A method to assess wetland ecological condition based on land-cover type

Part 2: Technical background

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A simple Citizen Science tool to assess the ecological condition of a wetland
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Executive summary

A wide variety of different land-cover types occur within wetlands and their upslope catchments, e.g. commercial annual crops or open water of dams, and each land-cover type tends to have associated with it particular ecological impacts. For example, commercial annual crops involve the complete clearance of the indigenous vegetation, application of fertilizers, etc. If this land-cover was in the wetland then these impacts could considerably diminish the ecological condition of the wetland, depending on its extent in the wetland. If located in the wetland's upslope catchment, the impacts would be less direct, e.g. the vegetation in the wetland would not be directly removed, but the quality, quantity and seasonal pattern of water inflows to the wetland could potentially be significantly affected even if the land-cover was located some distance upstream, but again dependent on extent. Therefore, by rapidly identifying which land-cover types occur in a wetland and its catchment and how extensive these land-cover types are, inferences can be drawn about the magnitude of impact on the ecological condition of the wetland. This is the rationale underlying the method given in this report, which is being developed with funding from WWF and the Water Research Commission.

The scoring system of the method is based on that applied by WET-Health, which is a tool developed for assessing the ecological condition of South African wetlands. This involves estimating the spatial extent of individual land-cover types (each expressed as a proportion of the wetland and then of its upslope catchment). Proportional extent is then multiplied by the intensity of impact of each individual land-cover type, which ranges from 0 (no impact or deviation from natural) to 10 (critical impact or complete transformation from natural) to give a magnitude of impact score. The impact magnitude scores for all of the individual land-cover types present in the wetland are added together to derive a total ecological impact score for all land-covers in the wetland. In a similar way, a total ecological impact score for all land-covers in the wetland's upslope catchment is derived, accounting for the moderating effect that a buffer zone of natural vegetation around the wetland is likely to have, depending on its extent. Finally, the total score for impacts of land-covers in the wetland is combined with the total score for land-covers in the wetland's upslope catchment to arrive at an overall impact score for the wetland, which also ranges from 0 to 10.

The method builds on the approach of the WET-Health level 1 vegetation component, where default intensity scores have been assigned to each of a range of disturbance (land-cover) types. This approach is extended to the hydrology, geomorphology and water quality components to align them more closely with the vegetation component. The operator of the method is presented with a comprehensive list of land-cover types, to which typical impact intensity scores have been pre-assigned based on the scientific literature, expert judgement and peer-review. The land-cover types are represented in photos to aid in their identification. A list of land-cover types potentially occurring in a wetland's upslope catchment is also provided. The primary task of the operator who is applying the method is to identify the different land-cover types present in a wetland and its upslope catchment and then to identify the extent of these types. The method does not require that the operator assign impact intensity scores, as required by WET-Health, thereby reducing the prominence that subjective judgments play on the part of the operator in the assessment, which is hoped will reduce the vulnerability of the method to inter-operator variability.

This method is divided into two parts: Part 1 (the user manual) is a detailed step-by-step description of the method; and Part 2 (this document) is a description of the technical background to the method, its scientific basis, and the specific rationale underlying the impact intensity scores assigned to different land-cover types.

Part 1 describes of two possible assessment options, both including steps to carry out in the office and steps for the field. The first option, a qualitative sketch-map option, is applicable if a brief scoping of the various factors impacting upon the wetland is needed but an overall score is not required. The second option, a semi-quantitative map-based option, is applicable if an overall ecological condition/health score is required and/or the condition of the wetland is being monitored and users of the tool have access to Google Earth Pro or other means of generating a land-cover map. In both options, there is provision for considering impacts not accounted for with land-cover, e.g. the point source release of wastewater into the wetland.

Users of the method should have reasonable field experience of wetlands in the region that they are assessing. However, they are not required to be wetland specialists, and might be field technicians or citizen scientists. The method is appropriate for situations where many wetlands need to be assessed across broad landscapes, particularly where good land-cover data are available. Some specific applications include: broad-scale catchment assessment and State of the Environment reporting. The method can also be applied where only one or two wetlands need to be assessed very rapidly or by citizen scientists lacking advanced technical training.

The method does, however, have several limitations which need to be recognized. In particular the method takes little account of the wetland's particular features, e.g. local climate and geology, the wetland's hydrogeomorphic type, the inherent erodibility of the soil in the wetland and the inherent infiltration potential of the soil in the wetland's upslope catchment. Although the method considers the extent to which a buffer zone of natural vegetation around the wetland moderates the impacts from the wetland's upslope catchment, this is done at a very coarse level. Given these limitations, it is important to recognize that the method is generally restricted to scoping-level assessments, and the results need to be seen as tentative, particularly with respect to the water quality component. Thus, a more detailed assessments of some of the assessed wetlands is likely to be required.

Contents

1. Background to the method

Wetlands may be impacted upon directly by land-uses located within the wetland or indirectly by land-uses located in the wetland's upslope catchment. The wetland's upslope catchment refers to that area upslope of the wetland from which water flows (above-ground and/or below-ground) into the wetland, including the slopes immediately adjacent to the wetland as well as including slopes further away which feed any streams ultimately supplying the wetland. A wide variety of different land-cover types occur within wetlands and their upslope catchments, e.g. commercial annual crops, open water of dams, and natural vegetation areas (Figure 1). Each land-cover type tends to have particular ecological impacts associated with it. For example, commercial annual crops involve the complete clearance of the indigenous vegetation, application of fertilizers, etc. If this land-cover was located directly in the wetland, it can be appreciated how these impacts could have a considerable effect on the ecological condition of the wetland, depending on its extent in the wetland. If located in the wetland's upslope catchment, the impacts would be less direct, e.g. the vegetation in the wetland would not be directly removed. Nonetheless, the quality, quantity and seasonal pattern of water inflows to the wetland could potentially be significantly affected even if the land-cover was located several kilometres upstream of the wetland, again depending on extent. Therefore, by rapidly identifying which land-cover types occur in a wetland and its upslope catchment and how extensive these land-cover types are, inferences can be drawn about the likely magnitude of impact on the ecological condition of the wetland.

