Oecologia Australis (ISSN: 2177-6199)
Ahead of print (https://revistas.ufrj.br/index.php/oa/issue/view/1109/showToc)
Article ID: AO#72318
Published online: 28 JULY 2026

CLASSIFYING THE HIERARCHY OF WATERCOURSES FOR ECOLOGICAL STUDIES

Valter Monteiro Azevedo-Santos[1,2,3]*, *Bianca de Freitas Terra*[4,5] & *Raoul Henry*[6]

[1] Universidade Federal do Tocantins, Programa de Pós-Graduação em Biodiversidade, Ecologia e Conservação, Câmpus de Porto Nacional, Rua 03, Quadra 17, Lote 11, s/nº, Bloco dos Professores, Sala 15, Setor Jardim dos Ipês, 77500-000, Porto Nacional, Tocantins, Brazil.

[2] Parque de Ciência e Tecnologia Guamá (PCT Guamá), Grupo de Ecologia Aquática, Avenida Perimetral da Ciência, km 01, s/nº, Guamá, 66075-750, Belém, Pará, Brazil.

[3] Universidade Federal do Maranhão (UFMA), Centro de Ciências Agrárias e Ambientais (CCAA), Laboratório de Sistemática e Ecologia de Organismos Aquáticos (LASEOA), Rodovia BR-222, Km 04, s/nº, Bairro Boa Vista, 65500-000, Chapadinha, Maranhão, Brazil.

[4] Universidade Estadual Vale do Acaraú (UVA), Centro de Ciências Agrárias e Biológicas (CCAB), Campus da Betânia, Avenida Padre Francisco Sadoc de Araújo, 850, 62040-370, Sobral, Ceará, Brazil.

[5] Universidade Estadual da Paraíba (UEPB), Programa de Pós-Graduação em Ecologia e Conservação (PPGEC), Câmpus I, Rua Baraúnas, 351, Bairro Universitário, 58429-500, Campina Grande, Paraíba, Brazil.

[6] Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Instituto de Biociências (IBB), Rua Prof. Dr. Antônio Celso Wagner Zanin, 250, Distrito de Rubião Júnior, 18618-689, Botucatu, São Paulo, Brazil.

E-mails: valter.ecologia@gmail.com (*corresponding author); biancafterra@gmail.com; r.henry@unesp.br

Abstract. The classification of a watercourse is fundamental in the field of ecology and other sciences, as it facilitates, for example, communication about the characteristics of the environment to be studied (or previously studied). Generally, for ecological studies of lotic ecosystems, many authors use classification in order, as proposed by Arthur N. Strahler in 1954 (widespread from 1957), or magnitude, a concept idealized by Ronald L. Shreve in 1967. In this article, we advocate that, from a logical perspective, the use of Shreve's method makes more sense in studies on the ecology of freshwater biodiversity. In addition, we call attention to the fact that (if possible) authors should also consider the type of environment (*i.e.*, perennial, intermittent, and ephemeral) in their classification.

Keywords: non-perennial; order; Shreve; Strahler; stream

INTRODUCTION

What is a watercourse? It is a waterbody that flows from its origin (generally a source) to its outlet in other watercourses, lakes, seas or other receiving bodies. A good definition is "a natural channel in which water flows regularly or intermittently" (Act 1998, p. 16). A watercourse is one of the basic components of a hydrographic basin. It is the morphological component for conveying water from one region to supply another.

Existing watercourses may be categorized into three basic types: (i) perennial, which maintains in its channel a continuous and lasting flow (Allen *et al.* 2020); (ii) intermittent, which spatially or temporally loses its regular water flow (Busch *et al.* 2020); and (iii) ephemeral, which may be considered a non-perennial watercourse and, generally, flows in the channel after rainfall (Busch *et al.* 2020). These three types of watercourses are important for maintaining freshwater biodiversity (*e.g.*, Benstead *et al.* 2003, Stubbington *et al.* 2017, Tickner *et al.* 2020, Steward *et al.* 2022, Sánchez-Montoya *et al.* 2023) and, therefore, for implementing conservation actions.

