# A gully is not a stream channel. How do we tell the difference and why does it matter?

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**Key Points**

- Gullies need to be distinguished from stream channels for scientific, technical, and legislative purposes;
- Current definitions are inadequate, but satisfactory, multi-functional definitions can be achieved;
- Gullies are specifically defined by a set of rules and 'stream channels' can be adequately defined to separate them from 'gullies';
- The results have implications for catchment modelling and rehabilitation decision-making, as well as for both Queensland and NSW policies and guidelines in management of gullies and watercourses.

## Abstract

Identifying and defining a gully as distinct from a steam channel may not appear to be important. We contend that the distinction matters. The ramifications of confusing the two landforms (and allied versions of them), or assuming them to be similar, are far-reaching for purposes such as the methods involved in achieving water quality targets, the modelling of catchment dynamics and sediment yields, and compliance with watercourse management policies.

We are categorically defining what is, and what is not a gully; stating the criteria that are the distinguishing factors; and defining a 'stream channel' more specifically. We are doing this through pioneering techniques for accurate, high-resolution, broad-scale mapping of gullies in catchments, and by developing classification methods for gullies.

Applying these definitions and criteria in our gully research has greatly aided the results of broad-scale mapping of gullies at high resolution, highlighted discrepancies with prior presence/absence mapping of gully features, allowed much more accurate estimation of eroded sediment volumes, erosion rates, and more accurate sediment yield estimations.

## Keywords

Gully erosion; fluvial geomorphology; streams; watercourse definition; drainage network; catchment processes.

## Introduction

Identifying and defining a gully as distinct from a stream channel may not appear, on the face of it, to be of great consequence. With more recent attention given to water quality monitoring and management both from stream networks and gullies, including their remote mapping for modelling purposes, we contend that the distinction between gullies and actual stream channels matters.

The ramifications of confusing the two landforms, or assuming them to be similar for most intents and purposes, are far-reaching, particularly for the following reasons:

- assumptions by technical and non-technical workers, particularly natural resource managers and consultants, that there is no difference and that they can be viewed and managed similarly,
- methods involved in achieving the Great Barrier Reef (GBR) water quality targets by focusing on upper catchment gully sources and floodplain alluvial gully sources, compared with stream-bank sources,
- the modelling of catchment dynamics and sediment yields in general, but particularly for the GBR SedNet estimations for sediment fluxes,
- recommending and prescribing of remediation/rehabilitation methods for either gullies or stream banks, and
- compliance with waterway management policies and guidelines, that may currently be, or will be, underpinned by environmental management legislation.

To address sediment sources from gullies in particular we need to know that what has been identified or mapped as a gully, actually *is a gully*, in more than just terminology. Likewise, catchment models need to distinguish a sediment source as a gully rather than a part of a stream network for reasons of different processes acting under different environmental conditions at different times.

The binary definition (is/is not) is important for environmental policies and guidelines from governing authorities not only to distinguish between a gully and a stream channel (usually called ‘watercourses’) that are often both mapped similarly on drainage network maps, but also to have clear definitions of the watercourse/network classification that may not include gullies per se. With legislation often specific to streams rather than gullies it is likely that gullies can be mis-classified as streams and therefore would require floral and faunal ecosystem restoration pertaining to streams rather than to (ephemeral flow) gullies for their remediation/rehabilitation and management. In the Queensland context of gully rehabilitation, currently underway in multi-million dollar projects, inappropriate legislated requirements, e.g. ‘riparian vegetation’ restoration, requirement for fish-ladders for engineering works, maintenance of flowing-water or pond habitats, and ecological connection to the stream network for fish passage, etc. would apply if a gully/stream transition is not adequately delineated or misinterpreted.

Such a legal argument over definitions is highlighted by a study by Taylor and Stokes (2005) (in this case concerning what constitutes a ‘river’ or ‘watercourse’ in NSW legislation) whereby temperate-climate European perspectives of streams are ill-applied to intermittent and ephemeral stream networks in NSW, and Australia in general. In this dispute the difference was emphasised between legislative and geomorphological definitions and descriptions of a ‘river’. Williams and Fryirs (2016) came up against a similar issue whereby ‘chain-of-ponds’ watercourses could not be protected under the definition of (continuous) ‘rivers’.