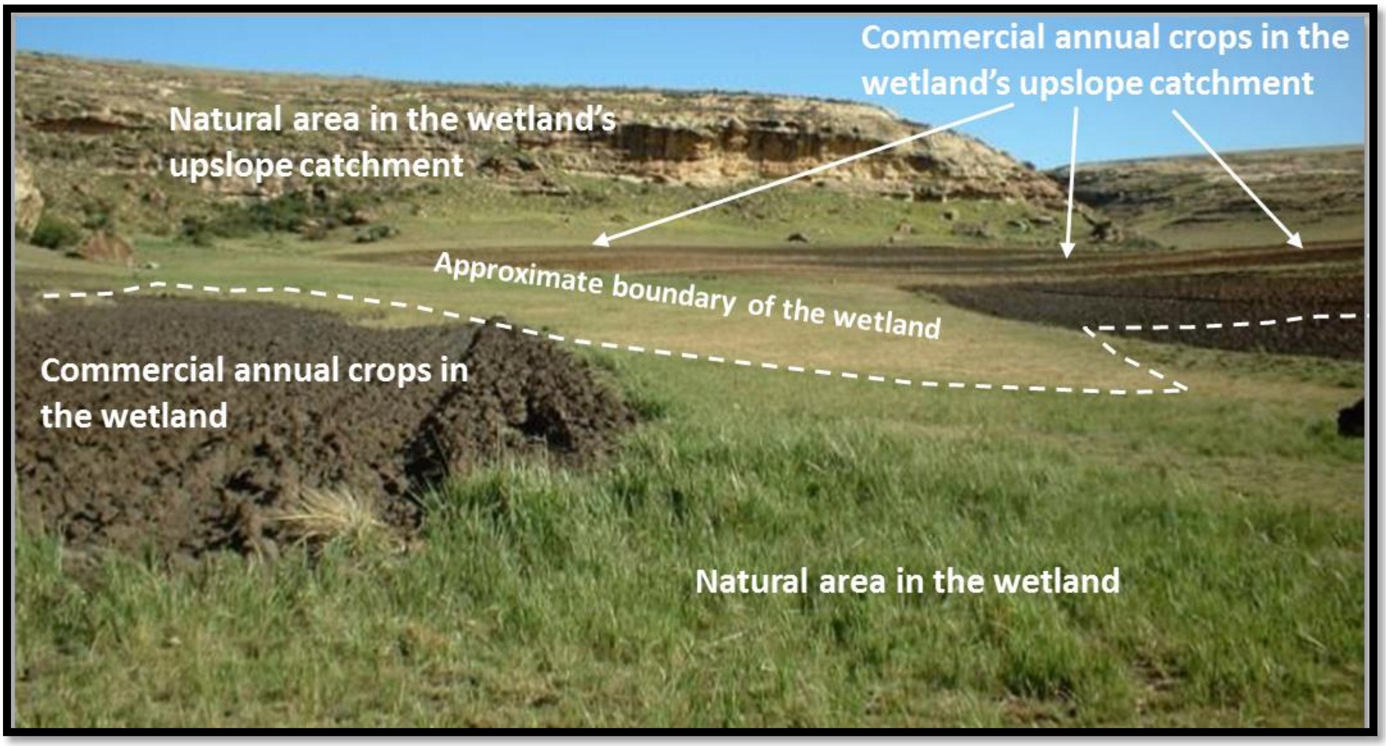

Figure 1: Different land-cover types in a wetland and the wetland's upslope catchment.

The ecological condition of a wetland (often referred to as "ecological health") refers to how close the system is to its natural (reference) condition – if it is close, then condition is taken as good but if far then condition is taken as poor. The natural condition is taken as that defined by Macfarlane et al. (2009), namely that condition in which natural inputs of resources or toxins have not been modified by recent human intervention, and which experiences levels of disturbance (e.g. from indigenous grazing animals) that are regarded as natural.

This report describes a method for assessing the ecological condition of a wetland based on identifying land-cover types in a wetland and its catchment and inferring impacts from the particular land-cover types present. The land-cover types used in method are based on those of Thompson (1996), expanded to account for specific land-covers associated with human use in wetlands. "Land-cover" refers to the physical cover on the earth's surface, including cultivated crops, buildings, natural grassland, etc. The term is distinct, but related to, "land use", which refers to how people use the land. It should be noted, however, that as with Thompson (1996) some of the land-cover types used in this method refer to land-use features, e.g. whether annual crops are irrigated or not.

Two methods, WET-Health (Macfarlane et al. 2009) and Wetland IHI (DWAF 2007), already exist for assessing the ecological condition of South African wetlands, prompting the question "why another method?" This new method is not being developed to replace WET-Health and Wetland IHI, but hopefully to fill some important gaps and limitations of these methods as described below.

Firstly, both of the existing methods require subjective scoring by the operators of the method. In a formal test of the robustness of WET-Health level 1 and Wetland IHI (DWAF 2007) Ollis *et al.* (2014) report that although independent operators scored relatively closely for wetlands which had been little transformed, some widely divergent scores were assigned to wetlands subject to high levels of transformation. In a robustness test of WET-Health Level 2 by Bodman (2011) independent operators scored closer than in the study of Ollis *et al.* (2014) but there was still some divergence. Therefore, Ollis *et al.* (2014) identified a need for trying different approaches for increasing assessment robustness, which this new method attempts to do. As explained further in the following section, the method presents (with example photographs) a broad range of land-cover types potentially occurring in wetlands and their upslope catchments, to which default impact scores have been assigned based on existing research and expert judgment. The new approach certainly does not eliminate the need for subjective judgments by the operator who is applying the method, but it reduces the prominence that such judgments play in the assessment, and makes it more appropriate as a tool to be used by non-scientists.

Secondly, WET-Health and Wetland IHI both give little coverage to impacts of land-uses in a wetland on water quality. While Malan *et al.* (2013) provides a very useful method for assessing the potential impacts of land-uses in a wetland's surrounding catchment on a wetland, it does not explicitly deal with the water quality impacts of different land-covers occurring within the wetland itself. This land-cover based assessment method explicitly attempts to do this. Nonetheless, it is important to emphasize that both this method and that of Malan et al. (2013) are designed merely as scoping tools for estimating water quality impacts to be used in situations where no actual water quality data are available.

Thirdly, WET-Health Level 1 and 2 and Wetland IHI (DWAF 2007) are primarily field-based techniques and are not designed for large-scale, coarse assessments undertaken primarily at a desktop level, e.g. across an entire sub-catchment. It is suggested that the land-cover based approach would assist greatly in undertaking these broad-scale assessments (with field verification) given that extensive land-cover data already exist both nationally and at a more detailed level for certain municipalities and catchments, and given the prohibitive expense and resources that are required for wetland assessment across a wide geographical expanse.

Suggestions have been made to revise and rationalize WET-Health and Wetland IHI, possibly through the development of a single "merged" method, which builds on the strengths of both methods (Ollis *et al.* 2014). The present new method has been designed so that its results will be as comparable as possible with these other two methods, and it is recognized that this new method, which has purposefully not been assigned a name, may get "absorbed" into this proposed "merged" method. However, in the meantime the new method needs to continue to be seen as exploratory and, as it is applied as widely as possible over the next year, it is hoped that valuable lessons will be learnt which help advance the science and practice of wetland assessment in South Africa.

The development of this method was jointly funded by WWF as part of a project to promote a Resilient Landscape Approach and by the Water Research Commission as part of a project (WRC/K5 2350) to develop innovative water resource monitoring tools for mainstreaming citizen science. In line with the goals of both initiatives, it is anticipated that the tool will make the assessment of wetland ecological condition more readily accessible to a wide range of role-players and production sectors and for a wide range of applications. It is hoped that this, in turn, will increase the active engagement of these different role-players and production sectors in monitoring and understanding wetlands, ultimately leading to better informed and more sustainable management of wetlands.

2. Overall structure of the method

The purpose of the method is to assess the ecological condition (health) of a wetland, as inferred from likely impacts associated with land-cover in the wetland and its upslope catchment. Ecological condition is assessed in terms of the following four components, which are combined to give an overall assessment score.

1. **Hydrology**, which in relation to wetlands 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 assessing a wetland's ecological condition (Macfarlane *et al.* 2009).

2. **Geomorphology**, which refers to the origin and development of landforms on earth. It is recognized that wetlands are subject to both inputs and outputs of sediment, and under natural conditions input is generally equal to or greater than output (Macfarlane *et al.* 2009). Therefore wetlands are generally areas where sediment is accumulated. Two types of sediment are associated with wetlands, namely: mineral (clastic) sediment and organic material (Macfarlane *et al.* 2009).

3. **Water quality**, which refers to the physical, chemical and biological characteristics of water controlled or influenced by substances either dissolved or suspended in the water. Wetlands are naturally more variable in terms of water chemistry than rivers, both in space and time, and they also tend to be systems that function as sinks rather than sources of sediment and hence are accumulating systems, which in turn affects water quality (Malan and Day 2012). Nonetheless, it is possible at a coarse level to identify the extent to which different land-uses increase the input of substances (e.g. through adding fertilizers) or disrupt the storage/assimilation of these substances, thereby increasing the "leakage"/leaching of substances from the wetland.

