease with the onset of dry weather conditions and (b) Lithology/fault controlled seeps issuing from geological contacts or uniformities which are characterized by sustained and relatively constant seepage.

Out of 53 springs investigated by Cleaver et al. (2003) in the Kammanassie Mountains, 27 (50%) clearly emanated from perched groundwater systems, and were concluded not to be vulnerable to groundwater abstraction. Sixteen (30%) of the springs were identified as supplied from deep groundwater and therefore potentially vulnerable to the effects of groundwater abstraction. The remaining 10 springs (19%) were identified by Cleaver et al. (2003) as possibly being springs emanating from perched systems but there was an element of doubt in terms of their identification. Similar finding are reported for a site in Kogelberg near Betty’s Bay and Purgatory, near the Franschhoek pass by Colvin et al. (2009) who concluded that most of the springs, wetlands and seeps studied in the two sites appear to receive groundwater discharge from the higher-lying flow paths in the upper part of the aquifer.

Karoo Supergroup, including dolerite dykes and sills

A major characteristic of the Karoo Supergroup, which consists mainly of sandstone, mudstone, shale and siltstone, is their low permeability resulting in a low water yield. However, dolerite dyke and sill intrusions are very widespread within the Supergroup (Figure A9) and exert a profound effect over sub-surface water movement and yield.

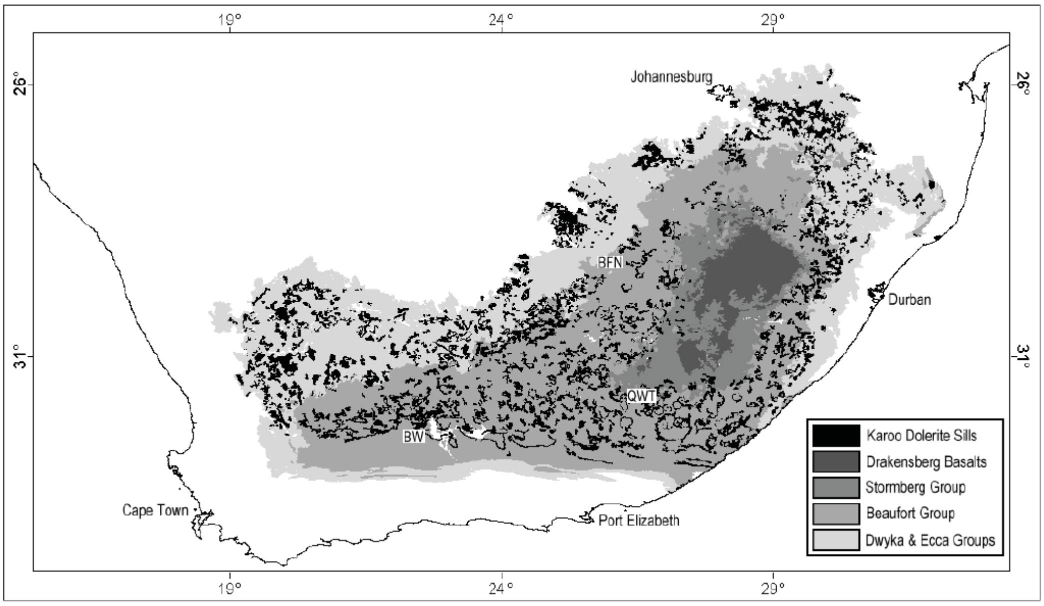

Figure A9: Dolerite sill distribution in the Karoo Basin, extracted from the 1/1,000 000 Geological Map (from Dondo et al., 2010).

In terms of their evolution the dykes “feed” the sills and therefore have the same geographical distribution as that shown for the sills. Dolerite dykes are vertical to sub-vertical discontinuities, generally with shrinkage joints (fractures) which extend a few meters from the dyke into the host rock (Woodford and Chevallier, 2002). The dyke may act as a semi- to impermeable barrier to the movement of groundwater and the fractured zone adjacent to the dyke as a conduit for groundwater flow within the aquifer, and is a favoured site for boreholes. (Woodford and Chevallier, 2002).

Dolerite sills refer to predominantly horizontal sheet intrusions that have intruded between older layers of sedimentary rock, and therefore the lithology of the country-rock strongly controls the emplacement of the sills. Dolerite dykes that cut sills are often good targets for groundwater, especially in a valley-bottom situation where the sill material is highly weathered, although the dyke-sill contact zone is generally not as wide or permeable as that of the dyke-sediment contact (Woodford and Chevallier, 2002). A series of inclined sills may appear as a saucer shaped feature, often kilometres across, and this is referred to as a dolerite ring.

