Geomorphology Module of WET-Health (Version 2.0)

Extract from the Report to the
WATER RESEARCH COMMISSION

by

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8. GEOMORPHOLOGY MODULE

8.1. Introduction

Wetland formation and persistence is ultimately controlled by hydo-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**).

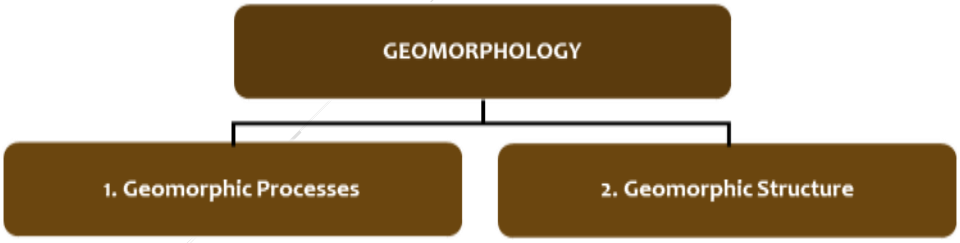

Figure 8.1. Primary components included in the assessment of wetland geomorphology

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.

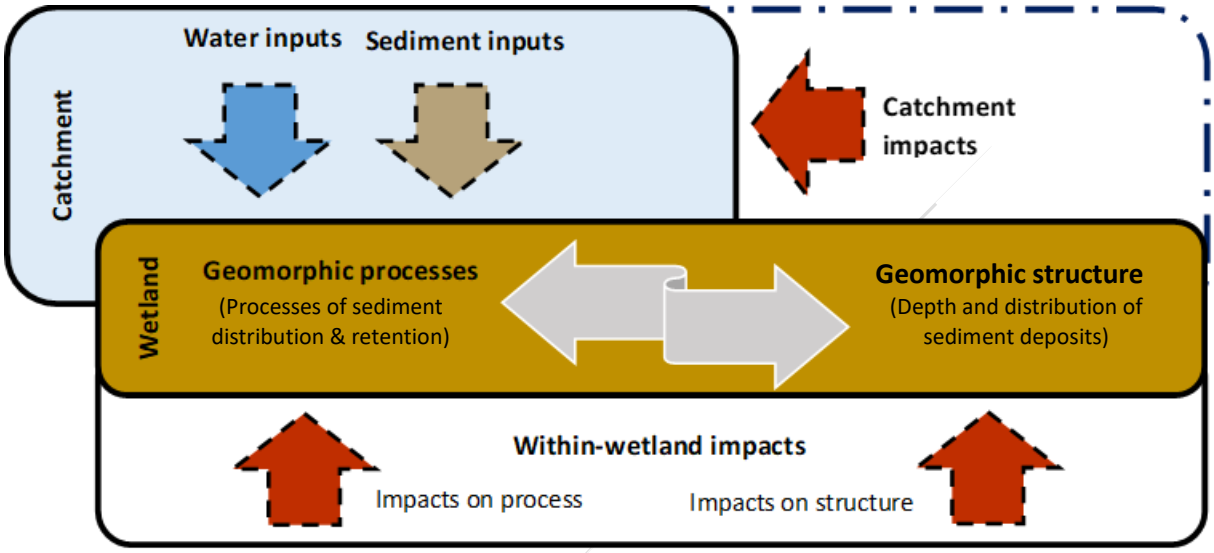

Figure 8.2. Conceptual framework for the geomorphology assessment

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

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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