4. **Vegetation**, which is specifically assessed in terms of vegetation composition, refers to the particular plant species that occur in a wetland under natural conditions. This vegetation not only provides habitat for a diversity of other species but also influences hydrological and geomorphological processes in the wetland and potentially provides important services such as forage for livestock grazing (MacFarlane *et al.* 2009).

The method uses the same scoring system applied in WET-Health (Macfarlane et al. 2009). This involves firstly assessing the spatial extent of individual land-uses (expressed as a proportion of the wetland or its catchment) and then separately identifying the intensity of impact of each individual land-use on each of the four components (hydrology, geomorphology, water quality and vegetation) on a scale ranging from 0 (no impact or deviation from natural) to 10 (critical impact or complete transformation from natural). The extent and intensity are then multiplied to give an overall magnitude of impact on a scale of 0 to 10. The method builds on the approach of the WET-Health (Macfarlane *et al.* 2009) level 1 vegetation component, where default intensity scores have been assigned by the method to each of a wide range of disturbance (land-cover) types. In the new method, this approach is extended to the hydrology, geomorphology and water quality components to align them more closely with the vegetation component.

The method, described in detail in Part 1, presents the user with a list of land-cover/disturbance types commonly occurring in wetlands, to which typical impact scores have been pre-assigned. These scores are based on the scientific literature and expert judgement, and were peer-reviewed in an attempt to make them as defensible as possible, and the rationale behind the scores is also provided. The land-cover types are also represented in photos in order to make then as easily identifiable as possible. This is similar in approach to the user-friendly photo guide developed by Graham and Louw (2009) for rivers (including riparian areas). The primary task of the operator who is applying the land-cover based method is to identify the different disturbance types present in a wetland and then to identify the extent of these land-cover types. The operator is provided with the following two options.

- The qualitative sketch-map option, which is applicable if a brief scoping of the various factors impacting upon the wetland is required but an overall score is not required, the information collected is not being used for monitoring or the users of the tool do not have access to Google Earth Pro or any other means of generating a land-cover map.

- The semi-quantitative map-based option, which is applicable if an overall ecological condition/health score is required and/or the condition of the wetland is being monitored over time and users of the tool have access to Google Earth Pro or other means of generating a land-cover map. Specific guidelines for mapping are given in Job *et al.* (in prep).

Part 1 (the user manual) provides a detailed, step-by-step description of the two options, including steps to carry out in the office and in the field. In both options, there is provision for considering impacts not accounted for with land-cover such as the point source release of wastewater into the wetland.

3. Land-cover impact scores and the rationale underlying these scores

As indicated in Section 1, impacts on wetlands which are related to land-cover may arise from within a wetland and from within the wetland's upslope catchment (Figure 2). Table 1, which deals with land-cover types potentially occurring in the wetland, and Table 2, which deals with land-cover types potentially occurring in the wetland's upslope catchment, represent the "engine" of the method. As can be seen from the respective tables, finer distinctions are made in terms of land-cover types within the wetland than for the wetland's upslope catchment given the more direct influence of land-cover in the wetland than upslope, as explained in Section 1.

As described in the detailed-map option in Part 1, the magnitude of impact for each land-cover present is determined by multiplying the relative extent of that impact by the pre-assigned intensity of impact score provided by the relevant table of the method. Then all of the impact magnitude scores for the individual land-covers present are summed to derive an overall ecological impact score for land-cover in the wetland and the wetland's upslope catchment respectively (a worked example is given in Part 1, Appendix A). The overall scores for land-cover both in the wetland itself and in the wetland's upslope catchment are finally combined using a 2:1 weighting ratio based on the assumption that a land-cover (e.g. commercial crops) in the wetland itself impacts more directly on the ecological condition of the wetland than if it is located in the wetland's upslope catchment.

A combined overall impact score is derived from the scores for Hydrology, Geomorphology, Water quality and Vegetation, weighted as 3:2:2:2, as recommended by Macfarlane et al. (2009). The overall score ranges from 0 to 10, and six Present Ecological State (PES) categories (A to F) are identified as follows: 0-0.9 =A; 1-1.9= B; 2-3.9= C; 4-5.9= D; 6-7.9 =E; and 8-10 =F (see Part 1, Table 5), where a category A means the wetland is in a totally natural state, and a category F means the wetland is highly degraded with virtually no wetland functioning remaining. These are the same categories used by DWAF (2007) and Macfarlane et al. (2009).

Figure 2: A wetland with extensive built up areas in its upslope catchment, and the considerable discharge of wastewater into the wetland. The wastewater treatment works are visible immediately adjacent to the wetland. The continuous wastewater inputs from this and other treatment works as well as from decanting mines have changed a naturally seasonal system into a continuously flooded system, which has greatly favoured the common reed (*Phragmites australis*).

3.1 Land-cover within the wetland

Impact intensity scores of different land-covers

Table 1 shows a list of land-cover types potentially occurring within a wetland. From Table 1 it can be seen that the intensity of impact varies widely amongst the different types, with mines and quarries having the highest impact intensity and natural land-cover the lowest impact intensity. The rationale following Table 1 attempts to explain the basis for these differences.

Table 1: Impact intensity scores for the hydrology, geomorphology, water quality and vegetation components of ecological condition for a range of different land-cover types potentially occurring **within a wetland**