Dondo et al. (2010) examined a study area which covers the Mzimvubu – Keiskamma Water Management Area (WMA 12) in the Eastern Cape Province, as well as some portions of the Mvoti – Umzimkulu WMA in KwaZulu-Natal (WMA 11). This area is characterized by generally higher rainfall than much of the Karoo basin, and the following conclusions were drawn from the study:

- The spring and seep density in the study area is higher than in the rest of the Karoo basin.
- Although varying across the overall area, springs and seeps tend to generally be linked to a dyke or a sill, as can be seen from a map of one of the study sites shown in Figure A10.
- Many heads of streams of the drainage system are fed by springs or seeps, which therefore make a significant contribution to discharge.
- The spring water in the study area is derived from water circulating at depths along secondary aquifers such as fractures and faults in the same manner as most of the springs in the Karoo basin.
- Perched water trapped between the top of a sill and the overlying sediment can emerge at high elevation and form elevated springs or seeps.
- High density fracturing or dyke occurrence inside a sill allows the water to circulate and emerge at a lower level either below the sill or at the foot of dolerite ring, where a high concentration of springs and seeps characteristically occur.

The contacts between sandstone-rich formations and mudstone-rich formations (Katberg above Balfour or Molteno above Burgersdorp) is favourable for spring or seep concentration in the sedimentary pile. This transition is characterised by a higher frequency of alternating sandstone and mudstone than the rest of the sequences which are either mainly sandstone dominated or mudstone dominated. The water percolates through the sandstone and emerges at the contact with the mudstone (Dondo et al., 2010).

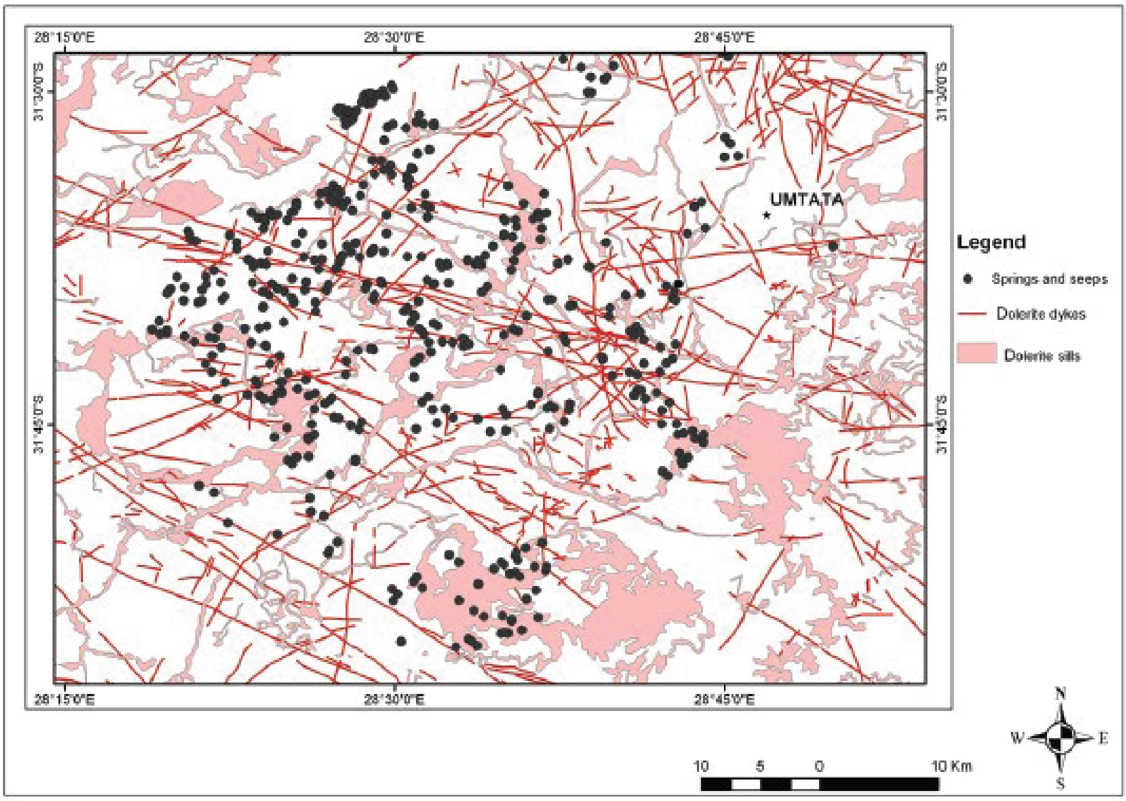

Figure A10: Distribution of springs and dolerite dykes and sills, west of Mthatha (from Dondo et al., 2010).