Taylor and Stokes (2005) highlight the other importance of this argument that insufficient definition of streams or watercourses will perpetuate disagreements between authorities and landowners or land managers/developers. Retaining such imprecise and inadequate definitions in legislative instruments also encourages poor land use decisions and practices which inevitably lead to further degradation and/or inappropriate use of that environment.

We believe the same issue and emphasis applies to definitions of a stream channel versus a gully.

## Background: Definitions

Streams, rivers, channels, watercourses and gullies have different definitions in Australia and around the world for different purposes and reasons. It also depends on the terms used. The confusion of definition between stream channels and gullies can be summed up neatly summed up by the US Bureau of Reclamation (2021) (ostensibly a major influential land stewardship authority): '***Gullying***. *Small-scale stream erosion*.' Confusion and, maybe, indifference.

Current definitions used in Queensland, and in Australia generally, are largely unhelpful for distinguishing between a gully and a small, ephemeral or intermittent stream channel (a first- or second-order stream).

### *Stream Channel*

The Federal Government Biodiversity legislation recommendations from the Threatened Species Scientific Committee: 'the terms "rivers" and "streams" are not defined and are not prescriptive - the term "watercourse" is less arbitrary, more commonly used, and defined in most State legislation' (Department of Agriculture, Water and the Environment, undated). The term 'watercourse' is defined for Federal Government legislation and differently in each State's legislation.

For a technical definition, the Australian Soil and Land Survey Field Handbook – taken as the standard for all landscape assessment in Australia – provides: '***Channel(s)****: linear, generally sinuous open depression, in parts eroded, excavated, or built up and aggraded by channelled stream flow. This element comprises stream bed and banks*.' Speight (2009).

Somewhat circular in the definition of channel being formed by channelled stream flow, this is not helped much by the definitions of 'bed' and 'banks' in the same 'landforms' section. The definition clearly derives from the Soil Conservation Service of NSW, strangely missing the added qualifier of streams including 'bars': '***Stream channel***. *Linear, generally sinuous, open depression, in parts eroded, excavated and aggraded by channelled streamflow. Includes streambed, banks and bars*.' (Houghton & Charman, 1986).

However, there is no mention of intermittency of flow in channels, which is a distinctive feature of Australian streams, creeks, and rivers and a critical aspect when differentiating from gullies.

The following definitions from a US state authority distinguish streams from a biophysical perspective as well as addressing the legal requirements, still with an intention of universality:

> ***Ephemeral Stream*** – *Ephemeral (stormwater) stream means a feature that carries only stormwater in direct response to precipitation with water flowing only during and shortly after large precipitation events. An ephemeral stream <u>may or may not have a well-defined channel, the aquatic bed is always above the water table, and stormwater runoff is the primary source of water</u>. An ephemeral stream <u>typically lacks the biological, hydrological, and physical characteristics commonly associated with the continuous or intermittent conveyance of water</u>.* (Division of Water Quality, 2005) (emphasis added)
>
> ***Intermittent Stream*** – *Intermittent stream means <u>a well-defined channel</u> that contains water for only part of the year, typically during winter and spring when the aquatic bed is below the water table. <u>The flow may be heavily supplemented by stormwater runoff</u>. An intermittent stream often lacks the biological and hydrological characteristics commonly associated with the conveyance of water*. (Division of Water Quality, 2005) (emphasis added)

These definitions and the concept expressed here are useful and are as good as any as a basis for distinguishing types of (non-continuous flow) stream channels from gullies for Australian environments.