Land-cover/disturbance types[1]		Intensity of impact[2] scores					
		Hyd-rology	Geomorphology[3] Mineral	Organic	Water quality	Vege-tation	Overall[2]
Annual crops, commercial, irrigated[5]	Conventional tillage, with severe artificial drainage[4]	7.5	4.0	7.0	7.0	10.0	7.5
	Conventional tillage, with moderate artificial drainage[4]	5.0	4.0	5.0	6.0	9.5	6.1
	Conventional tillage, with negligible/no artificial drainage[4]	3.5	3.0	3.0	5.0	9.0	4.9
	Minimum tillage, with severe artificial drainage[4]	7.0	2.5	5.0	5.0	10.0	6.5
	Minimum tillage, with moderate artificial drainage[4]	4.0	2.5	3.0	4.0	9.5	4.9
	Minimum tillage, with negligible/no artificial drainage[4]	2.5	2.0	2.0	3.0	9.0	3.9
Annual crops, commercial, not irrigated[5]	Conventional tillage, with severe artificial drainage[4]	7.0	4.0	7.0	6.0	10.0	7.1
	Conventional tillage, with moderate artificial drainage[4]	4.0	4.0	5.0	5.0	9.5	5.6
	Conventional tillage, with negligible/no artificial drainage[4]	2.5	3.0	3.0	4.5	9.0	4.5
	Minimum tillage, with severe artificial drainage[4]	6.5	2.5	5.0	5.0	10.0	6.3
	Minimum tillage, with moderate artificial drainage[4]	3.5	2.5	3.0	4.0	9.5	4.8
	Minimum tillage, with negligible/no artificial drainage[4]	2.0	2.0	2.0	3.0	9.0	3.8
Annual crops, subsistence[6]	With severe artificial drainage[4]	7.0	2.5	5.0	4.5	10.0	6.4
	With moderate artificial drainage[4]	3.5	2.5	3.0	3.5	9.5	4.7
	With negligible/no artificial drainage[4]	2.5	2.0	2.0	2.5	9.0	3.8
Sugarcane[7]	With severe artificial drainage[4]	8.0	3.5	6.5	5.0	10.0	7.1
	With moderate artificial drainage[4]	5.0	2.5	4.5	4.0	9.5	5.4
	With negligible/no artificial drainage[4]	3.5	2.0	2.5	3.0	9.5	4.4
Vineyards[7]	With severe artificial drainage[4]	7.0	2.0	5.0	4.0	10.0	6.2
	With moderate artificial drainage[4]	3.5	2.0	3.0	3.0	9.5	4.5
	With negligible/no artificial drainage[4]	2.5	1.5	2.0	2.0	9.0	3.7
Orchards[7]	With severe artificial drainage[4]	7.0	2.0	5.0	5.5	10.0	6.6
	With moderate artificial drainage[4]	4.0	2.0	3.0	4.5	9.5	5.0
	With negligible/no artificial drainage[4]	3.0	1.5	2.0	3.5	9.0	4.2
Planted pastures, annual[7,8]	With severe artificial drainage[4]	7.0	3.0	6.0	4.5	10.0	6.6
	With moderate artificial drainage[4]	3.5	2.5	4.0	3.5	9.5	4.8
	With negligible/no artificial drainage[4]	2.5	2.0	2.0	3.0	9.5	4.1
Planted pastures, perennial[7,8]	With severe artificial drainage[4]	7.0	2.0	3.5	3.5	9.5	5.8
	With moderate artificial drainage[4]	3.0	1.5	2.5	3.0	9.0	4.1
	With negligible/no artificial drainage[4]	1.5	1.0	1.0	2.0	9.0	3.2
Unmaintained perennial pastures	With severe artificial drainage[4]	7.0	2.5	3.5	2.0	9.0	5.4
	With moderate artificial drainage[4]	3.0	1.5	2.5	1.5	8.5	3.7
	With negligible/no artificial drainage[4]	1.0	1.0	1.0	1.0	8.0	2.6
Recently abandoned lands[9]	With severe artificial drainage[4]	7.0	2.0	6.0	2.5	9.0	5.8
	With moderate artificial drainage[4]	3.0	2.0	3.0	2.0	8.5	3.9
	With negligible/no artificial drainage[4]	1.0	2.0	2.0	1.5	8.0	2.9
Semi-natural areas[10], including old abandoned lands[9]	With severe artificial drainage[4]	7.0	3.0	5.5	2.0	8.0	5.5
	With moderate artificial drainage[4]	3.0	2.5	2.5	1.5	6.0	3.2
	With negligible/no artificial drainage[4]	1.0	1.5	1.5	1.0	4.0	1.8
Tree plantations	Plantations of eucalypt trees	8.0	4.0	4.0	3.0	10.0	6.4
	Plantations of pine, wattle or poplar trees	6.0	4.0	3.0	3.0	10.0	5.7
Dense infestations of invasive alien plants	Eucalypt trees	8.0	4.0	4.0	3.0	9.0	6.2
	Pine, wattle or poplar trees	6.0	4.0	3.0	3.0	9.0	5.4
	American brambles or other herbaceous invasive alien plants	2.0	4.0	3.0	3.0	8.5	4.0
Erosion gullies	Erosion gully with negligible vegetation colonization	7.0	10.0	10.0	5.0	9.0	7.7

Land-cover/disturbance types[1]		Intensity of impact[2] scores					
		Hyd-rology	Geomorphology[3] Mineral	Organic	Water quality	Vege-tation	Overall[2]
	Erosion gully colonized with vegetation (mainly alien species)	6.0	7.0	7.0	3.0	9.0	6.2
	Erosion gully colonized with vegetation (mainly indigenous species)	6.0	7.0	7.0	2.0	7.0	5.6
Infrastructure (Urban and roads)	Formal residential	10.0	7.0	7.0	4.0	10.0	8.0
	Informal residential	8.0	6.0	6.0	7.0	10.0	7.8
	Commercial/industrial/agricultural (e.g. piggery)	10.0	7.0	8.0	7.0	10.0	8.8
	Roads[11]	10.0	8.0	7.0	6.0	10.0	8.6
Infilling without infrastructure	Natural sediment/soil used as infill	10.0	8.0	7.0	4.0	10.0	8.1
	Landfill material or solid waste (e.g. concrete rubble, plastic)	10.0	8.0	7.0	5.0	10.0	8.3
	Mine dumps (spoil from the mining of underlying rock)	10.0	9.0	8.0	10.0	10.0	9.7
Mines and quarries	Mining of clay or sand	9.0	10.0	10.0	7.0	9.0	8.8
	Mining of underlying rock	10.0	10.0	10.0	10.0	10.0	10.0
Sports fields or gardens[12]	Sports fields or gardens on the original wetland ground surface	3.0	2.0	3.0	3.0	9.0	4.2
	Sports fields or gardens on wetland which has been infilled	10.0	6.0	5.0	3.0	10.0	7.4
Recent sediment deposits	Recent sediment deposition (deep, resulting in loss of wetland conditions).	10.0	6.0	3.0	3.0	10.0	7.2
	Recent sediment deposition (shallow, with wetland conditions persisting, although diminished).	4.0	3.0	2.0	2.0	5.0	3.4
Dams, ponds and areas where were water supply has been artificially sustained	Deep flooding by dams/ artificial ponds or upstream of embankments, not used for aquaculture	7.0	6.0	3.0	1.0	10.0	6.0
	Deep flooding by dams/ artificial ponds or upstream of embankments, used for aquaculture	7.0	6.0	3.0	5.0	10.0	6.7
	Shallow flooding by dams/ artificial ponds or upstream of embankments in the unit[8]	3.0	3.0	2.0	1.0	5.0	3.1
	Paddy fields	5.0	2.0	5.0	5.0	7.0	5.1
Natural, drained[13]	Natural vegetation with severe artificial drainage[4]	6.0	1.5	4.0	0.5	6.0	3.9
	Natural vegetation with moderate artificial drainage[4]	3.0	1.0	1.5	0.5	3.0	2.1
Natural, with wastewater flows[13]	Natural area of wetland into which the point-source release of untreated or poorly treated wastewater flows	4	3	3	8	6	5.1
	Natural area of wetland into which the point-source release of treated wastewater flows	4	3	3	2	5	3.6
Natural areas, very frequently burnt	Natural area of wetland which is burnt every year (e.g. as part of a firebreak)	2	1	3	2	3	2.2
Natural areas with small on-site impacts	Natural area of wetland affected by scattered invasive alien plants or other minor impacts	1	1	1	1	2	1.2
Natural	Natural vegetation with negligible/no artificial drainage or other impacts	0.0	0.0	0.0	0.0	0.0	0.0

[1]Intensive livestock grazing is not listed as a land-cover as such, but is assumed to be associated with planted pastures. If it occurs in any of the other land-covers listed in the table (e.g. semi-natural vegetation) it is suggested that the overall impact score be increased by 2 points. Intensive livestock grazing is taken as a stocking rate of higher than 2 ha per large stock unit.

[2]The "Mineral" component of Geomorphology refers to impacts on mineral sediments, while the "Organic" component refers to impacts on organic sediment.

[3]Intensity of impact is scored on a scale of 0 (nil/negligible) to 10 (critical) and Overall intensity is calculated as the average of Hydrology, Geomorphology, Water quality and Vegetation, weighted as 3:2:2:2.

[4]Artificial drainage generally comprises open artificial drainage furrows (canals) which are visible on the ground surface, as well as including the draining effect of erosion gullies and incised stream channels. However, it may also comprise buried perforated pipes, which are not visible on the ground surface. Severity of artificial drainage depends on spacing, depth and orientation of drainage furrows/pipes in relation to flows (including sub-surface) and tends to be most severe where drainage furrows/pipes

are deep, dense and/or oriented to effectively intercept flows through the wetland. **For any cultivation type where the level of artificial drainage is not known then it should be assumed to be moderate** given that most wetland cultivation is associated with at least some level of drainage.

[5]For annual crops, commercial, if it is unknown whether there is irrigation or not then it should be **assumed that there is irrigation** because annual crops are usually irrigated. If it is unknown whether tillage is conventional or minimum tillage then **conventional tillage should be assumed** because this is still much more widespread than minimum tillage.