The hierarchical classification of a watercourse is fundamental in freshwater ecology and other sciences, as it facilitates, for instance, communication about the characteristics of the study environment. Generally, for ecological studies of lotic ecosystems, most authors use the classification proposed by Strahler (1954) *apud* Strahler (1957), which is also detailed in this latter study. However, from an ecological perspective, we believe that the use of Shreve's (1967) method is more appropriate.

In this essay, we advocate that future studies on ecology should employ Shreve's method and, ideally, apply it considering perennial, intermittent, and ephemeral watercourses. Although the term watercourse can refer to both artificial and natural channels, here, we will focus on natural systems commonly referred to as streams, creeks, and rivers.

STRAHLER AND SHREVE METHODS

The analysis of the hydrological hierarchy involves classifying stretches (also called segments or reaches) of a watercourse in different sections of a watershed. To this end, different approaches have emerged from the scientific literature of fluvial geomorphology. However, the most widely used methods for determining watercourse hierarchy in ecological studies are those proposed by Strahler (1957) and Shreve (1967). The approaches proposed by these authors have been used in numerous studies across diverse riverine ecosystems globally (*e.g.*, Cao *et al.* 2015, Naumov *et al.* 2017, Vorste *et al.* 2017, Correa *et al.* 2025, Zhang *et al.* 2025, Stack *et al.* 2026).

The concept of hierarchy proposed by Arthur N. Strahler was first presented at the "International Geological Congress (1952, Algiers, Algeria)" (Strahler 1954 *apud* Strahler 1957). However, it was likely Strahler's (1957) publication, cited over 9,100 times (according to Google Scholar on 02 May 2026), that led to the widespread recognition of his watercourse classification. Strahler (1957, p. 914) considers different types of watercourses, clearly mentioned as "intermittent and permanent". According to Strahler (1957, p. 914), "(...) smallest finger-tip tributaries are designated Order 1. Where two first-order channels join, a channel segment of Order 2 is formed; where two of Order 2 join, a segment of Order 3 is formed; and so forth".

Alternatively, Ronald L. Shreve, in his 1967 study, cited 828 times (according to Google Scholar on 02 May 2026), explicitly explaining his classification based on watercourse magnitude. According to Shreve (1967, p. 179): "(1) Each exterior link has magnitude 1. (2) If links or magnitude $\mu 1$ and $\mu 2$ join, then the resultant link downstream has magnitude $\mu 1 + \mu 2$". For example, a stream that has just started (at its source) and flows into another should be considered of magnitude 1, and if two streams of magnitude 1 connect, the section immediately

Oecologia Australis (ISSN: 2177-6199)
Ahead of print (https://revistas.ufrj.br/index.php/oa/issue/view/1109/showToc)
Article ID: AO#72318
Published online: 28 JULY 2026

downstream should be considered of magnitude 2. In other words, the method is the cumulative sum of watercourses.

STRAHLER VERSUS SHREVE METHODS

Classifying watercourse stretches according to Strahler (1957) presents limitations. Watercourses of order higher than first-order are not readily comparable or accurately interpretable by readers. For example, under Strahler's method, a second-order watercourse may receive several first-order tributaries (Figure 1a), whereas another watercourse, also classified as second-order, may result from the confluence of just two first-order watercourses, without any additional tributary (Figure 1b). Along the same lines, Gutierrez *et al.* (2022) argued that this method is unfeasible to adequately show the fluvial hierarchy in a hydrographic basin. We agree with them.

The problems raised above are clearly solved using the method of Shreve (1967). For example, a second-magnitude watercourse, in all cases, is the result of the connection of only two first-magnitude watercourses. This allows both comparison of ecological aspects with others of similar hierarchy and unequivocal characterization (Figure 1c-d). Therefore, if used, Shreve's methods, as also mentioned by Gutierrez *et al.* (2022) in their article, seem more appropriate for application in freshwater ecological studies.