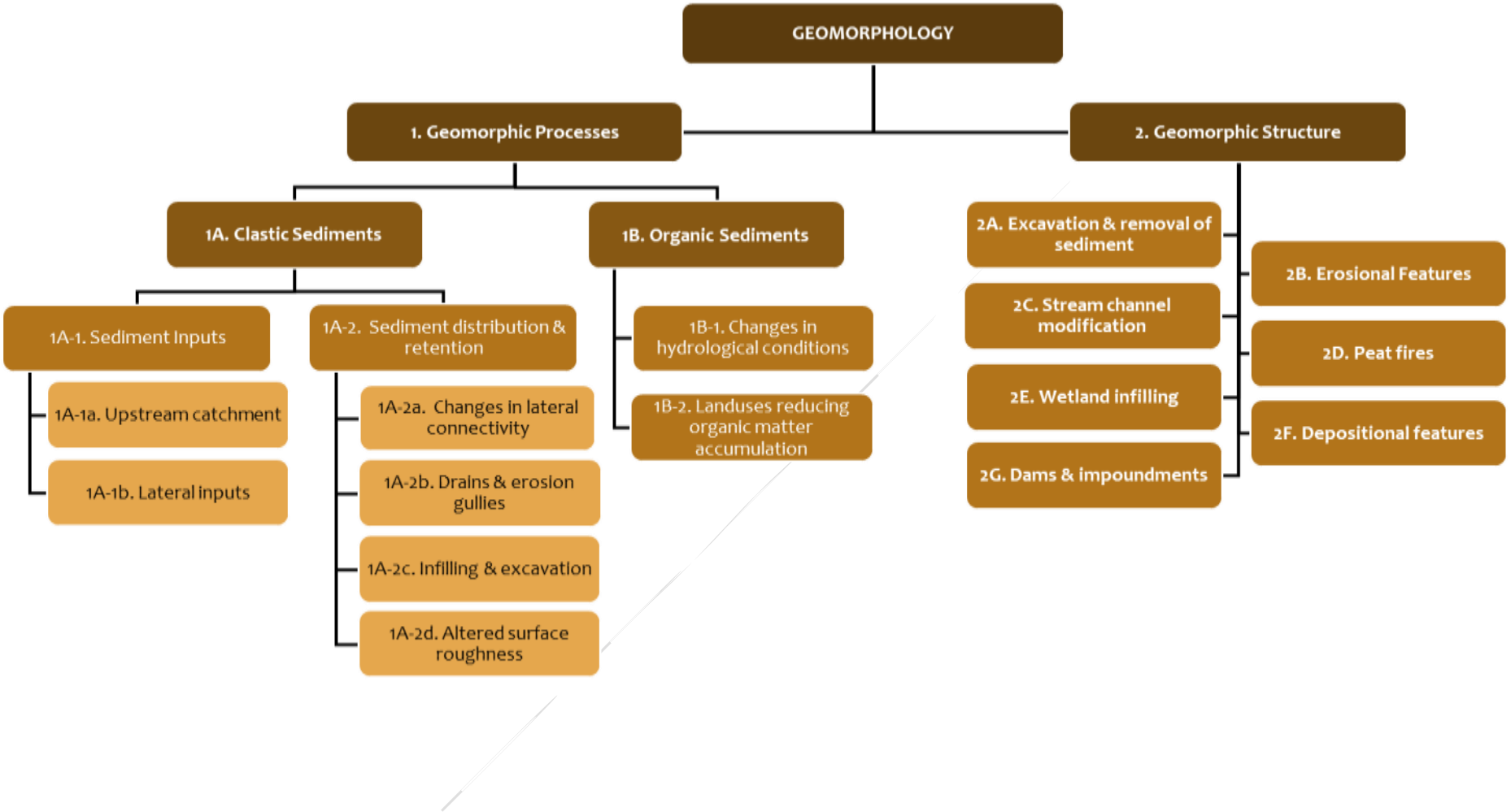

Figure 8.4. Schematic illustrating the overall structure of the geomorphology module

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[1] (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**).

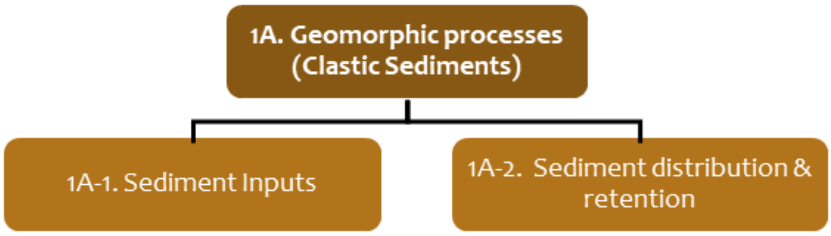

Figure 8.5. Secondary components included in the assessment of changes to the processes of clastic sediment deposition in the wetland

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).