[6]It is assumed that for subsistence agriculture, tillage is by hand and that limited supplementary irrigation takes place.

[7]It is assumed that **annual planted pastures (usually ryegrass), vineyards and orchards are all irrigated** but perennial pastures and sugarcane are not irrigated.

[8]For **planted pastures, it is assumed that fertilizer is applied periodically and the pasture intensively grazed**. If it is unknown whether the planted pasture is annual or perennial then it should be assumed that it is annual, because in wetlands these are much more widespread than perennial pastures.

[9]Recently abandoned lands are taken as those which have been abandoned within the last year or two (following a period of being under cultivation, timber plantations or subject to some other form of physical disturbance which removed all of the natural vegetation, e.g. with a bulldozer) and are still strongly dominated by annual weedy plants. Old abandoned cultivated lands are taken as those which have been abandoned for long enough for perennial indigenous species to become reasonably well represented. If it is unknown when the lands were abandoned then it should be **assumed that they are old abandoned cultivated lands** (i.e. lands abandoned more than three years ago) unless it can be seen that the area is still dominated by annual weeds. Old abandoned lands are generally likely to be more widespread than recently abandoned lands.

[10]Semi-natural vegetation refers to vegetation in which the species composition has been significantly altered, but characteristic indigenous species are still reasonably well represented. **If the drying effect of the semi-natural areas by adjacent erosion gullies, etc. is not known then it should be assumed to be negligible**.

[11]The impact of a road is scored up to the edge of the road embankment, but does not include any damming effect of a road, which is dealt with under “Dams and ponds”.

[12]If it is unknown whether sports fields or gardens are infilled then **assume that they have been infilled** because this is probably the most widespread option.

Assumed practices associated with different agricultural land-covers

The scores assigned in Table 1 are based on the physical characteristics (mainly relating to vegetation cover) and practices commonly associated with the particular land-cover type, which vary widely amongst different agricultural land-covers, as follows:

Level of tillage is highest in commercial conventional annual crops, followed by subsistence annual crops, and annual planted pastures. Sugar cane (for which it is assumed that re-planting is after approximately 12 years) is intermediate with respect to level of tillage. Planted pastures, perennial, orchards and vineyards (which are generally replanted at an interval of >15 years) and annual crops grown under minimum till have the lowest level of tillage.

Periodic Removal of vegetative cover (thereby exposing the soil) is greatest in commercial conventional annual crops, followed by subsistence annual crops and annual planted pastures. Sugar is intermediate given the assumed 18 month harvesting rotation. In all of the remaining agricultural land-covers the periodic removal of vegetation is low.

Level of fertilizer application is highest in annual crops (conventional and minimum tillage) and sugar and intermediate for the remaining agricultural land-covers.

Level of biocide application is generally highest in orchards, followed closely by commercial annual crops (minimum till and conventional) and sugar, and intermediate in the remaining agricultural land-covers, except for subsistence crops, where it is generally moderately low.

Rationale relating to hydrological impacts

For the various forms of cultivation and abandoned lands included in Table 1, the primary physical characteristic impacting upon the hydrology of the wetland is the level of artificial drainage. Part 1 has several photographs showing different types of drains and levels of drainage and Job et al. (in prep) includes several satellite images of different wetland areas which have been artificially drained. The potentially profound impact of artificial drainage on wetlands has been widely demonstrated, e.g. by Scaggs (1980), Mitsch and Gosselink (1986) and Dunn and Mackay (1996) and is recognized in WET-Health. The hydrology impact scores in Table 1 also take into account whether the crop is irrigated, which is taken to increase the impact.

For tree plantations and invasive alien trees, 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, e.g. confirming 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.

Infilled areas and roads generally occur with a sufficient depth of fill to completely eliminate wetland conditions, resulting in major environmental impacts (Mitsch and Gosselink 1986). Therefore roads and infilling are scored very high in terms of hydrological impacts. Formal settlements 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 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.

Mines and quarries 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.

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. If the wetland is deeply buried and wetland conditions completely eliminated then a very high impact score is given, approaching that assigned to an infilled wetland. In contrast, if the deposit is relatively shallow and wetland conditions persists then a much lower impact score is given.

The majority of South African wetlands are very shallowly flooded, many of them for relatively short periods. Therefore deep flooding by dams represents a large departure from the natural condition and the impact score is thus relatively high.

The discharge of wastewater (whether treated or not) typically continues throughout the year, often altering the seasonal flow patterns in a wetland, and hence the hydrological condition of the wetland.

Rationale relating to geomorphological impacts

The greater the level of artificial drainage, the greater the impact on the geomorphology of the wetland. Artificial drainage acts directly to prevent the natural spreading of flow, thereby also affecting the natural trapping of sediment which characteristically occurs when flows are spread and therefore slowed down. Drainage also acts indirectly by reducing the level of wetness in the soil, which in turn increases the rate of breakdown of soil organic matter. The strong relationship that exists between level of wetness and soil organic matter has been well demonstrated (Tiner and Veneman 1988).

Similarly, cultivation practices, notably tillage and removal of vegetative cover, impact directly on the geomorphology of the wetland by increasing the susceptibility of the area to erosion and the loss of mineral and organic sediments (Kotze 2010). These practices also impact indirectly on organic sediments by reducing organic matter inputs and increasing the rate of break-down of soil organic matter. Thus, those cultivated land-cover types which have the highest levels of tillage and removal of vegetative cover (i.e. conventional tillage of annual crops), have the highest geomorphology impact scores. Macfarlane et al. (2010) provides further information on erosion in wetlands and Kotze (2010) provides further information dealing specifically with the effect of wetland cultivation on soil organic matter levels and erosion.

Infestations of invasive alien plants tend to be less effective than the indigenous vegetation in controlling erosion, one of the reasons being that they generally support more intense fires which are more damaging to the soil (Chamier *et al.* 2012).

Although the mineral sediment and some of the organic sediment in the wetland soils is preserved when it is buried beneath fill material, the wetland is no longer receiving active input of organic matter from vegetation growing in the area and the natural movement of sediment through the system is completely disrupted. Thus, the geomorphological impact score of infilling is relatively high.

Where wastewater entering a wetland may greatly increase discharge, which in turn greatly increases the capacity of flow to erode the channel banks and carry sediment, thereby promoting channel enlargement and impacting upon geomorphological condition (MacFarlane *et al.* 2009).

A marked increase in the frequency of fire in the wetland is likely to result in a somewhat higher exposure to erosion, also potentially reducing infiltration into the soil, with implications for hydrology, geomorphology and water quality (Kotze 2013).

Rationale relating to water quality impacts

The greater the level of artificial drainage of cultivated wetland areas, 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).

Runoff from roads can have a major impact on the water chemistry of wetlands and aquatic systems, as a source of hydrocarbons, metals and other pollutants (Ellis *et al.* 1987; Mitsch and Gosselink 1993; Trombulak 2000). Several studies (e.g. Motha *et al.* 2004) have shown that unpaved (gravel) roads are a major source of sediment into aquatic and wetland receiving environments, often contributing disproportionately more on an area basis than cultivated lands.

Extensive evidence exists (e.g. that presented by Schoonover and Lockaby (2006) and Carey *et al.* (2011)) linking urban developments, and specifically impervious surfaces, with declining water quality from a range of different pollutants, including toxic heavy metals, faecal coliforms, hydrocarbons (e.g. from vehicle oil), elevated nutrients etc.

As indicated in the previous section, invasive alien trees are generally less effective than indigenous vegetation in controlling erosion. The increased erosion has implications for water quality as a result of increased sediment loads in the water, which in turn increase turbidity as well as increasing the levels of nutrient and solutes, which were adsorbed on the sediment and become released into the water column (Chamier *et al.* 2012).