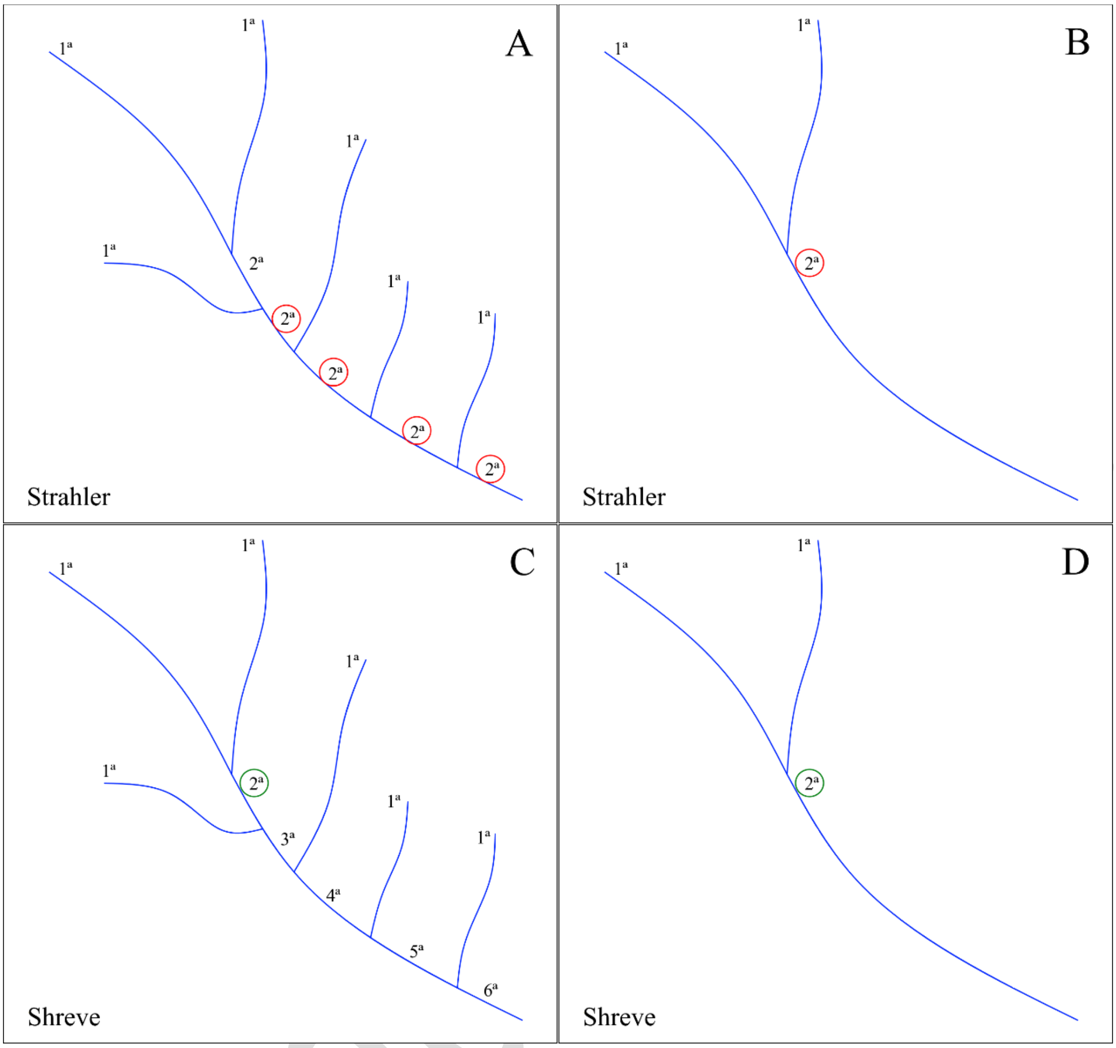

Figure 1. Hypothetical hydrographic basin showing the differences between Strahler's (1957) and Shreve's (1967) methods: A and B are not equivalent second-order stream (red circle); C and D are equivalent second-magnitude stream (green circles).

HOW TO APPLY THE SHREVE'S METHOD?

The application of Shreve's (1967) method should consider all types of watercourses (*i.e.*, perennial, intermittent, and ephemeral) in the existing ecosystem. However, we recognize that, in many cases, it is very difficult to determine certain categories of watercourses (*e.g.*, ephemeral) in ecological and other types of studies. For instance, some channels may not be visible during non-rainy periods. In these cases, we suggest that authors clearly state their use of the Shreve method. Afterward, they may explain that no differentiation of watercourse types occurs in their classification. Alternatively, authors may use the Shreve method and consider only perennial ones, but this last piece of information also should be mentioned to the readers to facilitate their understanding and reproducibility. Generally, several authors do not mention the type of watercourse considered in their classification of the hydrological hierarchy (*e.g.*, Casatti *et al.* 2001, Castro *et al.* 2003, Azevedo-Santos *et al.* 2020, Stahl *et al.* 2023). This should be avoided in the future for the reasons we explained previously.