[1] 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**).

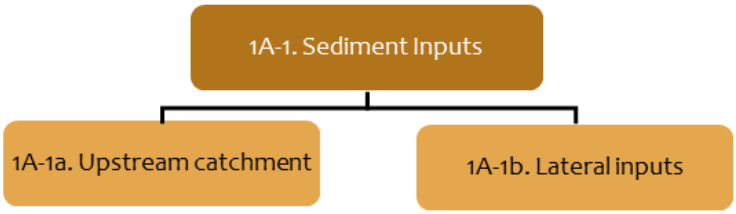

Figure 8.6. Sub-components used to evaluate changes in sediment inputs from the wetland's topographical catchment

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.

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

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 (200m)

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 200m 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 200m 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[2])	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						

[2] 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

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

A2. Presence / extent of tracks and dirt roads in the catchment
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).

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

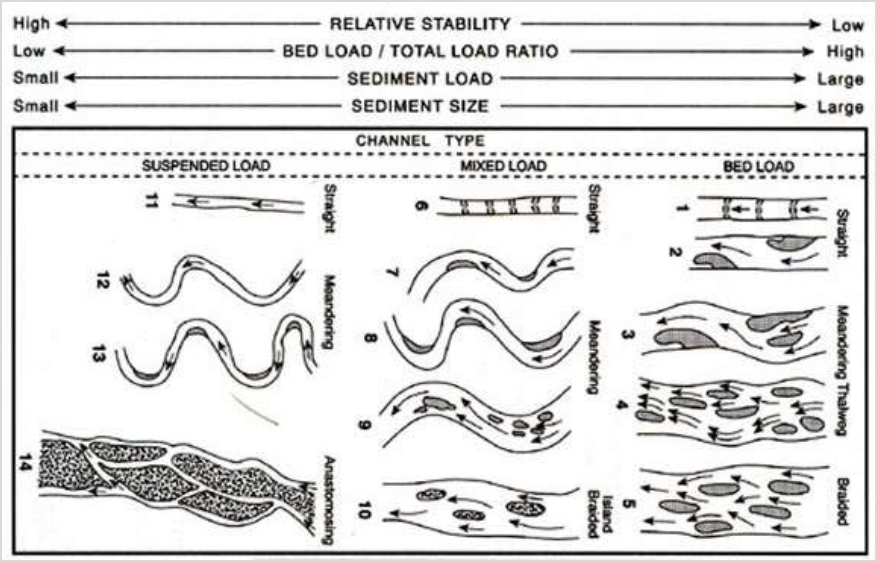

Figure 1. Typical channel characteristics in river channels characterised by different sediment loads (After Schumm, 1981)

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					

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

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 200m 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 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 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.

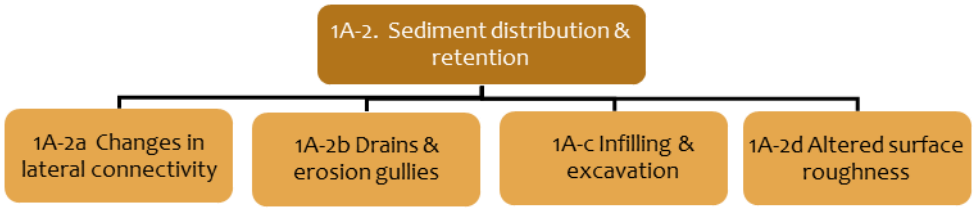

Figure 8.7. Sub-components used to assess changes to the conveyance of sediment through the wetland

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[1] (**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.

[1] 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.