Several studies (e.g. Buck *et al.* 2004) have demonstrated the effect of high densities of livestock on water quality in receiving waters.

The very high impacts on water quality that are generally associated with mining are well documented (Mitsch *et al.* 1983; Heath *et al.* 2009; Barkley *et al.* 2011).

Wastewater, even where it has been ameliorated, typically increases the loading of nutrients and other solutes in a wetland. This has direct impacts on the ecological condition of the wetland in terms of water quality. The elevated nutrient levels, in turn, impact upon vegetation condition by generally favouring a few tall-growing competitive species at the expense of naturally growing, much more diverse vegetation (Hillebrand 2003).

Rationale relating to the impacts on vegetation composition

Land-covers where vegetation is replaced completely (e.g. by infrastructure or deep flooding by dams) resulting in there being no vegetation at all, have been assigned the highest possible vegetation impact score (i.e. 10).

Cultivation with moderate or negligible drainage often supports a few indigenous wetland species that are well adapted to high levels of disturbance (e.g. *Commelina africana*) but their abundance is generally very low and the overall composition of the vegetation is very different to the native vegetation. Thus, although not scoring the maximum in terms of vegetation impacts, these types are scored very close to the maximum score. Cultivation with severe drainage tends to entirely prevent the growth of indigenous wetland species and therefore scores the maximum impact.

Provided that the area is not severely drained, perennial crops generally provide slightly greater opportunities than annual crops for indigenous wetland species which are well adapted to high levels of disturbance (e.g. *Commelina africana*) to survive. However, the overall composition of the vegetation is very different to the native vegetation, and thus the score assigned is close to the maximum.

Unmaintained perennial pastures are not subject to any removal of non-crop plants, as occurs in actively cultivated areas (i.e. the first eight land-cover types in Table 1) and therefore indigenous wetland species are more abundant than in actively cultivated areas. However, the introduced pasture maintains a strong dominance (as shown in an example with *Paspalum dilatatum* by Cowden *et al.* (2014)), and the vegetation is therefore still quite different to the native vegetation and the impact score assigned is therefore not much less than the maximum.

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 during the dry season of wastewater discharge impacts on the vegetation by also generally favouring tall-growing competitive plants such as bulrushes (*Typha*) even in situations where nutrient levels are not elevated (Boers and Zelder 2008).

A marked increase in the frequency of fire in the wetland is likely to most obviously impact upon the vegetation species composition of the wetland, favouring species well adapted to a high fire frequency over those less well-adapted species (Kotze 2013).

3.2 Land-cover within the wetland's upslope catchment

Table 2 illustrates how the impacts on a wetland in terms of water inflow quantity and seasonal pattern and water quality vary greatly depending on the particular land-cover types located in the wetland's upslope catchment.

As indicated earlier, the overall method focuses in most detail on impacts from land-cover in the wetland (Table 1 and 2). As such, fewer distinctions are made in terms of land-cover types in the wetland's upstream catchment than in the wetland itself. Also fewer components related to wetland ecological condition are considered, i.e. scores are not presented separately for hydrology, geomorphology, vegetation and water quality as is done for land-cover in the wetland. In addition, although it is recognized that for a wetland's upslope catchment, the closer a specific land-cover impact is to the wetland, the less opportunity there is for the impact on the wetland to be buffered, the method does not consider distance of the land-cover to the wetland. However, the method does consider the level to which the wetland is surrounded by a buffer zone of natural vegetation, which is assumed to have a moderating influence over the overall impacts from the wetland's upslope catchment. In addition, in the Limitations of the method it is suggested how refinements could be made in order to better account for the moderating influence of the buffer, with reference to the buffer guidelines of Macfarlane et al. (2014).

Table 2: Impact intensity scores for a range of different land-cover types potentially occurring in a wetland's upslope catchment

Land-covers in the wetland's catchment	**Impact intensity[1]**		
	Water quantity & pattern[2]	**Water quality[3]**	**Overall[4]**
Tree plantations, eucalypt	8.0	3.0	5.5
Tree plantations, pine, wattle or poplar	6.0	3.0	4.5
Orchards	5.0	6.0	5.5
Vineyards	4.0	4.0	4.0
Annual commercial (row) crops, irrigated	5.0	6.0	5.5
Annual commercial (row) crops, not irrigated	4.0	5.0	4.5
Annual subsistence crops	4.0	4.0	4.0
Sugarcane	4.0	4.0	4.0
Mines and quarries	7.0	9.0	8.0
Built up dense settlements, roads, railway lines & airfields	7.0	5.0	6.0
Golf courses, sports fields & low density settlements	2.0	4.0	3.0
Semi-natural vegetation, including old lands	0.0	1.0	0.5
Natural vegetation	0.0	0.0	0.0
Eroded areas	5.0	5.0	5.0
Dams	7.0	2.0	4.5

[1]Intensity of impact is scored on a scale of 0 (nil/negligible) to 10 (critical)

[2]For a more detailed assessment of the impacts on the quantity and seasonal pattern of water inputs from a wetland's upslope catchment see the hydrology component of MacFarlane *et al.* (2009).

[3]For a more detailed assessment of the impacts on the quality of water inputs from a wetland's upslope catchment see Malan and Day (2012) and Malan *et al.* (2013).

[4]The overall score is calculated as the average of the scores for (1) water quantity and pattern and (2) water quality.

Rationale behind the scores assigned to different land-cover types

The effect that different plantation trees (e.g. eucalypts vs. pines) have in reducing catchment yield is well demonstrated (see Rationale for Table 1). It is also important to add that tree plantations characteristically include a network of roads, which act to some extent as a drainage network increasing the collection and delivery of stormflows.

Orchards and vineyards, which characteristically occur in the winter rainfall area of South Africa, are subject to extended irrigation during the dry summer season, which generally results in increased dry season water inputs to downslope areas from irrigation return flows. Orchards tend to have relatively high levels of biocide application with vineyards having somewhat less, while levels of fertilizer application for both tend to be intermediate.

Commercial row-crops are generally subject to some of the highest levels of tillage, thereby exposing this land-cover to some of the highest levels of soil and nutrient loss, with important implications for water quality in downstream environments. Downstream impacts both in terms of water quantity and pattern and water quality (through increased leaching) tend to be further increased with irrigation.

Sugarcane is subject to less tillage and exposure of the soil than row-crops but nonetheless is subject to relatively high levels of agrochemical application and therefore the impacts on water quality are slightly lower than for row-crops, particularly those that are irrigated, but are still notable.

Mines and quarries represent an extreme form of hydrological disruption and; in the case of mines in particular are generally associated with severe impacts on water quality of downstream environments, e.g. through acid mine drainage.

Built-up dense settlements, roads railway lines and airfields 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 (Macfarlane *et al.* 2009). Water quality is also affected by pollutants (e.g. hydrocarbons from motor vehicles) washed off the impermeable surfaces.

Golf courses, sports fields and low-density settlements have limited hardened surfaces, moderate levels of fertilizer application and maintenance of good ground cover. Therefore, these areas are generally not a major sources of sediment.

Semi-natural vegetation (including old lands) are not subject to tillage and fertilizer and biocide application and generally maintain good ground cover. However, very slightly higher levels of soil loss are generally anticipated compared with natural vegetation because of historical disturbance.

Eroded areas lack the protection of vegetation cover and generally result in significantly increased stormflows and sediment to downstream environments.

Dams have the potential to reduce both catchment yield and downstream flood-peaks (MacfFarlane *et al.* 2009).