WHERE TO APPLY THE SHREVE'S METHOD?

The method we advocate can be applied in various contexts. For example, it is useful in studies that compare ecological aspects (*e.g.*, species richness) in watercourses of equivalent hierarchies. It serves to efficiently communicate the hierarchy of a watercourse that is to be (or has been) sampled in different types of studies, such as inventories or surveys, community ecology, population ecology, ecotoxicology, biogeography (*e.g.*, to better understand organism dispersal patterns) and even in taxonomic studies (*e.g.*, when describing the type locality of a species). Furthermore, it appears to be a viable alternative to Strahler's method for use in new biogeographical and ecological approaches (*e.g.*, the iPODfish proposed by Duarte et al. 2022), as well as in restoration and other conservation strategies (*e.g.*, FitzHugh 2005). It can potentially be used to distinguish a stream from a river for ecological purposes. Finally, it can be included in databases (*e.g.*, Ottocoded Hydrographic) that are potentially used in ecological studies.

CONCLUSIONS

The classification approach we advocate enhances clarity, with authors communicating watercourse hierarchies to readers. Furthermore, it will make it possible to compare the biodiversity among equivalent watercourses. Finally, if possible, authors should ideally consider the different existing types of watercourses (*i.e.*, perennial, intermittent, and ephemeral) in the watershed studied during the classification. This has important implications for applications by scientists and technicians studying freshwater biodiversity.

ACKNOWLEDGMENTS

We would like to thank Clarice Casa Nova (UFRJ), and the two anonymous reviewers, for the constructive comments and suggestions on the manuscript.

REFERENCES

Act. 1998. Government Gazette. Republic of South Africa. (Retrieved on December 16, 2024, from https://www.gov.za/sites/default/files/gcis_document/201409/a36-98.pdf).

Allen, D. C., Datry, T., Boersma, K. S., Bogan, M. T., Boulton, A. J., Bruno, D., Busch, M. H., Costigan, K. H., Dodds, W. K., Fritz, K. M., Godsey, S. E., Jones, J. B., Kaletova, T., Kampf, S. K., Mims, M. C., Neeson, T. M., Olden, J. D., Pastor, A. V., Poff, N. L., Ruddell, B. L., Ruhi, A., Singer, G., Vezza, P., & Ward, A. S. 2020. River ecosystem conceptual models and non-perennial rivers: A critical review. Wiley Interdisciplinary Reviews: Water, 7(5), e1473.

Azevedo-Santos, V. M., Pelicice, F. M., & Henry, R. 2020. Knowing biodiversity: Fishes from the Guareí River basin, a tributary of the Jurumirim reservoir, Paranapanema River, Brazil. Biota Neotropica, 20(3), e20201031.

Benstead, J. P., De Rham, P. H., Gattolliat, J. L., Gibon, F. M., Loiselle, P. V., Sartori, M., Sparks, J. S., & Stiassny, M. L. J. 2003. Conserving Madagascar's freshwater biodiversity. BioScience, 53(11), 1101–1111.

Busch, M. H., Costigan, K. H., Fritz, K. M., Datry, T., Krabbenhoft, C. A., Hammond, J. C., Zimmer, M., Olden, J. D., Burrows, R. M., Dodds, W. K., Boersma, K. S., Shanafield, M., Kampf, S. K., Mims, M. C., Bogan, M. T., Ward, A. S., Rocha, M. P., Godsey, S., Allen, G. H., Blaszczak, J. R., Jones, C. N., & Allen, D. C. 2020.

What's in a name? Patterns, trends, and suggestions for defining non-perennial rivers and streams. Water, 12(7), 1980.

Cao, Y., Stodola, A., Douglass, S., Shasteen, D., Cummings, K., & Holtrop, A. 2015. Modelling and mapping the distribution, diversity and abundance of freshwater mussels (Family Unionidae) in wadeable streams of Illinois, USA. Freshwater Biology, 60(7), 1379–1397.