Acknowledgements

Very valuable ideas and feedback on the guidelines are gratefully acknowledged from the following individuals: Damian Walters, Pieter le Roux, Nancy Job, Jenny Day, Fred Ellery, Dean Ollis and Doug Macfarlane. Pieter le Roux is further thanked for his very comprehensive and insightful comments provided on earlier drafts of the guidelines.

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Appendix B: The geomorphic dynamics typical of different wetland hydrogeomorphic (HGM) types

Compiled by: Donovan Kotze and Michael Grenfell

In order to be able to assess the impacts of human activities on wetlands and identify appropriate management responses, it is necessary to understand how these wetlands evolve and change as a consequence of natural processes such as sedimentation and erosion (Ellery et al., 2008). These processes may lead to changes in wetland morphology and dynamics that are autogenic (i.e. an inherent part of system behaviour, such as the progressive steepening of a valley bottom leading to gully initiation), and/or they may be allogenically-forced by natural climate change (pre-Anthropocene). Human impacts within catchment systems lead to acceleration or deceleration of these natural processes, although the fundamental principles still apply (Leopold et al., 1964). The challenges lie in determining when a change is more rapid and/or more severe than would be expected naturally, and whether the human impact is enduring and will therefore prevent processes of natural recovery. The purpose of this section is to briefly describe the typical range of geomorphic variability associated with different wetland hydrogeomorphic (HGM) types. This is intended as an aid to assessing geomorphic integrity by assisting in describing the natural reference state(s) of a wetland, and informing decisions around whether to attribute observed deposition/erosion to natural or anthropogenic causes. This is done for each of the main HGM types described by Ollis et al. (2013).

It is important to add that this Appendix serves only to provide an initial orientation. A new genetic geomorphic classification system for southern African palustrine wetlands by Grenfell et al. (Under Review) is anticipated to significantly improve the characterization of wetland morphodynamics, by outlining a generic set of geomorphic modes of wetland formation common in dryland environments, by providing a context for geomorphic change and processes typically associated with each mode of formation, and by clarifying when and how longitudinal (dis)connectivity in material fluxes most significantly influences wetland ecological integrity..

Floodplains

Meandering river floodplains typically occur in low gradient broad valley floors, such as that of the Klip River floodplain wetland, which owes its origin to the presence of erodible sandstone and mudstone geology, located upstream of a resistant dolerite intrusion (Tooth et al., 2004, 2010). Meandering river floodplain wetlands are characterized by a dynamic channel, which migrates laterally across the valley floor. Channel dynamics may include point bar (inner bend) deposition and cutbank (outer bend) erosion, as well as larger-scale dynamics through meander cutoffand wholesale channel realignment through avulsion, with the latter involving abandonment of the old channel and concomitant development of a new course, as described in the Mfolozi (Grenfell and Ellery, 2009) and the Klip (Tooth et al., 2010) floodplains. The frequency with which channel avulsions occur depends on factors such as rates of floodplain and levee aggradation (for sedimentation-driven progradational avulsion), or rates of channel length extension through meander development (for headward-erosion-driven incisional avulsion), and where these rates are low, such as in the Klip River wetland, avulsions may occur at intervals of several thousand years (Tooth, 2007). Processes of channel extension, levee development, meander cutoff and avulsion create a complex physical habitat mosaic of convex and concave features, inducing spatial variation in hydroperiod, which can lead to vegetation diversity.

Channel cutoff can be affected deliberately by humans, through excavating a channel across a meander bend neck. Since the majority of meander cutoffs observed in slowly migrating meandering river floodplains of the South African interior are neck cutoffs, which form when opposing meander bend limbs meet one another, the presence of a relatively long channel connecting opposing limbs (a 'chute' channel) is often an indicator that cutoff has been anthropogenically forced, especially when surrounded by other signs of physical surface disturbance such as the development of ridge and furrow or other drainage networks. Chute cutoffs are common in rapidly migrating meandering river systems and semi-braided systems, which are on the whole not commonly observed in South Africa. Avulsion may similarly be accelerated by the deliberate excavation of diversion channels (e.g. Ellery et al., 2003; McCarthy et al., 2010). Unless the new channel has been set in position by embankments or some other form of engineering, natural meander migration processes will in time re-establish a sinuous planform, although not always over a timescale deemed acceptable to managers (McCarthy et al. 2010).