Once an total score has been determined of the impact on the wetland of land-covers in the wetland's upslope catchment then this score is automatically adjusted based on the extent to which the wetland is surrounded by a buffer zone of natural vegetation (see Part 1, Figure 4). The adjustment is based on following multiplier: Low to moderately low extent of buffer zone= 1 (i.e. the impact score remains the same); Intermediate = 0.9; moderately high to High = 0.7. Thus, it can be seen that as the buffer extent is increased, the impact score is reduced accordingly. It has been well demonstrated that particularly with respect to non-point source impacts on water quality, the greater the extent of the buffer of natural vegetation surrounding the wetland, the greater will be the moderating effect of the buffer on these impacts (Lovell and Sullivan 2006; Macfarlane et al. 2014). However, it is important to recognize that buffers generally have limited influence over certain impacts, notably point-source discharges and hydrological impacts caused by stream flow reduction activities (abstraction from an upstream dam) (Macfarlane et al. 2014) (Figure 3).

Figure 3: A valley bottom wetland with extensive dense infestations of the invasive alien plant American bramble. Extensive areas of the wetland's upslope catchment are occupied by tree plantations, although there is a buffer of natural vegetation approximately 20 m wide between the wetland and the adjacent tree plantations.

3.3 Combining the total score from within the wetland with that from the wetland's upslope catchment

The total impact score from within the wetland and that from the wetland's upslope catchment are combined into a single overall impact score in such a way that the higher score has the dominant effect but is adjusted by the lower score (see Appendix 1).

It is not necessary to weight the catchment lower than the within-wetland. This is because the scores in the original impact tables take into account the fact that the land-covers within the wetland's upslope impact less directly on the wetland than those arising from within the wetland. For example, a mine in the wetland's catchment scores 8 whereas a mine directly in a wetland scores 10. In addition, impacts from the catchment are further reduced based on the extent of a buffer around the wetland.

4. Limitations of the method & suggestions for addressing these limitations

Key limitations of the method

The following are probably some of the most important limitations of the method:

Site-specific features of the wetland not considered

The method generalizes broadly about the ecological impacts associated with particular land-covers, with little account taken of the wetland's particular features, notably its hydrogeomorphic type and ecoregion. Although studies such as Grundling (2014) are shedding valuable light on the hydrological characteristics of different HGM types, understanding of how the different hydrogeomorphic types influences land-use impacts has not been well developed. However, it is hoped that as this understanding improves, a consideration of the influence of hydrogeomorphic type will be able to be included in the method. Understanding of how the sensitivity of a wetland to human impacts might vary across different ecoregions is also limited, but with increased understanding, the method could potentially be tailored for specific ecoregions. The method also does not account for other site-specific features such as the erodibility of the soil, where for a given land-use/ land-cover, a site with a higher erodibility is likely to be subject to higher impacts. Such factors could potentially be accounted for in a refinement of the method, e.g. by including soil erodibility as a weighting factor.

Some land-cover types vary widely in terms of land-use practices

Although many different land-cover types were identified to try to limit the variability within each type, it is recognized that for certain types and for certain environmental impacts the impact intensity may vary quite widely from one site to the next. An important factor affecting this deviation will be the extent to which Best Management Practices are followed. For example, the water quality impact score for commercial/industrial infrastructure was assigned based on the assumption that the effectiveness of handling potential pollutants is moderate (i.e. there are occasional spillages of pollutants). However, in the wetland being assessed, handling of potential pollutants may be exceptionally good. If this information was available then the impact score could be adjusted down but in most cases such detail would not be available.

The influence of a buffer of intact vegetation around the wetland is considered at a coarse level

The method considers the degree to which the wetland is buffered (e.g. by a broad strip of intact natural vegetation around the wetland) from the overall land-cover impacts on the wetland from the wetland's upslope catchment. However, this consideration is at a course level. Thus, if a more refined assessment of impacts was required then the extent of individual land-cover types in the immediate buffer (e.g. of 100 m) surrounding the wetland could be quantified. In a further refinement, account could be taken of other influencing factors such as the gradient of the slope adjacent to the wetland. Macfarlane et al. (2014) provide comprehensive guidelines for determining adequate buffer widths taking into account factors such as the threats associated with the specific land-uses, gradient of the slope and the sensitivity of the downslope wetland, which provides useful guidance in conducting such refinements.

Defining the natural reference state of the wetland

The method largely avoids the issue of explicitly defining the natural reference state of the wetland being assessed. There is no quick fix for this challenging issue, which besets all of the methods. One of the resulting problems is that of deciding if the vegetation is natural. A possible future solution is to develop regional versions of the method with photos of typical natural wetland vegetation for each region together with typical examples of vegetation which has been compromised.

Additional limitations include the following:

- The method accounts only superficially for point source impacts, e.g. water abstraction from within the wetland and the discharge of untreated wastewater into the wetland. For guidance in carrying this out in more detail refer to Malan et al. (2013) and Macfarlane et al. (2009).
- The method assumes that the boundary of the wetland's upslope catchment can readily be seen based on the surface topography of the wetland. However, for depression wetlands on coastal plains in particular, this may not always apply, and a wetland may be fed by a much larger area than the wetland's local, topographically-defined catchment. However, as recommended by Malan and Day (2012) for the purposes of the assessment the wetland's local catchment could be used for these problematic wetlands, based on the fact that impacts arising from areas in close proximity to the wetland will have the most influence over inputs to the wetland.
- The method does not provide guidance for interpreting satellite imagery and mapping the land-cover units identified in a wetland. However, detailed interpretation and mapping guidance is provided by the national guideline for wetland mapping and inventory (Job et al. in prep)
- Although a comprehensive list of land-cover types is included in the method, this is not exhaustive, and inevitably users of the method will encounter land-covers which do not fit well any of those listed. If this takes place then it is recommend that the land-cover be recorded under the land-cover type which is closest match and a brief written description be given of the type. The pre-assigned impact scores can then be adjusted based on specific knowledge of the site provided that the basis for these adjustments is given.
- The method provides inadequate detail to be used in the context of Environmental Impact Assessments, which require that due consideration be given to the wetland's biotic and hydrogeomorphic features.

The level of confidence which can be placed in the method

Given all of the limitations described above, it is important to recognize that the method is generally restricted to scoping-level assessments, and is likely to require a more detailed assessments of a sub-set of the assessed wetlands. In the absence of such detailed site-specific assessments, it is important to recognize that the level of confidence which can be placed in the use of land-cover to infer the ecological condition of a wetland is likely to vary across the four respective components of ecological condition (Table 3). The score for that component with the lowest confidence, i.e. water quality, should be considered the most tentative. As a first step in better considering site-specific influences, a list of potential influencing factors is given in Table 4. Although this is not an exhaustive list, it attempts to capture a broad spectrum of potential influencing factors which could be potentially investigated in more detail in order to improve confidence in the assessment.

Table 3: level of confidence in the use of land-cover to infer wetland ecological condition according to the four respective components of condition

Components of ecological condition	**Level of confidence**	**Rationale**
Hydrology	Intermediate	The strong link between land-cover and hydrology has been well demonstrated, but is potentially influenced by several site-specific factors, e.g. the inherent infiltration potential of the soil in the wetland's upslope catchment. For further information on these factors see Macfarlane et al. (2009).
Geomorphology	Intermediate	Land-cover relates directly to geomorphology in as far as eroded areas are identified as a specific land-cover type. However, land-cover can also have several indirect effects, but, as is the case with hydrology, these effects may potentially be influenced by several site-specific factors, e.g. the longitudinal slope of the wetland, which affects surface water flow velocity (and therefore the potential to erode). For further information on these factors see Ellery et al. (2009) and Macfarlane et al. (2009).
Vegetation	Moderately high	Vegetation itself is a prominent feature of land-cover and therefore the link between land-cover and vegetation is very direct. Nonetheless, this link is still subject to the influence of site-specific factors. For example, the land-cover type "old cultivated lands" may represent varying levels of recovery of the native vegetation, subject to the influence of site-specific factors such as soil type or varying levels of competition from invasive alien species. For further information on these factors see Macfarlane et al. (2009) and Corry (2012).
Water quality	Intermediate/ Moderately low	While the link between land-cover and water quality has been very well demonstrated, it is probably the least direct and clear of all of the components, and therefore potentially most influenced by several site-specific factors. For further information on these factors see Malan and Day (2012).