Casatti, L., Langeani, F., & Castro, R. M. C. 2001. Peixes de riacho do Parque Estadual Morro do Diabo, bacia do alto rio Paraná, SP. Biota Neotropica, 1(1), 1–15.

Castro, R. M. C., Casatti, L., Santos, H. F., Ferreira, K. M., Ribeiro, A. C., Benine, R. C., Dardis, G. Z. P., Melo, A. L. A., Stopiglia, R., Abreu, T. X., Bockmann, F. A., Carvalho, M., Gibran, F. Z., & Lima, F. C. T. 2003. Estrutura e composição da ictiofauna de riachos do rio Paranapanema, sudeste e sul do Brasil. Biota Neotropica, 3(1), 1–31.

Correa, S. B., Coronado-Franco, K. V., Jézéquel, C., Rodrigues, A. C., Evans, K. O., Granger, J. J., Ter Steege, H., Amaral, I. L., Coelho, L. S., Wittmann, F., Matos, F. D. A., Lima Filho, D. A., Salomão, R. P., Castilho, C. V., Guevara, J. E., Carim, M. J. V., Phillips, O. L., Fernandez Piedade, M. T., Demarchi, L. O., Schöngarth, J., Cardenas Revilla, J. D., Martins, M. P., Irume, M. V., Guimarães, J. R. S., Ramos, J. F., Quaresma, A. C., Pitman, N. C. A., Luize, B. G., Novo, E. M. M. L., Venticinque, E. M., Silva, T. S. F., Núñez Vargas, P., Manzatto, A. G., Reis, N. F. C., Terborgh, J., Casula, K. R., Honorio Coronado, E. N., Montero, J. C., Monteagudo Mendoza, A., Feldpausch, T. R., Durgante, F. M., Castaño Arboleda, N., Marimon, B. S., Marimon-Junior, B. H., Killeen, T. J., Vasquez, R., Mostacedo, B., Assis, R. L., Amaral, D. D., Householder, J. E., Simon, M. F., Medeiros, M. B., Queiroz, H. L., Lopes, M. A., Magalhães, J. L. L., Stevenson, P. R., Cintra, B. B. L., Araujo-Murakami, A., Baker, T. R., Feitosa, Y. O., Mogollón, H. F., Duivenvoorden, J. F., Ferreira, L. V., Toledo, J. J., Comiskey, J. A., Lopes, A., Damasco, G., Vicentini, A., Cornejo Valverde, F., Gomes, V. H. F., Alonso, A., Dallmeier, F., Aguiar, D. P. P., Gribel, R., Licona, J. C., Villa Zegarra, B. E., Carneiro Guedes, M., Cerón, C., Thomas, R., Milliken, W., Campelo, W., Albuquerque, B. W., Klitgaard, B., Tello, J. S., Fuentes Claros, A., Rivas-Torres, G., Phillips, J. F., von Hildebrand, P., Gonzales, T., Vela, C. I. A., Hoffman, B., Flores, B. M., Pombo, M. M., Rocha, M., Holmgren, M., Cano, A., Umaña, M. N., Casas, L. F., Balslev, H., Urrego Giraldo, L. E., Bigorne, R., Oberdorff, T., Maldonado-Ocampo, J. A., Ortega, H., Hidalgo, M., Martens, K., Torrente-Vilara, G., Zuanon, J., Acosta, A., Agudelo, E., Barrera Maure, S., Bastos, D. A., Bogotá Gregory, J., Cabeceira, F. G., Canto, A. L. C., Carvajal-Vallejos, F. M., Carvalho, L. N., Cella-Ribeiro, A., Covain, R., Dias, M. S., Donascimiento, C., Dória, C. R. C., Duarte, C., Ferreira, E. J. G., Galuch, A. V., Giarrizzo, T., Leitão, R. P., Lundberg, J. G., Maldonado, M., Mojica, J. I., Montag, L. F. A., Ohara, W., Pires, T. H. S., Pouilly, M., Prada-Pedreros, S., Queiroz, L. J., Rapp Py-Daniel, L., Ribeiro, F. R. V., Ríos Herrera, R., Rodrigues dos Anjos, M., Lourenco, I. H., Sarmiento, J., Sousa, L. M., Stegmann, L. F., Valdiviezo-Rivera, J., Villa, F., Yunoki, T., & Tedesco, P. A. 2025. Floodplain forests drive fruit-eating fish diversity at the Amazon Basin-scale. Proceedings of the National Academy of Sciences, 122(3), e2414416122.