In many South African meandering river floodplain wetlands, the main channel through the floodplain rests on or very close to bedrock (Tooth et al., 2004, 2007). In such floodplains the sediment tends not be very deep, and is usually <4 m deep as a result of low levels of aggradation (Tooth and McCarthy, 2007). A low sediment supply relative to the capacity for onward transport means that the channel bed remains grounded on bedrock (Tooth et al., 2007). However, in some floodplains, where sediment supply relative to transport capacity is high, the valley fill is much deeper, with one of the deepest recorded being that of ~35 m for the Nyl floodplain wetland, which occurs in a semi-arid climate (McCarthy et al., 2011). Thus, it can be appreciated how climate may have an important influence over the net accumulation of sediment in floodplains. This is further demonstrated by Grenfell et al. (2014) who examined two floodplains with comparable geology and catchment position but contrasting climate. In the Seekoei River floodplain in the semi-arid Karoo, flows are likely to be episodic and characterized by floodouts and avulsing distributaries, and net retention of sediment is greater than in the sub-humid Nsonge River Floodplain in the KwaZulu-Natal Province, where flows are much more sustained and in a continuous meandering channel, and sediment depth is limited (Grenfell et al., 2014).

Channelled valley bottom

Channelled valley bottom wetlands are characterised by much less lateral reworking of sediment than floodplains (Ellery et al., 2016) and generally lack meander cutoffs and channel avulsions. However, there is localized dynamics of the channel through bank cutting and point bar deposition. In addition, as described for unchannelled valley bottoms, channelled valley bottoms may also be subject to cut and fill cycles, as found by Ngetar (2011) in a channelled valley bottom in the headwaters of the Manalana stream, Bushbuck Ridge. Ngetar (2011) showed that long-term climate change has resulted in the formation of two terraces, the older, 1670 ± 890 years old and the younger, 320 ± 80 years old in the wetland. The former probably eroded during the medieval warming around 1230 AD while the younger terrace, which likely formed during the last half of the Little Ice Age, has been eroding since the renewed warming thereafter. This erosion has been exacerbated by short-term periodic or seasonal climatic changes, especially episodic summer rainfall events (Ngetar, 2011).

Unchannelled valley bottoms

In terms of dynamics, it is useful to distinguish between unchannelled valley bottoms which owe their origin to in situ weathering (Edwards et al., 2016) and those which owe their origin to impounding, usually due to tributary-trunk interactions (Joubert and Ellery, 2013; Walters, 2015). The in situ weathering situation is characterized by a slow geomorphological evolution as the wetland surface gradually sags over time (Edwards et al., 2016). The latter, which are the more commonly occurring form of unchannelled valley bottom in South Africa, appear to be very dynamic in terms of cut and fill processes (Grenfell et al., 2009; Pulley et al., 2018; Walters, 2015).

The latter is illustrated with a palmiet (*Prionum serratum*)-dominated unchannelled valley bottom wetland on the Kromme River, which is associated with alluvial fan sediment deposits fed my major tributaries of the Kromme River. Coring of this wetland by Lagesse (2017) showed the presence of deep, drowned, trench-like features (up to 8 m deep) beneath floating mats of palmiet, which were predominantly free of sedimentary fill and found opposite tributary alluvial fans. These trench-like features appear to be remnants of deep, narrow, discontinuous gullies. Dating of sediment from the base of these features (460-7040 BP) confirmed that they were formed prior to European settlement in the area (Lagesse, 2017). Lagesse (2017) suggests that over geological time the localised increase in longitudinal slope, caused by sediment deposition on the alluvial fans, transgresses a geomorphic threshold slope and initiates gully erosion. Given that gully erosion pre-dates the introduction of intensive farming practices in the late 18th century, Pulley et al. (2018) argue that a natural explanation based on intrinsic factors is required for gully formation. They suggest further that repeated cycles of gully incision may laterally plane bedrock, as shown by the presence of episodic phases of gully formation and the flat cross-sectional bedrock profile (Pulley et al., 2018). This picture of episodic gully initiation and infilling over centennial to millennial timescales is in contrast to some of the degradation that has occurred in recent times within this and other palmiet wetland systems, such as those in the Agulhas area, where extensive swaths of valley floor have been planed out within a century (e.g. Fig. 16.8 in Rebello et al., 2013; Grenfell and Grenfell, 2019). Active clearing of wetland surfaces for cultivation, invasion and subsequent clearing of alien woody vegetation within wetlands and their catchments, and poorly-designed road crossings that confine flood flows and enforce channelled conditions, may all contribute to changing the dynamic and increasing the severity of wetland erosion, from natural gully development and infilling processes, to valley-wide evacuation of wetland sedimentary fill (Grenfell and Grenfell, 2019).