Table 4: Some key site-specific factors influencing land-cover effects on the four respective components of ecological condition, hydrology (Hyd), Geomorphology (Geo), Water Quality (WQ) and Vegetation (Veg)

Some key site-specific factors	**Components of condition**				**Some examples of site-specific effects and the potential need for adjusting the default scores given in Table 1**
	Hyd	**Geo**	**WQ**	**Veg**	
Local climate and geology	**	**	**	**	Landscapes dominated by sandstone tend to yield soils and ecosystems (including wetlands) which are low in nutrients. Such wetlands are considered vulnerable to elevated nutrient inputs, potentially requiring that the default scores for water quality impacts be increased.
Endorheic (no surface or sub-surface outflow) vs. Exorheic (with surface and/or sub-surface outlfow)	*	*	**	*	If a wetland is endorheic then pollutants and nutrients tend to accumulate more readily then if exorheic, where much greater opportunities exist for “flushing” of the system. Thus, default scores for water quality impacts should potentially be increased for endorheic systems.
Infiltration potential of the soil in the wetland’s upslope/upslope catchment	**	**	*		If the inherent infiltration potential of the soil is high then the introduction of impermeable surfaces (e.g. through urban developments) will impact proportionally much more on a downslope wetland than if the inherent potential is low.
Vulnerability of the wetland to erosion, given its longitudinal slope and discharge/size	*	**			If the vulnerability of the wetland to erosion and/or the erodibility of the soil in the wetland were very high then the impact on geomorphology by land-covers involving physical disturbance in the wetland (e.g. through tillage) is potentially higher than the default impact scores given in Table 1. Conversely, if both the vulnerability of the wetland to erosion and the erodibility of the soil are low then the impact is potentially lower than the default impact scores.
Erodibility of the soil in the wetland	*	**			
Presence of soils with a naturally high organic content, including peat		**			If soils with a naturally high organic content are present in the wetland then the impact on geomorphology of land-covers involving artificial drainage and physical disturbance in the wetland (e.g. through tillage) is potentially higher than the default impact scores given in Table 1.
Invasive species in the species pool				**	In some wetlands there are many invasive alien plants already present or nearby to the wetland which can readily capitalize on human disturbance. In such wetlands the recovery of the natural vegetation in abandoned cultivated lands may be impaired much more than in wetlands where invasive alien plants pose much less of a threat, but recognizing the nowhere in South Africa are wetlands “out of reach” of invasive alien plants.
The direct deposition of nutrients into the wetland by fauna (e.g. as a result of a bird roosting site within a wetland).			**	*	The extent to which the default score for water quality impacts needs to be adjusted will depend on whether this deposition is natural or caused by human influence, e.g. the planting of trees, which in turn become used as a bird roosting site.

* =A direct influence is likely, although probably not a major influence

** =A direct influence is likely, and is potentially a major influence

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Appendix A: An explanation of the formula used for combining the total impact scores from the wetland's upslope catchment and from within the wetland

The impact score from within the wetland and that from the wetland's upslope catchment are combined in such a way that the higher score has the dominant effect but is adjusted by the lower score using the following formula.

If IWithin> ICatchment then	IOverall= IWithin + (10-IWithin)*ICatchment/10
But if IWithin< ICatchment then	IOverall= ICatchment + (10-ICatchment)*IWithin/10

Where:

IOverall is the combined overall impact score (from 0 [no impact] to 10[critical impact])

IWithin is the Total Impact score (0 to 10) from land uses within the wetland

ICatchment is the Total Impact score (0 to 10) from land uses in the wetland's upslope catchment

This above option is preferable to, and somewhat of a compromise between, the following three options:

- Taking the highest score alone, and therefore leaving the lower score without any influence over the overall score, which is of particular relevance should one of the scores be moderately high. For example, if IWithin =6.0 and ICatchment =4.5, it would be inappropriate to take IOverall as 6.0, without any regard for how the ICatchment impact of 4.5 was having on the remaining integrity of the wetland.
- Combining the two scores as an average, thereby overly "diluting" a high score if the other score was low. This option fails to recognize that if a wetland is critically impacted from land-uses within the wetland, for example, say IWithin scores 9.5, which effectively leaves almost "no remaining" integrity, it is of no "compensation" that impacts from its catchment are low, say ICatchment scores 1.5. Therefore, to represent the overall impact (IOverall) as 5.5 (the average of the two scores) is inappropriate.
- Adding the two scores together, which would potentially result in IOverall exceeding the maximum score, as would be the case for both of the above examples.

Let us now apply the formula, IWithin + (10-IWithin)*ICatchment/10, to the above two examples.

Example 1, IOverall: 6.0 + (10.0-6.0)*3.5/10 = 7.4

Example 2, IOverall: 9.5 + (10.0-9.5)*1.5/10 = 9.6

From the two examples it can be seen how the lesser impact adds to the greater, but as the greater tends towards 10 (the maximum impact) this additional contribution is proportionally less. This can be more clearly seen in Table A1, which shows how the combined score for Overall magnitude of impact changes across the range of impacts represented for within the wetland and from the wetland's upstream catchment.

Table A1: Scores for overall magnitude of impact on a wetland based on the joint consideration of total impacts arising from within the wetland and total impacts arising from with the wetland's upslope catchment

		Total impacts from within the wetland									
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Total impacts from the wetland's upstream catchment	*1*	**1.9**	**2.8**	**3.7**	**4.6**	**5.5**	**6.4**	**7.3**	**8.2**	**9.1**	**10.0**
	2	**2.8**	**3.6**	**4.4**	**5.2**	**6.0**	**6.8**	**7.6**	**8.4**	**9.2**	**10.0**
	3	**3.7**	**4.4**	**5.1**	**5.8**	**6.5**	**7.2**	**7.9**	**8.6**	**9.3**	**10.0**
	4	**4.6**	**5.2**	**5.8**	**6.4**	**7.0**	**7.6**	**8.2**	**8.8**	**9.4**	**10.0**
	5	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**
	6	**6.4**	**6.8**	**7.2**	**7.6**	**8.0**	**8.4**	**8.8**	**9.2**	**9.6**	**10.0**
	7	**7.3**	**7.6**	**7.9**	**8.2**	**8.5**	**8.8**	**9.1**	**9.4**	**9.7**	**10.0**
	8	**8.2**	**8.4**	**8.6**	**8.8**	**9.0**	**9.2**	**9.4**	**9.6**	**9.8**	**10.0**
	9	**9.1**	**9.2**	**9.3**	**9.4**	**9.5**	**9.6**	**9.7**	**9.8**	**9.9**	**10.0**
	10	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**

Note: while it may be so under exceptional circumstances, impacts from a wetland's upslope catchment seldom exceed a total score of 8, and therefore the shaded cells fall beyond the maximum impact generally resulting from even the most extreme land-cover types in a wetland's upslope catchment.

It is not necessary to weight the catchment lower than the within-wetland. This is because the scores in the original impact tables take into account the fact that the land-covers within the wetland's upslope impact less directly on the wetland than those arising from within the wetland. For example, a mine in the wetland's catchment scores 8 whereas a mine directly in a wetland scores 10.