Duarte, G., Branco, P., Haidvogl, G., Ferreira, M. T., Pont, D., & Segurado, P. 2022. iPODfish–A new method to infer the historical occurrence of diadromous fish species along river networks. Science of the Total Environment, 812, 152437.

FitzHugh, T. W. 2005. GIS tools for freshwater biodiversity conservation planning. Transactions in GIS, 9(2), 247–263.

Gutierrez, M. F., Mayora, G., Licursi, M., Michlig, M., Repetti, M. R., & Negro, L. 2022. Zooplankton shifts from headwater to lowland streams: insights into the role of water quality to assist the protection and restoration of agricultural waterways. Ecohydrology, 15(4), e2432. DOI: 10.1002/eco.2432

Naumov, V., Angelstam, P., & Elbakidze, M. 2017. Satisfying rival forestry objectives in the Komi Republic: effects of Russian zoning policy change on wood production and riparian forest conservation. Canadian Journal of Forest Research, 47(10), 1339–1349.

Sánchez-Montoya, M. M., Datry, T., Ruhi, A., Carlson, S. M., Corti, R., & Tockner, K. 2023. Intermittent rivers and ephemeral streams are pivotal corridors for aquatic and terrestrial animals. BioScience, 73(4), 291–301.

Shreve, R. L. 1967. Infinite topologically random channel networks. The Journal of Geology, 75(2), 178–186.

Stack, T., Harris, A. C., Fairchild, M. P., Oyler-McCance, S. J., Fike, J. A., Winkelman, D. L., & Kanno, Y. 2026. Riverscape genetics of nonnative Brook Trout to inform native cutthroat trout conservation. Transactions of the American Fisheries Society, 155(1), 26–40.

Stahl, L. L., Snyder, B. D., McCarty, H. B., Kincaid, T. M., Olsen, A. R., Cohen, T. R., & Healey, J. C. 2023. Contaminants in fish from US rivers: probability-based national assessments. Science of the Total Environment, 861, 160557.

Steward, A. L., Datry, T., & Langhans, S. D. 2022. The terrestrial and semi-aquatic invertebrates of intermittent rivers and ephemeral streams. Biological Reviews, 97(4), 1408–1425.

Strahler, A. N. 1954. Quantitative geomorphology of erosional landscapes. 19th International Geological Congress, Algiers, 1952, sec. 13, pt. 3, pp. 341–354.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Eos, Transactions American Geophysical Union, 38(6), 913–920.

Stubbington, R., England, J., Wood, P. J., & Sefton, C. E. M. 2017. Temporary streams in temperate zones: recognizing, monitoring and restoring transitional aquatic-terrestrial ecosystems. Wiley Interdisciplinary Reviews: Water, 4(4), e1223.

Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Bunn, S. E., Cooke, S. J., Dalton, J., Darwall, W., Edwards, G., Harrison, I., Hughes, K., Jones, T., Leclère, D., Lynch, A. J., Leonard, P., McClain, M. E., Muruven, D., Olden, J. D., Ormerod, S. J., Robinson, J., Tharme, R. E., Thieme, M., Tockner, K., Wright, M., & Young, L. 2020. Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. BioScience, 70(4), 330–342.

Vorste, R. V., McElmurray, P., Bell, S., Eliason, K. M., & Brown, B. L. 2017. Does stream size really explain biodiversity patterns in lotic systems? A call for mechanistic explanations. Diversity, 9(3), 26.

Zhang, H., Meiller, C., Morsdorf, F., Hueni, A., Helfenstein, I. S., Blackman, R. C., Schaepman, M. E., & Altermatt, F. 2025. Hyperspectral imagery, LiDAR point clouds, and environmental DNA to assess land-water linkage of biodiversity across aquatic functional feeding groups. Remote Sensing in Ecology and Conservation, 11(5), 618–635.

Submitted: 26 January 2026

Accepted: 06 July 2026

Published: 28 July 2028

Associated Editor: Clarice Casa Nova