Depressions and flats

Several mechanisms or combinations of mechanisms have been identified as accounting for the origin of pans (a term widely applied in South Africa to depression wetlands) (Goudie and Thomas, 1985, Marshall and Harmse, 1992, De Klerk et al., 2016). These include: (1) the availability of susceptible surfaces, the subsequent disturbance of such surfaces through salt-weathering and/or trampling by animals; and (2) a lack of integrated fluvial systems (e.g. associated with ancient river courses resulting from stream capture) and the subsequent effect of deflation processes (Goudie and Thomas, 1985, Marshall and Harmse, 1992, De Klerk et al., 2016). Given their origin, the majority of depressions are not connected to a drainage network and associated fluvial influences, and thus are generally very seldom characterized by major deposition or erosion events. Changes in the natural flow paths of water through landscapes, such as the development of flood diversion drains in the Kars floodout wetland on the Agulhas plains, can result in the ingress of sediment-rich floodwaters into previously isolated plains pan-scapes, leading to anthropogenically accelerated clastic sedimentation.

Wetland flats are limited in their occurrence within South Africa, and specific geomorphological studies on this wetland type are lacking. Flats are defined by Ollis et al. (2015) as level or near-level wetland areas that are not fed by water from a river channel, and which are typically maintained primarily by precipitation or, if located on a coastal plain, also by groundwater. Horizontal water movements within the wetland are therefore typically weak and unidirectional, if present at all (Ollis et al., 2015). Therefore, flats are not connected to a drainage network and associated fluvial influences, and, like depressions, flats are unlikely to be affected major deposition or erosion events mediated through water flows.

Seeps

Seep wetlands are located on hillslopes, and by definition are dominated by colluvial (gravity-driven) rather than fluvial geomorphologic processes (Ollis et al., 2013). Seeps tend to be located outside of the valley floor on hillslopes, including midslopes (usually concave) or footslopes, but may be associated with the valley such as on upper river terraces, as described by Mapeshoane and Van Huyssteen (2016) or at the head of first order streams (Riddell et al., 2010). Further adding to the diversity of seeps arising from their wide-ranging locations, is the fact that some seeps are drained by a channel whereas others are not.

There appears to be a considerable lack of research on the geomorphic dynamics of seep wetlands. However, studies such as Riddell et al. (2010) and Ngetar (2011) would suggest that seep wetlands associated with headwater streams are likely to be affected by any cut and fill cycles taking place in these headwater streams, as described earlier. Although no relevant research could be found on seep wetlands which are not closely associated with the valley head (e.g. located on a midslope) the work of Botha et al. (1994) and Botha and Fedoroff (1995) in hillslopes with deep colluvial deposits in northern KwaZulu-Natal is informative. An examination of sediment profiles covering a period of ~120 000 years revealed hillslope cycles with extended phases of colluviation punctuated by episodic erosion, which appear to be linked to climate change associated with the glacial-interglacial cycle (Botha et al., 1994; Botha and Fedoroff, 1995).

Seeps on hillslopes are obviously vulnerable to direct disturbance by the plough or drainage development, easily identifiable on imagery, while those with a strong outflow channel connection may be affected by culvert emplacement across the outflow, or by headward erosion initiated by disturbance of the valley floor.

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Appendix C: Technical GIS guidance for completing Level 1 assessments

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C1] Technical GIS guidance for completing a Level 1A assessment

NOTE: This guidance is for assessors using ESRI's ArcGIS software. Most of the tasks can be undertaken in other GIS software, such as the Free Open Source Software (FOSS) alternative Quantum GIS (QGIS). At this point in time, however, there is no built-in function in QGIS or other FOSS GIS software equivalent to the "Tabulate Area" function in ArcGIS. This requires the assessor to use landcover data in a vector format (instead of raster format) when using alternative GIS software to ArcGIS for the completion of a WET-Health Level 1A assessment, or to adapt existing raster data analysis tools to complete the tasks. If a User Manual is produced for WET-Health Version 2.0 in the future, it should include detailed technical guidance for completing Level 1 assessments with FOSS GIS software such as QGIS.

