APPENDIX 2

MORE INFORMATION REGARDING THE SCIENCE OF TRIBUTARIES

1. Delineation Between Ephemeral and Intermittent Waters in Colorado

There is unlikely to be always be a bright line between ephemeral and intermittent waters in Colorado. It is common to define intermittent streams as those streams with seasonal surface flow and ephemeral streams as those streams flowing in response to short term precipitation events. But these definitions represent an artificial, discrete construction imposed on a dynamic and continuous variable (surface flow). In one year a stream may appear ephemeral and in others may appear intermittent. Similarly, some streams may appear perennial (flowing for years at a time) but may lose surface flow during periods of drought. In the west and other arid climates, streams and stream reaches may be devoid of surface flow, with a channel morphology indicative of ephemeral flow, but which may flow for years at a time after a large precipitation events fill perched aquifers (impermeable layers of rock or sediment which hold water above the main water table) that sustain baseflow in streams thought to be ephemeral. In fact, there are a number of mechanisms which determine flow and loss of flow in these temporary river systems and which can be classified beyond simply “intermittent” or “ephemeral.”

Table 1 (below) assembled by researchers at the New Zealand National Institute of Water and Atmospheric Research illustrates how these various mechanisms of water loss can be used to classify temporary rivers along a geologic and geographic gradient. Evaluating over 20 publications (Larned et al. 2010), classified 7 classes of temporary river based on predominant mechanism of water loss including 1) Snowmelt and Glacial Meltwater, 2) Perch and Semi-Perched Alluvial, 3) Non-Perched in Arid and Semi-Arid Regions, 4) Zero-Order and Headwater Streams, 5) Permafrost, 6) Karstic and 7) Streams Below Lake Outlets. These systems each have unique ecologies and flow dynamics. As these systems receive more attention in the future, it is likely that more classifications/theoretical models will be made to account for their diversity, which will further erode the conceptual utility of describing temporary rivers as simply intermittent or ephemeral.

Table 1 Geographic and geologic classes of temporary rivers, and mechanisms controlling water loss

Class*	Predominant mechanisms of water loss	Example	Reference
Snowmelt and glacial meltwater	Cessation of melting/ablation, freezing of surface and shallow subsurface water	Dry Valley streams, Antarctica; Val Roseg, and Macun catchments, Switzerland	Bronge (1996), McKnight *et al.* (1999), Tockner & Malard (2003), Conovitz *et al.* (2006), Robinson & Matthaei (2007)
Perched and semi-perched alluvial	Transmission loss, depletion of bank storage and floodplain aquifer	Selwyn River, New Zealand; Tagliamento River, Italy; Cooper Creek, Australia, Kuiseb River, Namibia; Mohave River, USA; Shashane and Wenlock Rivers, Zimbabwe	Jacobson *et al.* (2000), Hamilton *et al.* (2005), Lange (2005), Mansell & Hussey (2005), Konrad (2006), Doering *et al.* (2007), Izbicki (2007), Larned *et al.* (2008)
Non-perched, in arid and semi-arid regions	Depletion of surface water and shallow groundwater by direct evaporation and evapotranspiration	Sycamore Creek, USA	Stanley *et al.* (1997)
Zero-order and headwater streams	Cessation of overland flow, depletion of saturated soil water or hillslope aquifer, macropore recession	Maybeso Creek, USA; Riera de Fuirosos, Spain; Stillman Creek watershed, USA	Butturini *et al.* (2002), Gomi *et al.* (2002), Hunter *et al.* (2005)
Permafrost	Soil freezing, soil water and wetland recession	Granger Creek and Wolf Creek, Canada	Metcalfe & Buttle (2001), Carey & Quinton (2005)
Karstic	Transmission loss, cessation of spring discharge	River Lathkill and River Wye tributaries, UK; Coulazou River and Vene Rivers, France	Wood *et al.* (2005), Jourde *et al.* (2007)
Lake outlets	Lake level drops below outlet elevation	Shadow Lake, Canada	Mielko & Woo (2006)

*These classes are not mutually exclusive; for example, alluvial rivers in desert regions are often perched or semi-perched, and water loss is jointly controlled by transmission loss and evaporation (Knighton and Nanson, 1994; Jacobson *et al.*, 2000).