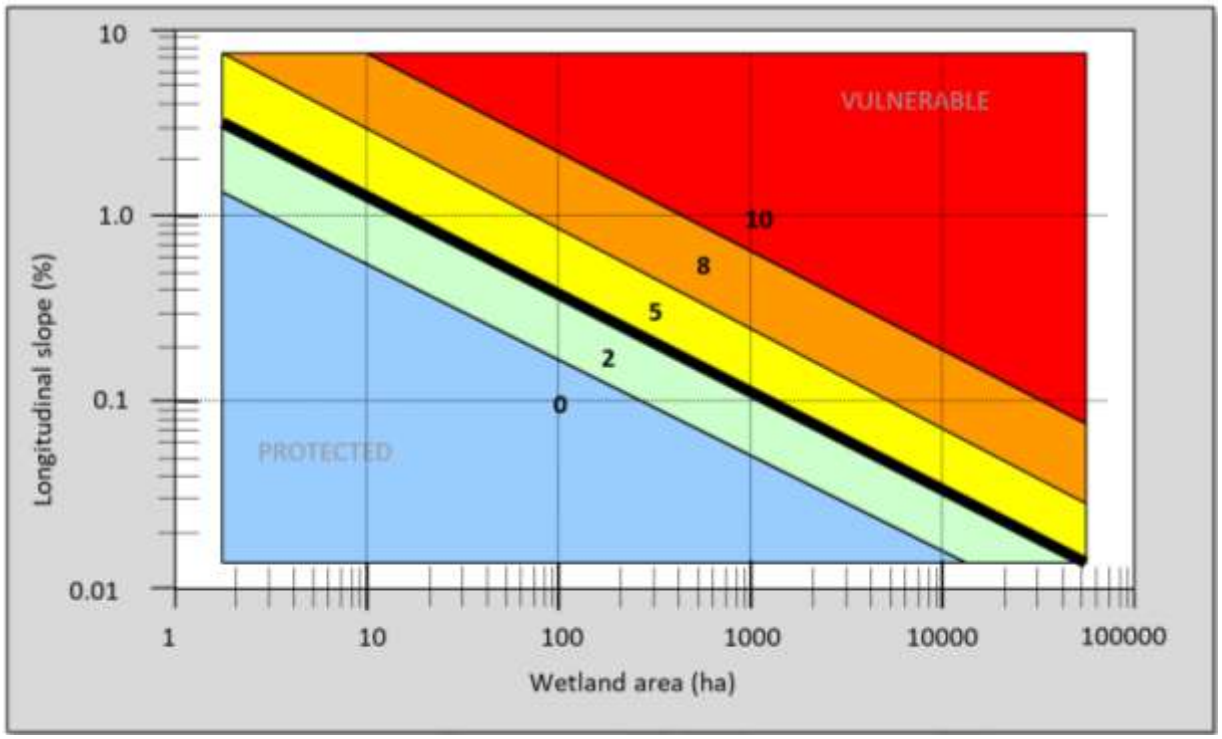

Figure 8.8. Propensity of a wetland to erode based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope (Macfarlane et al. 2008)

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. m

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

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 coarse 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 coarse 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 50cm.

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

A. Activities enhancing rates of sediment accumulation						
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	Moderate	Large	High		
Dams that extend laterally across the wetland (Upstream effects)						
A2. Determine the size of dam and the nature of sediment load being transported						
	Volume of dam in relation to MAR (in the wetland)					
Relative 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	4	6	8	
Moderate	2	4	6	8	10	
High	4	6	8	10	10	
B. Activities reducing rates of sediment accumulation						
Roads and berms that extend laterally across the wetland (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	Large	Serious	Complete	
Further guidance *Low flows deflected?*	*Yes*		*Yes*		*Yes*	
Annual floods deflected?	*No*		*Yes*		*Yes*	
Large floods deflected?	*No*		*No*		*Yes*	
Dams that extend laterally across the wetland (Downstream effects)						
Indicator	**-1**	**-3**	**-5**	**-8**	**-10**	**Score**
B2. Interception by the dam of the streams entering the downstream wetland area	Dam intercepts <20% of the affected area's catchment	Dam intercepts 21-40% of the affected area's catchment	Dam intercepts 41-60% of the affected area's catchment	Dam intercepts 61-80% of the affected area's catchment	Dam intercepts >80% of the affected area's catchment	
B3. Determine the size of dam and the nature of sediment load being transported						
	Volume of upstream dam/s in relation to MAR (in the wetland)					
Relative 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	-4	-6	-8	
Moderate	-2	-4	-6	-8	-10	
High	-4	-6	-8	-10	-10	
Intensity Score for Dams (Downstream Effects) = B2 x B3/10						

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

A1. Change in roughness

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 then 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[2]) 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

[2] 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).