1. ***Prepare project and feature class***
    - Open the ArcMap window and select 'Add' data to the map window; alternatively, data can be accessed on ArcCatalog. To access the data, navigate on the Catalog Tree to locate the location of the data and drag it into the ArcMap window.
    - Create a Geodatabase into the ArcCatalog folder to store all relevant data for your project. A geodatabase is used primarily to store information about the geographic features, query, and manipulate spatial data
    - Evaluate data by checking the attributes of the dataset, ensure that the dataset contain the relevant attributes like HGM type. Check the 'Coordinate system', the datasets needs to be in correct geographic and/or projected coordinate system required for the tasks.
    - Save the project on the ArcMap window, select file and save the project.

2. ***Apply the Buffer Tool (Geoprocessing Tool)***
    - Buffer Tool will be used to create new output feature classes with polygons around features of the input feature classes, based on a buffer distance. The following input feature classes (Zones of Influences) will be buffered based on different buffer distances; **Wetland (200 metres)**, **Pseudo-catchment (600 m).** Ensure that the 'FULL' buffer option is selected to allow the output feature class to contain input feature and overlap the area of the input features.
    - The Pseudo-catchment zone of influence (600 m buffer) is assigned to **Flat, Seep and Depression** HGM types and Sub-Quaternary Catchment is assigned to **Channelled Valley Bottom, Unchannelled Valley Bottom, Floodplain and Depression (exceed 1000 ha)**.
    - Create a Geodatabase into the ArcCatalog folder to store all relevant data for your project. A geodatabase is used primarily to store information about the geographic features, query, and manipulate spatial data.

3. ***Spatial Join (assigning HGM Types to Pseudo-catchments Sub-Quaternary)***
    - To ensure that HGM Types (**Channelled Valley Bottom, Unchannelled Valley Bottom, Floodplain and Depression (exceed 1000 ha)**) are assigned to Sub-Quaternary and contain the same attribute FIELD ID, a join should be performed. The Spatial Join tool joins the attributes of a feature class (join feature class) to another feature class (Target feature class) based on spatial relationships such as proximity or containment.
    - Navigate to the Target feature class and **Right Click and select Joins and Relates>Join,** on the Join Table, **What do you want to join to this layer?** drop down option select Join data from

another layer based on spatial location, load the Sub-Quaternary catchment feature class and check 'Each Polygon will be given the attributes of polygon it falls' option and run the tool.

- Alternatively Spatial Join can be executed in FME Desktop (https://www.safe.com/fme/fme-desktop/). Open FME WorkBench and search for **MaxOverlappingFeatureMerger** in the Transformer Gallery: The tool joins the attributes from the maximum overlapping polygon onto the incoming features. It performs spatial joining of two polygons based on the maximum area based where the majority of the one polygons area lies. The tools assigns weight to polygon based on the max area overlap. The max overlapping area is created on the attribute, called maxOverlap. Overlapping feature class will be assigned new ID.

4. *Clipping Landcover to Zones of influences*

- The application of the Level 1A tool requires the user to estimate the extent of each of a predefined list of broad landcover categories within the following three "zones of influence":
  - within the wetlands;
  - within a 200 m wide buffer area around the wetlands; and
  - within the pseudo-catchments selected as a proxy for the true topographical catchments of the wetlands (e.g. 600 m Buffer or relevant Sub-Quaternary Catchments).
- Load the modified Landcover Dataset with predefined broad landcover categories for Level 1A assessment. The landcover raster dataset will be clipped to an area of interest (zones of influences).
- Clip the raster for your area of interest, firstly, locate and identify raster landcover dataset. 2. Identify the vector (zone of influence). 3. Locate ArcToolbox > Spatial Analyst Tools > Extraction > Extract by Mask. Another method to clip the raster for your area of interest is by using the "Clip" Tool, navigate to > Data Management toolbox > Raster toolset > Raster Processing toolset > Clip.
- To ensure that the results of the conversion will align properly with a class raster input, it is recommended that you set the environment settings and check that the extent and snap raster are set appropriately in the environment settings and the raster settings. You can locate this on the ArcMap file menu >Geoprocessing> Environment Settings>Processing Extent.
- After identifying the raster dataset and vector dataset for the zone of influence, locate Arc System ToolBoxes > Spatial Analyst toolbox >Zonal> Tabulate Area. Tabulate Area calculates cross-tabulated areas between two datasets and outputs a table. Open the Tabulate Area tool, On the **Input raster or feature data zone** select your area of interest/zone of influence (vector polygon), on the **Zone Field** select the field from the attribute table that will be used to define each zone to landcover extents. Load the landcover raster dataset on **the Input raster of feature class data,** on the **Class field** use drop down option to select 'LC_OllisTXT' field, **Output**, save the output table to the project destination, Output table that will contain the summary of the area of each class in each zone. The format of the table is determined by the output location and path. By default, the output will be a geodatabase table. If the path is not in a geodatabase, the format is determined by the extension. If the extension is .dbf, it will be in dBASE format. If no extension is specified, the output will be an INFO table.
- The output table contains a summary of the landcover area extents for each feature dataset (zone of influence).The area units of the output summary are in **Square Meters**, to convert to Hectares you can use the Field Calculator in the attribute table or you can convert in the Excel spreadsheet. The output table summary can be stored as a dBase file and be opened in Microsoft Excel.