### *Gully*

A commonly accepted definition of gullies is that they are erosion features larger than rills – which are '*erosional features < 0.3 m deep which can be ploughed out or easily crossed, but smaller than streams, creeks, arroyos, or river channels*' (Wells, 2004). A description that actually harks back to the National Soil Conservation Service of the 1930's using the arbitrary rule of 1 ft depth. The Australian Soil and Land Survey

Handbook (NCST, 2009, p.39), which is the Australian standard for landscape description, defines a gully as a Landform Element that is an,

> *'(o)pen depression with short, precipitous walls and a moderately inclined to very gently inclined floor or small stream channel, eroded by channelled stream flow and consequent collapse and water aided movement" and, that it is, "… a channel more than 0.3 m deep'* (NCST, 2009 pp. 39 & 136) emphasis added to indicate the confusion of concepts.

This is by no means a clear definition, and it confuses the concept by stating that gullies are '… eroded by channelled stream flow … and is ambiguous as to what is meant by 'short' walls. This vague definition used as the Australian 'standard' has introduced considerable confusion by referring to gullies as 'channels' and thereby allowing first and second order stream channels to be included in the concept of a gully. This definition, however, includes no reference to what most practitioners would consider to be one of the essential characteristics of a gully, which is the presence of a head wall or head scarp.

Brooks, et al. (2019) have provided an objective definition of a gully distinguished from a stream channel that is directly relevant. It is presented and discussed in modified form in the Results section below.

Through a comprehensive literature review Thwaites et al. (2021) have grappled with the problem of defining gullies from a world-wide perspective and addressed the issue of differentiating them from other 'incisional land-surface forms', and specifically stream channels. This included and modified the definitions of Brooks et al. (2019).

## Background: Recognition and identification

Argument over the identifiable geomorphological form and processes between gullies and stream channels will continue. However, more germane to this discussion is the differentiation between these landforms and their identification drawn on maps or detectable on aerial photographs and other imagery. What is the relation between stream channels drawn on official, gazetted maps and actual stream channels on the ground and how are they differentiated for gullies (if at all)?

Generally when aerial photos and high-resolution imagery are used, there are often problems of visibility below tree canopies and as always, the scale of the photograph or the map will be a constraint on the resolution achievable. Thus, what is measured by one assessor may not be the same phenomenon as that which is measured by another (Slaymaker, 2004).

In addition, the use of blue lines (whether continuous or dashed) on a map to indicate the presence of rivers or streams (perennial, or intermittent, or ephemeral?) is manifestly inadequate for determining if a watercourse is a stream channel or a gully. They are often little more than an assessors/cartographer's interpretation of reality.

## Methods. How can we make the distinction?

For the reasons given above it appears crucial that we have a common understanding of exactly what a gully looks like, in all its forms, and how we can distinguish these from stream channels, in biophysical, geomorphological, hydrological perspectives, and be able to communicate it in standardised digital and qualitative terms.

To this end, we have attempted to distinguish and define 'gullies' from 'stream channels' through:

a) pioneering techniques for accurate, high-resolution, broad-scale digital mapping of gullies in the GBR catchments (Daley et al. 2021), and
b) developing classification and typology methods specifically for gullies (Brooks et al. 2019; Thwaites et al. 2021).

To undertake the classification of gullies and to map them digitally from lidar imagery (in northern Queensland GBR catchments), we

i) categorically defined what is, and what is not, a gully;
ii) stated the criteria that are the distinguishing factors;
iii) defined a stream channel as not-a-gully;
iv) defined a stream channel independently of a gully;

v) evaluated the distinction through the weight-of-evidence.

The procedure involved identifying key geomorphological concepts that pertain to gullies rather than low-order, ephemeral stream channels; identifying criteria to define gullies and stream channels; and developing a rule-set to classify gullies distinctly or, at least, to an acceptable degree.

Importantly, it was recognised that a transition zone often exists where gullies have formed in the upper part of drainage network. Work in clarifying and characterising this zone and distinguishing 'boundaries' between gullies and stream channels is continuing.

## Results: definitions of gullies and stream channels

### *Definition of a gully*

Thwaites et al. (2021) have provided a provisional, objective definition of a gully, as distinguished from a stream channel, that is unique as far as we are aware.

Their identification and categorisation into one or the other definitions is by weight-of-evidence – not all criteria are necessary, nor is each characteristic in isolation a defining feature of a gully. The following definition is the result of their analysis.

