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Re: Methods and considerations for streamflow augmentation

Uma,

This review of scientific literature highlights the significance of hyporheic zone groundwater connections and their role in maintaining the sustainability and health of stream ecosystems. This review was compiled with respect to the question about options to “augment” streamflows in Little Rock Creek. The Department of Natural Resources (DNR) has concluded that direct pipe discharge into Little Rock Creek would bypass these important connections and therefore does not satisfy statutory requirements for protecting ecosystems as a means of complying with the required sustainable diversion limits as established in the Commissioners' Order dated 22 April 2024.

Review of the Ecological Benefits of the Hyporheic Zone and Groundwater Connections with the Stream Surface

Groundwater and surface water interactions play a crucial role in maintaining the health of stream ecosystems. These connections occur through the riparian and hyporheic zones (i.e., the sediments under and adjacent to the channel), which influence the biological, physical, and chemical characteristics of streams.

Issue

- The authorized level of water use is having a negative impact on the Little Rock Creek stream ecosystem as determined by the degradation of aquatic habitat.

- As a means of addressing the degraded aquatic habitat, one preliminary solution offered is to substitute baseflow entering the stream through the riparian and streambed connections with discharge of water directly into the stream channel.
- This solution may address the lost hydraulic habitat in the active stream channel but does not address the lost stream functions provided by groundwater flow through the hyporheic and riparian zones or lost unique habitat created by groundwater flow paths.
- Groundwater is often thermally and chemically distinct and the flow paths through the riparian and hyporheic zones and into the stream channel provide unique ecosystem functions (e.g., denitrification, habitat, and organic matter breakdown) and is therefore considered non-substitutable with surface water (Gleeson and Richter 2018) or with direct discharge of water into the stream channel.

Context

- The impact of streamflow depletion is assessed by quantifying the change in fish habitat before and after streamflow depletion. Fish are reliable indicators of ecological status, as they occupy diverse ecological niches and have well-documented life history traits (Ibanez et al. 2010). However, while habitat quantification measures ecological change, it is only one ecological component of stream ecology.
- The stream ecosystem is an open system, encompassing (1) the active channel, (2) the floodplain, and (3) the subsurface hyporheic zone (Harvey and Gooseff 2015; Wohl et al. 2024). Rather than acting as an isolated conduit, the stream interacts with multiple surface water and groundwater flow paths that move into and out of the channel (Bencala et al. 2011). These complex exchanges influence water quality, nutrient dynamics, habitat availability, and overall ecosystem health, highlighting the importance of considering both surface and subsurface hydrological processes in stream management.
- The hyporheic zone (HZ) includes the saturated sediments below and adjacent to a stream where surface water and groundwater mix (Boulton et al. 2010; Marmonier et al. 2012).
- The negative impact in Little Rock Creek stems from groundwater pumping, which captures water before it can flow through the riparian and hyporheic zones to contribute to baseflow.
- The flow of groundwater through the soil and sediments of the hyporheic and riparian zones is essential for maintaining critical ecological functions in streams. These functions include denitrification, breakdown of organic carbon, and providing refuge and habitat benefiting stream ecosystems.

The importance of the Hyporheic Zone, Riparian Area, and Groundwater Connectivity

Hyporheic Zone and Groundwater

Recognition of the critical functions occurring within the hyporheic zone (HZ) has been highlighted in substantial reviews over the past few decades (Stanford and Ward 1993; Brunke and Gosner 1997; Boulton et al. 1998). However, discussions on the management and restoration of HZ have emerged more recently, within the last 15 years (Hester and Gooseff 2011).

The chemical and physical characteristics in HZ create essential conditions for (1) biogeochemical processes (e.g., denitrification) and nutrient supply (e.g., organic carbon, nitrates), (2) unique habitats and biological diversity (e.g., anoxic conditions for microbial biofilms, fish egg and larval development), and (3) refuge for surface water organisms (e.g., moderated temperature and ice-free conditions). These functions, which drive stream food productivity and ecosystem resilience, occur strictly due to the gradual mixing of surface water and groundwater within the HZ (Williams and Hynes 1974; Hayashi and Rosenberry 2002; Wagner et al. 2014; Dole-Olivier et al. 2022).

The upper part of the HZ contains a mixture of oxygenated surface water and anoxic groundwater, creating a thermally stable environment. The lower HZ contains mainly upwelling anoxic groundwater, supporting microbial processes vital to nutrient cycling and detoxification of chemicals. The effectiveness of biogeochemical processes in the HZ relies on several groundwater characteristics:

- Consistent moderate temperatures,
- Anoxic or low-oxygen concentration,
- Injection of dissolved organic carbon,
- Presence of nitrates,
- Slow movement of water through the porous sediments, which facilitates nutrient conversion and microbial activity.