5. ***Linking Level 1A output back to GIS***
   - After populating area extents from GIS to the Level 1A spreadsheet and generating results. Navigate to PES summary in the Level 1A spreadsheet and copy all the generated records including the **Wetland_ID** to a new spreadsheet and save the save the file as CSV file format and load the Excel spreadsheet file inside ArcMap.
   - After loading the Excel file, locate the wetland dataset used to generate landuse mapping and **Right Click** and select **Joins and Relates>Join.** The spatial join tool joins the attribute of a feature class to another feature class based on a field between the two feature classes. On the **Join Attribute Table** of the feature class, choose the field in the layer that the join will be based on, Select the Excel spreadsheet Table in the **Table to join to this layer** and choose the field from the table that will be used to base the join. Select the '**Keep all records'** Join Option and run the tool. The output feature class will have the same attribute as the Target feature class, but contains attributes from both the join and the Target feature class.

C2] Technical GIS guidance for completing a Level 1B assessment

Level 1B is a desktop assessment using more refined landcover categories than a Level 1A assessment, and requires some "heads up" interpretation of aerial imagery by the assessor, as well as potentially involving limited field verification. In the case of Level 1B, the user is required to map landcover categories within each of the zones of influence that are considered, typically by interpreting aerial imagery and digitising polygons representing the various landuse categories in Google Earth, ESRI's ArcGIS Earth or Cape Farm Mapper, or using GIS software.

1. ***Prepare project and feature class***
   - Open the ArcMap window and select 'Add' data to the map window; alternatively, data can be accessed on ArcCatalog. To access the data, navigate on the Catalog Tree to locate the location of the data and drag it into the ArcMap window.
   - Create a Geodatabase into the ArcCatalog folder to store all relevant data for your project. A geodatabase is used primarily to store information about the geographic features, query, and manipulate spatial data
   - Evaluate data by checking the attributes of the dataset, ensure that the dataset contain the relevant attributes like HGM type. Check the 'Coordinate system', the datasets needs to be in correct geographic and/or projected coordinate system required for the tasks.
   - Save the project on the ArcMap window, select file and save the project.

2. ***Create feature templates (polygons)***

   ArcMap (ArcGIS):

   - On ArcMap, Create a new feature (vector) to map the landcover categories within zones of influence. Start ArcCatalog or ArcMap and open the Catalog window. Create a connection to your database. Right-click the table, point to New, and click Feature Class. Type a name for the feature class. Choose the type of features to store in the table, Polygon Features. Display the Editor Toolbar and start and edit session, open the Create Features window and click create. After you select a feature template, you can use Construction tools for polygons to create polygons. During the edit session, in the attribute table, enter the landcover categories during mapping and then close the template properties. (Refer to **ArcGIS Help** for more details)

   Google Earth:

   - To create a polygon in Google Earth, navigate to the Tool Bar at the top; click **Add Polygon** (CTRL + Shift + G). The new Polygon dialog box will appear, enter the landcover category field and properties when mapping. Click on the map to start drawing using Google Earth methods

(**Free-Form shape, Regular Shape or use Measurement tab** within the Polygon dialog box to adjust the dimensions of the drawing. To edit a saved drawing, select the drawing from the Places dialog box, left mouse click and select Properties.

Cape Farm Mapper:

- Cape Farm Mapper (https://gis.elsenburg.com/apps/cfm/) can be used to map the landcover using online landcover maps and other updated spatial datasets, the online tool is designed for the Western Cape area. The online tool only works with KML, GPX, KMZ or Shapefile (Zipped). To add a feature on the Cape Farm Mapper dashboard, navigate to Import/Export>Import Features from File>Add File. Then navigate to **Layers** to display aerial images inside **Basemap** filter and Land Cover inside **Resource Layer.** To map landcover categories for your area of interest, navigate to Tools>Drawing Tools> Polygons. The landcover features created during the mapping will generate area extents for each landcover category automatically. Once the mapping is completed you can export the features to file on **Import/Export**, the file is converted to KML and Shapefile.