***A gully*** *(see Figure 1):*

*a. is not a 'stream channel' (or watercourse);*
*b. is a persistent erosional feature, with active head or walls on average > 0.5 m deep, and has multiple modes of expansion, but always including headward retreat into an otherwise un-dissected landscape;*
*c. erodes unconsolidated materials and saprolite, but not bedrock;*
*d. must have an active head scarp or head wall at the upslope limit of the gully (which may or may not be a clear nick point):*
  - *sometimes a series of head scarps may occur;*
  - *a 'scalded' or desiccated area (i.e. an area stripped of its topsoil with degraded vegetative cover) may often fringe the upslope area of the head scarp and head walls;*
  - *has an erosional gully wall scarp, or clear erosional cut.*
  - *some exceptions, such as the expanding, shrink-swell, cracking clays (i.e. Vertosols† and friable Black Dermosols, or 'blacksoil', and 'reactive clays') that may have convex walls and a head 'ramp' need considering for evidence of other active erosion present in these cases, e.g. piping, tunnels or slumping;*
  - *has the head (head scarp, head wall), or heads, marking the upstream boundary of concentrated water flow and sediment transport between definable banks;*
*e. has a cross-sectional shape (U-shaped, V-shaped, trapezoidal, slot, or tiered‡) that is permanently recognizable without flow;*
*f. has a straight bed long-profile, rather than a curved one (of stream channels);*
*g. has a dominant proportion of a 'hard margin' (a comparatively sharp break of slope from the unbroken land surface to the incisional feature, that represents a gully head scarp and wall scarp of active erosion, commonly referred to as a rim, edge or scarp), active or otherwise, or equivalent;*
*h. has active erosional walls of at least moderately steep gradient (~ 30°; ~ 60 %), and gully walls are dominantly bare soil materials;*
*i. are autonomous – having the active sediment source predominantly within the gully (a clear autocthonous, or 'internal', erosional zone);*
*j. may have land upslope of the head, or beyond, that may be a drainage depression (swale), or marshland in keeping with the incisional caveats above;*
*k. is typically driven by proximal ephemeral flows (i.e. associated with rainfall directly in the gully and in the gully catchment).*

† Australian Soil Classification (Isbell and NCST, 2012).
‡ defined in Thwaites et al. (2020)

Thwaites et al. (2021)

The definition of a gully, like that of most landscape features, is scale-dependent: components of gullies have to be identified as well as broad systems of gullies into a single system. A digital gully nomenclature has been developed to address this Daley et al. (2021).

## *Definition of a stream channel*

A stream channel is considered to be a permanent feature formed by flowing water (ephemeral, intermittent, or perennial) through both erosion and deposition. It is a fluvial form that shows features such as terraces, channel bars, and deposited materials derived from distant up-stream sources. Channels also show evidence of intermittent overbank flooding (Brooks et al. 2019). Definition overall is again by weight-of-evidence.

***A stream channel*** *(see Figure 1) assuming formation in unconsolidated materials (i.e. alluvium, colluvium), excluding bedrock gorges, has:*

- *defined channel bed and banks, and evidence of fluvial processes and dynamics, e.g.*
    - *they are dynamic and are both erosional and depositional systems (i.e. not autonomous: comprising both autocthonous (internal) and allocthonous (external) sediment sources);*
    - *without an obvious, active upslope head scarp (other than the rare case of active knick point migration triggered by downstream or base-level changes);*
- *features that indicate fluvial processes and dynamics, for example:*
    - *the presence of a self-formed floodplain;*
    - *a distinct assemblage of fluvially derived depositional geomorphic units, e.g. point bars, lateral bars, benches;*
    - *a bed material load that is distinctly different to the locally available sediment source (i.e. from head or wall erosion), i.e. allocthonous sources;*
    - *a width/depth ratio > 1;*
    - *meander development of the bed/floor (not just <u>within</u> the bed).*

Thwaites et al. (2021)