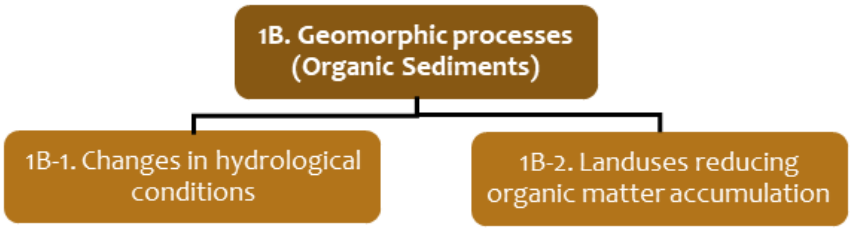

Figure 8.9. Secondary components included in the assessment of changes to the processes of organic sediment deposition in the wetland

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

A1. Landuses potentially affecting organic matter accumulation

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.

A2. Inundation from impoundments

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**).

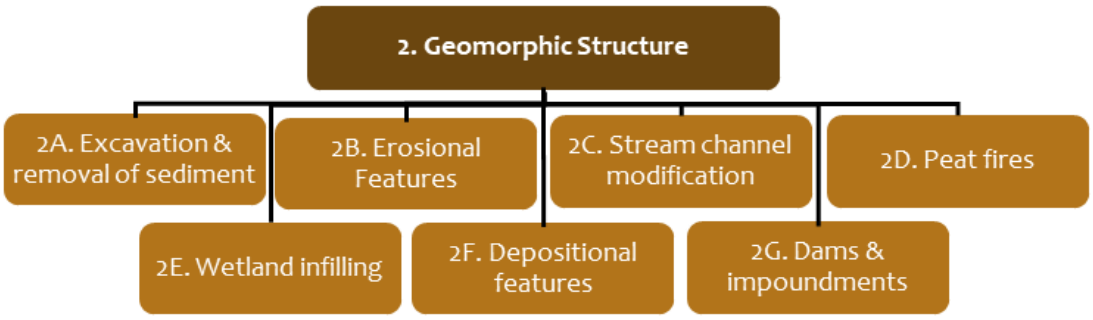

Figure 8.10. Sub-components included in the assessment of changes to the geomorphic structure of the wetland

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	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	
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	201-400m/ha	>400 m/ha	
Indicator	**-1**	**-2**	**-5**	**-8**	**-10**	**Score**

B2. Average depth of drains/gullies	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	
Intensity Score (B): B1 x -B2/10						

Rationale for Table 8.28.

A1. Average depth of excavation & removal:

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 (<2m). 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 5m, impacts associated with excavation of 1m should be moderated to an intensity score of 2).

B1. Density of drains (metres of drains per hectare of wetland):

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 >400m/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.

B2. Average depth of drains/gullies:

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 (<2m). 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 5m, impacts associated with drains of 1m 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	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	
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 coarse estimate of gully width relative to the width of the wetland, expressed as a percentage (%).

A2. Mean depth of gullies:

This simply requires a coarse estimate of gully depth and assumes that most wetlands are characterised by relatively shallow sedimentary deposits (<2m). 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 5m, impacts associated with excavation of 1m 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 – contributing factors		None evident	
Adjustment factor = Max of above three scores						
Scaled intensity of impact score = A x B						

Rationale and guidance for Table 8.30

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 2m 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	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	
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

A1. Depth of peat fires

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 1.5m 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	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	

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 >1.5m 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	<20cm	21-50cm	51cm – 1m	1 – 1.5m	>1.5m	
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™ 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**).