3. Map landuses within wetland polygon

- Refer to the refined landcover categories for "Level 1B assessment" table, which provides a list of landcover types for mapping.
- Refer to: ***2. Create feature templates (polygons)***
- Map the landcover categories within the zone of influence based on an interpretation of aerial imagery in ArcMap, Google Earth or using Cape Farm Mapper. Calculate the area extents of each mapped landcover categories in Hectares.
- Revise the landcover map for the zone of influence based on field observations and landcover datasets and save the output for the Level 1B spreadsheet.

4. Demarcate boundaries of "external areas of influence"

The boundaries of the predefined "external areas of influence" surrounding the wetland must be demarcated to allow for the extent of the various landuses within these areas to be determined.

Wetland Buffer (excluding wetland):

- Run a **Buffer Tool** to create new output feature classes with polygons around features of the input feature classes, based on a buffer distance.
- Create a 200 m Buffer width **around** the wetland polygon that accurately represents distances on Earth's surfaces. Ensure that you select "OUTSIDE ONLY' buffer option, buffers will be generated only outside the input polygon, the area inside the input feature polygon will be erased from the output buffer.
- The output feature, 200 m buffers around the wetland, need to be clipped to the catchment. Run the **Clip Tool**, navigate to System Toolboxes > Analysis Tools> Extract > Clip, the **Clip Tool** cuts out the area of a feature class (200 m buffer input feature) that intersects with a feature class (catchment).

Inflowing instream buffers:

- Load the River coverage -1:50 000 dataset on GIS and clip the dataset to the up-slope catchment using **Clip Tool**, alternatively, map the streams on Google Earth falling inside the up-slope catchment (excluding the wetland buffer and wetland).
- Run a **Buffer Tool** to create a 200 m buffers around the inflowing stream.

Remaining upslope catchment:

- The differences between a Level 1A and a Level 1B (and Level 2) assessment, in terms of landcover mapping, is that the true catchment of the wetland needs to be demarcated (not a pseudo-catchment) by the user.
- In a Level 1B assessment, there is flexibility and freedom for the user to choose how best to demarcate the upslope catchment.
- Recommended methods to demarcate a wetland upslope catchment include; **Arc Hydro Tool for ArcGIS** (Watershed Processing>Batch Watershed Delineation for Polygons), **Demarcate endorheic watersheds and Demarcate non-endorheic watersheds** (Collins, in prep.), **Google Earth** elevation profile and **Contour map** of the area, useful to assist in mapping the catchment.
- After the up-slope catchment is demarcated, the feature should be refined by excluding the wetland and its buffer, and excluding the inflowing stream buffers.
- To exclude (eliminate) features or portions from the other features, run **Erase Tool**, the erase tool creates a feature class from the features or portion of features outside the erase feature class (inverse of the Clip Tool). Navigate to System Toolboxes>Analysis Tools>Overlay>Erase. Open the Erase Tool, load the demarcated up-slope catchment in the **Input Features** and for the **Erase Features** load the features to be used for erase (Inflowing stream buffers or 200 m buffer around wetland or wetland).

5. Map landuses in "external areas of influence"

- Refer to the refined landcover categories for "Level 1B assessment" table, which provides a list of landcover types for mapping.
- Refer to: ***2. Create feature templates (polygons)***
- Map the landcover categories within (1) the **200 m buffer around the wetland** (excluding the wetland), (2) the **200 m buffer area adjacent to the inflowing streams** (excluding the portion within the wetland buffer), and (3) the **remaining up-slope catchment** (excluding inflowing instream buffers, 200 m buffer around wetland and wetland). This mapping should be based on an interpretation of aerial imagery and landcover maps in ArcMap, Google Earth or Cape Farm Mapper.
- Calculate the areal extent of each mapped landcover category in each "external area of influence" in Hectares.
- Revise the landcover map for the zone of influence based on field observations and landcover datasets and copy the output to Level 1B spreadsheet.

Appendix D: List of electronic data sources provided with this report

1) WET-Health Version 2.0 spreadsheets (x2) for Level 1A assessment, catering for 500 wetlands and 2000 wetlands, respectively

2) WET-Health Version 2.0 spreadsheet for Level 1B assessment

3) WET-Health Version 2.0 spreadsheet for Level 2 assessment

4) GIS coverage of the Quaternary catchments in South Africa

5) GIS coverage of hydro-geological type settings at a coarse national scale

6) GIS coverage of the predefined broad landcover categories for the whole country (raster format), as derived from the NLC-2014 dataset

7) GIS coverage of slope/relief categories at a coarse national scale

8) GIS coverage of SAS-SA soil groups

9) DWS database of major WWTW outlets