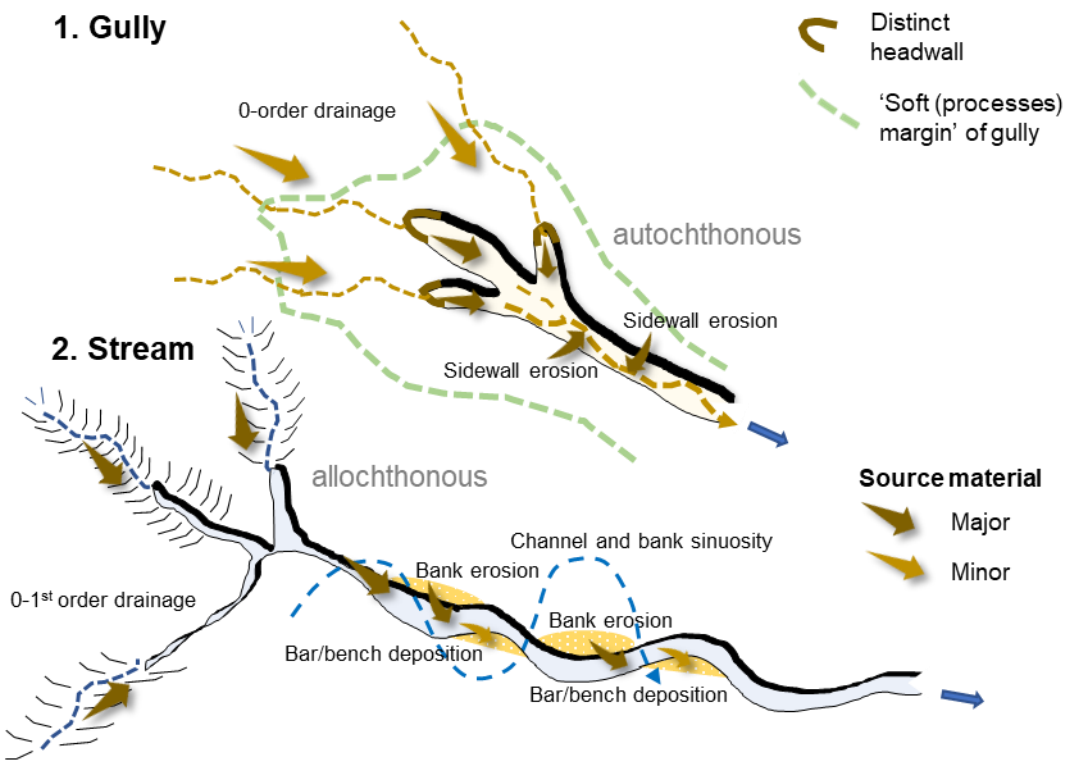


**Figure 1** The concept of differentiation between gullies and steam channels (from Thwaites et al. 2020)

This conceptual understanding is often not directly translatable to extracting metrics from remotely sensed data but relates to forms and processes that fundamentally distinguish gullies from stream channels and other erosional landscapes. For practical mapping purposes from imagery and DEMs, we consider gullies to have:

- High surface roughness from multiple erosional forms within the gully – e.g. rilling, fluting, block collapse and slumping
- Slopes > 25% along flow lines
- Change in slope range > 30% along scarps
- Has a definable head scarp
- Dominantly bare, exposed soil materials on the surface
- Do not include ordered fluvial depositional units such as bars, benches and floodplains

(Daley et al. 2021)

## Discussion

The boundary between gullies and stream channels can still be a fuzzy one, both physically and conceptually. The physical boundary may better be viewed as a transition zone. However, there is still a need to focus on where a gully ends or transitions. A gully 'terminus' can sometimes be quite clearly defined using these criteria but is usually arbitrary where the transition occurs. The definition of the transition zone needs development and is currently being investigated.