Table 1 from "Emerging concepts in temporary-river ecology" (Larned et al. 2010).

2. Importance of Ephemeral and Intermittent Waters to Downstream Waters

The recent scientific literature illustrates an increasingly clear picture of the importance of these systems and their influence on downstream waters.[1] The preponderance of results from

[1] Heine, R.A., C.L. Lant, and R.R. Sengupta. 2004. *Development and Comparison of Approaches for Automated Mapping of Stream Channel Networks.* Annals of the Association of American Geographers 94(3):477-490
Alexander, R.B., E.W. Boyer, RA Smith, G.E. Schwartz, and RB. Moore, 2007. *The Role of Headwater Streams in Downstream Water Quality*. Journal of the American Water Resources Association 43, DOl: 10.1111Jj.1752-1688.2007.00005.x.
Bogan, M. T., K. S. Boersma, and D. A. Lytle. 2013. *Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. Freshwater Biology* 58:1016–1028
Colvin, S. A., Sullivan, S. M. P., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., ... & Danehy, R. J. 2018. *Headwater Streams and Wetlands Are Critical For Sustaining Fish, Fisheries, and Ecosystem Services*. *Fisheries* 44(2):73-91.
Cummins, K.W. and M.A. Wilzbach. 2005. *The Inadequacy of the Fish Bearing Criterion for Stream Management*. *Aquatic Sciences* 67(4):486 49
Del Rosario, R.B. and V.H. Resh. 2000. *Invertebrates in Intermittent and Perennial Streams: Is the Hyporheic Zone a Refuge from Drying? Journal of the North American Benthological Society*, Vol. 19, No. 4. p. 680-696.

hundreds of scientific publications ranging from studies on macroinvertebrates and fish to nutrient and sediment cycling indicate that even stream networks which are dry for most of their existence play a large collective role in maintaining and defining the physical, chemical and biological integrity of perennial waters. Although the citations listed in this document make up a fraction of the total scientific literature on this subject, they provide an overview of the science of temporary stream systems and their role in maintaining the integrity of downstream perennial waterbodies. These publications cite and refer collectively to hundreds of other ecological, chemical, biological and physical studies of intermittent and ephemeral streams and taken in conjunction provide strong evidence for the following facts:

- The measured extent of these systems are severely underestimated in common map surveys and GIS data.
- Upwards of 70-80% of stream network lengths have seasonal or precipitation dependent flow.
- Fish and macroinvertebrates utilize and depend on the exports from these systems for food/nutrients/carbon inputs.
- A wide diversity of macroinvertebrates inhabit these systems and are specifically adapted to the unique physical and chemical conditions.
- Multiple threatened and endangered species rely on these systems as predator and invasive species refuge and as seasonal spawning habitat.
- These systems are the conduit by which land uses impact downstream waterbodies.
- These stream networks provide runoff to regional aquifers which provide critical base flows to perennial streams.
- Intermittent and ephemeral system impairment, loss, unregulated fill or pollution would have considerable and long lived negative consequences for fisheries, ecosystem services and economies dependent on them.

Labbe, T. R. and K. D. Fausch. 2000. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales. *Ecological Applications* 10: 1774-1791.
Larned, S. T., Datry, T., Arscott, D. B. and Tockner, K. (2010), *Emerging Concepts in Temporary-River Ecology*. Freshwater Biology, 55: 717-738. doi:10.1111/j.1365-2427.2009.02322.x
Levick, L.R., Goodrich, D.C., Hernandez, M., Fonseca, J., Semmens, D.J., Stromberg, J.C., Tluczek, M., Leidy, R.A., Scianni, M., Guertin, D.P. and Kepner, W.G. 2008. *The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-Arid American Southwest*. US Environmental Protection Agency, Office of Research and Development; U.S. EPA. Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/475F, 2015.
Meyer, Judy L., David L. Strayer, J. Bruce Wallace, Sue L. Eggert, Gene S. Helfman, and Norman E. Leonard, 2007. *The Contribution of Headwater Streams to Biodiversity in River Networks*. *Journal of the American Water Resources Association* (JAWRA) 43(1):86-103.
Williams, D. D. 2006. *The Biology of Temporary Waters*. Oxford University Press, Oxford, UK.