Additionally, the upper HZ provides habitat for many aquatic species, including those that migrate vertically from the streambed surface into the HZ and others that reside solely in the HZ, serving as a crucial link in the stream ecosystem food web.

Key stream ecosystem benefits unique to areas of upwelling groundwater into HZ are highlighted below.

Biogeochemical Inputs and Processes

- Denitrification (Nitrogen Cycle):
    - Denitrification occurs predominately in the anerobic conditions of upwelling groundwater by microbes within biofilms in the lower HZ (Hendricks 1993; Boulton et al. 1998; Birgand et al. 2007; Harvey et al. 2013).
- Ammonification (Nitrogen Cycle):
    - Ammonification, the breakdown of organic nitrogen by microbes, requires anerobic conditions provided by upwelling groundwater (Hendricks 1993; Boulton et al. 1998).
- Nutrient Enrichment and Productivity:
    - Upwelling nutrient rich groundwater is considered a hotspot of primary productivity and microbial activity (Boulton and Hancock 2006; Boulton et al. 2010).
    - The groundwater is an important source of dissolved organic carbon which fuels stream metabolism (Boulton et al. 2010; Wagner et al. 2014).
    - Upwelling zones have higher algal biomass and nitrates and as a result algal biomass recovers more quickly from floods (Wondzell 2011).

- Breakdown of Organic Matter:
    - Biodegradation of organic material, including sulfate reduction, is an anerobic process carried out by microbes in the HZ making the nutrients available for other organisms (Hendricks 1993; Jones and Holmes 1996).
- Mitigation of pollutants by biofilms:
    - Microbial communities break down various contaminants including trace organic compounds (Lewandowski et al. 2019; Majeed et al. 2024) and toluene (Hester and Gooseff 2013).

Biological/Habitat

- Upwelling groundwater sites are recognized as hotspots of invertebrate species diversity (Stanford and Ward 1993; Edwards 1998; Merill and Tonjes 2014; Dole-Olivier 2022).
- The oxygenated upper HZ sediments provide conditions for developing salmonid fish eggs and larvae (Boulton and Hancock 2006; Brunke and Gonser 1997; Cardenas et al. 2016; Hancock 2002).
- HZ invertebrates feed on biofilms that use upwelling dissolved organic carbon and downwelling particulate organic carbon, therefore, contributing significantly to the stream food web (Marmonier et al. 2012).
- Some mussel species rely on upwelling groundwater (Rosenberry et al. 2016).
- Some invertebrate species only reside in areas of upwelling groundwater and are referred to as stygofauna (Boulton and Hancock 2006).
- Uncoupling the stream with the groundwater can result in blocking hyporheic interstitial spaces with fine sediment reducing habitat quality (Boulton and Hancock 2006).

Refuge - Stable Temperature and Hydrology

- The stable temperature and hydrology in the HZ provide refuge for many small stream dwelling species (Hayashi and Rosenberry 2002; Merill and Tonjes 2014).
- Groundwater inflow provides fish such as benthic darters, redhorse species, and smallmouth bass overwinter habitat free of anchor ice and refuge from high temperatures (Peterson and Rabeni 1996; Power et al. 1999; Schaefer et al. 2003).

Riparian Zone and Groundwater

In addition to groundwater flow through the HZ, groundwater flow through the riparian area is critical for:

- Vegetation growth and diversity (Hayashi and Rosenberry 2002; Jannson et al. 2007; Wang et al. 2017),
- Nutrient processing such as nitrate removal through the denitrification process (Maitre et al. 2003).

River ecosystems greatly benefit from intact riparian areas, which perform several essential functions including stream bank stabilization, pollutant and sediment buffering, hydrologic storage, temperature regulation and providing food to stream biota (Odum 1979; Naiman and Decamps 1997; Pusey and Arthington 2003; Singh et al. 2021).

Conclusion

The hyporheic zone and upwelling groundwater are critically important to the health of streams and rivers. Upwelling groundwater does more than simply provide cold water from the aquifer; it plays a central role in maintaining biological diversity, enhancing stream productivity, and improving water quality. The ecosystem functions that occur within the groundwater flow paths cannot be replicated by direct discharge of surface water or groundwater into the stream. Restoration or maintenance of stream geomorphic complexity and hydrologic connectivity (vertically with the HZ-groundwater and laterally with the riparian zone) is a recognized practice to enhance denitrification thereby lowering the concentration of nitrates in the water (Kaushal et al. 2008; Newcomer Johnson et al. 2016).

To achieve sustainable streamflow diversion, alternatives to bypassing the groundwater flow paths include:

- reducing groundwater pumping within the zone of influence,
- moving some groundwater pumping locations further away from the stream to delay the timing of the streamflow depletion,
- and managed aquifer recharge.

Managed aquifer recharge has been used to maintain summer baseflow using groundwater flow paths (Ronayne et al. 2017; Van Kirk et al. 2020)

Sincerely,

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