Applying these definitions and criteria in our gully research has greatly aided the technique for broad-scale digital mapping of gullies (distinct from stream channels) at high resolution. In the process, this definition that can be applied as 'rules' has highlighted discrepancies with prior presence/absence mapping of gully features from imagery and limited field validation by the Queensland State Government (Daley et al. 2021). It has allowed much more accurate estimation of eroded sediment volumes and erosion rates for research into sediment sources and loads from gullies, Similarly, the more accurate sediment yield estimations for rehabilitation prioritization analysis and economic modelling has allowed more confident estimations of rehabilitation and management costs and requirements. All of these have also assisted the development of a gully typology from the gully classification (Thwaites et al. 2021)

## Conclusions

This refined gully conceptual model differs significantly from that of the Australian Soil and Land Survey Handbook (NCST, 2009), because we believe it is necessary to distinguish ephemeral stream channels from gullies, for the main reason that their evolution and sediment yield is governed by different processes.

Separating gullies from streams has importance for current gully management guidelines and is also being recognised in the nascent Queensland river and stream bank management guidelines.

Applying these definitions and criteria in our gully research has greatly aided the results of broad-scale mapping of gullies at high resolution, highlighted discrepancies with prior presence/absence mapping of gully features, allowed much more accurate estimation of eroded sediment volumes, erosion rates, and more accurate sediment yield estimations.

True objectivity remains elusive, however, so reasonable decisions – based on weight-of-evidence – still must be made to make the necessary distinctions. For scientific purposes in the future we foresee that a Bayesian or fuzzy classification and machine-learning approaches will be needed to aid the decision process.

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Modelling for Queensland' from the Queensland Water Modelling Network (QWMN) at the Department of Environment and Science, Queensland State Government.

## References


Brooks A.P., Thwaites, R.N., Spencer, J., Pietsch, T. and Daly, J. (2019). A Gully Classification Scheme to Underpin Great Barrier Reef Water Quality Management: 1st Edition. NESP Project 4.9 Final Report. The National Environmental Science Programme, Townsville. http://www.nesptropical.edu.au

Daley, J., Stout, J.C., Curwen, G., Brooks, A.P. and Spencer, J. (2021) Development and application of automated tools for high resolution gully mapping and classification from lidar data. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (169pp.).

Division of Water Quality (2005). Identification Methods for the Origins of Intermittent and Perennial streams, Version 3.1. North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC.

Houghton, P.D. and Charman, P.E.V. (1986). Glossary of terms used in Soil Conservation. Soil Conservation Service of New South Wales.

Slaymaker, O. 2004. Drainage Density. In Goudie A, (ed.) Encyclopedia of Geomorphology, Volume 1, pp 277-279.

Speight, J.G. (2009). Landform. In NCST (3rd edn) Australian soil and land survey field handbook, CSIRO Publishing, Melbourne.

Taylor, M., and Stokes, R. (2005). Up the creek: What is wrong with the definition of a river in New South Wales?: 193-211. Environmental and Planning Law Journal, 2005, Volume 22, Issue 3.

Thwaites, R. N., Brooks, A.P., Pietsch, T.J., and Spencer, J. (2021) What Type of Gully is That? I. The Need for a Classification of Erosion Gullies. Earth Surface Processes and Landforms (in publication).

Thwaites, R.N., Brooks, A.P., Spencer, J. and the QWMN Working Group. (2020). The Queensland Gully Classification 2.2 Handbook Version 1.0 (Draft), Griffith University and Queensland Water Monitoring Network (QWMN), Queensland Government. https://www.griffith.edu.au/__data/assets/pdf_file/0023/1274216/Qld-Gully-Classification_Handbook_2021_v1.4_DRAFT_locked.pdf

US Bureau of Reclamation. (2021). Glossary. https://www.usbr.gov/library/glossary (updated 1/5/2021)

Wells, N.A. 2004. Gully. In Goudie A, (ed.) Encyclopedia of Geomorphology, Volume 2, IAG, Routledge; 503–506.

Williams R. and Fryirs K. (2016) Management and conservation of a unique and diverse Australian river type: Chain-of-ponds Vietz, G.J., Flatley, A.J. and Rutherfurd, I.D. (2016) Proceedings of the 8th Australian Stream Management Conference, 31 July – 3 August 2016, Leura, New South Wales.