For instance, these waters are critical to downstream water quality. They regulate the supply of nutrients and sediments to downstream waters (Meyer et al. 2007), improving water quality (Alexander et al. 2007), and providing a source of food for downstream species occupying perennial waters. (Cummins and Wilzbach 2005). These waters provide an important point of nutrient uptake and removal that reduces nutrient loads to perennial downstream waters and associated aquatic communities. Degradation of these headwater streams would impair their function and alter delivery of macroinvertebrates, organic matter, and nutrients to downstream waters, often in other states, and for this reason they should be federally protected. For example, controlled experiments and field observations have shown that even small increases in nutrients can have dramatic effects on the aquatic community, and the macroinvertebrate community in particular. The conceptual model (Figure 2) shows how nutrient additions affect all aspects of the stream ecosystem.

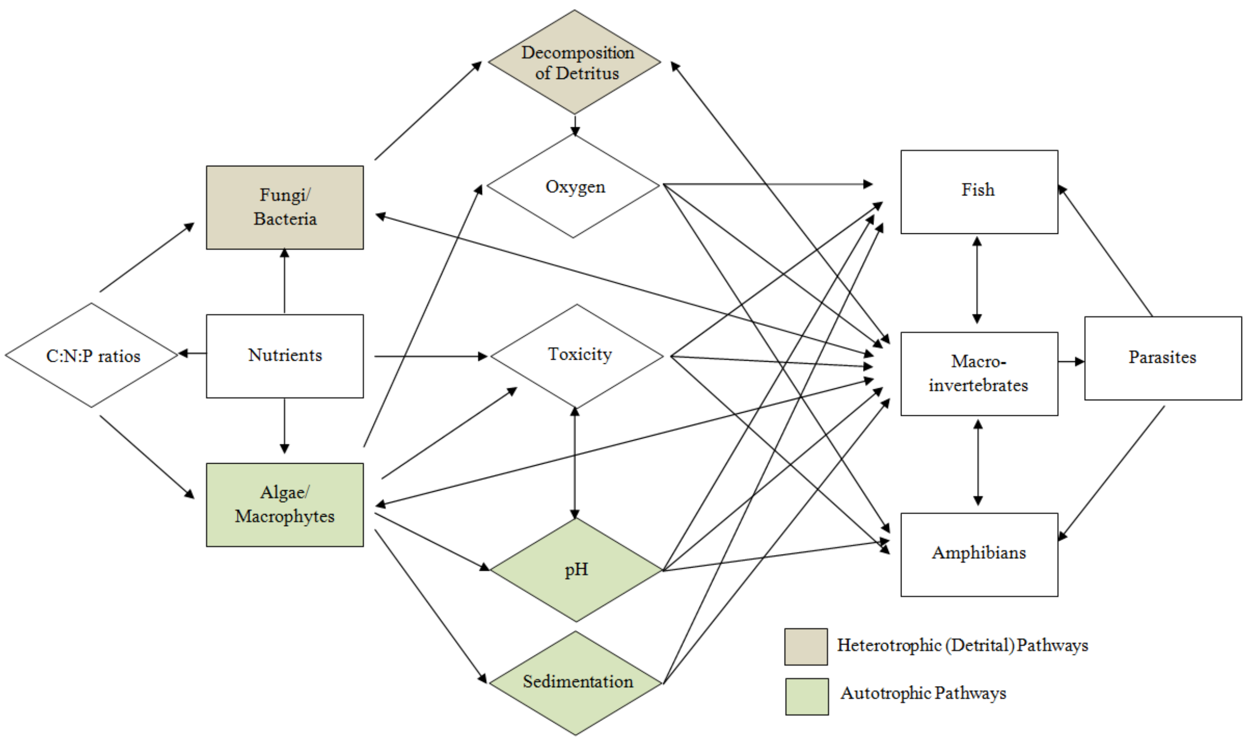

Figure 2. Conceptual model of nutrient effects in stream ecosystems.

Finally, the “Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence’’ (“Connectivity Report”), and review of the report by EPA’s Science Advisory Board (SAB Review) concluded that tributary streams, and wetlands and open waters in floodplains and riparian areas, are connected to and strongly affect the water quality of downstream traditional navigable waters, interstate waters, and the territorial seas. 80 Fed. Reg. 37,057.