HYPORHEIC EXCHANGE AS PART OF STREAM RESTORATION IN FLORIDA

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INTRODUCTION

Hyporheic exchange is the interaction between surface water and groundwater at the bottom and sides of a stream channel. This interaction takes place in the channel substrates below and beside the stream as surface water flows through soils and interacts with groundwater. These surface/groundwater interactions take place in areas known as hyporheic zones (Figure 1). This interaction between ground and surface water is important for multiple reasons. Hyporheic exchange alters water quality in several ways such as increasing solute residence times, increasing solute contact with substrates, and causing interaction of nutrients and toxins with gradients in dissolved oxygen and pH levels. They also support microorganism and invertebrate communities which can improve water quality and can also provide habitat and spawning grounds for fish.

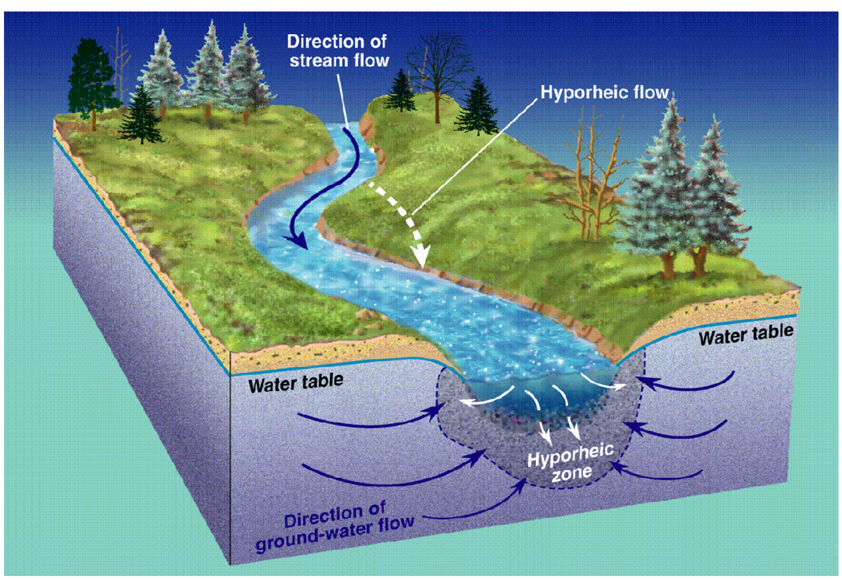

Figure 1. Conceptual diagram of hyporheic environments (Buss et al., 2009; modified from the USGS).

BENEFITS OF HYPORHEIC EXCHANGE IN STREAM RESTORATION

The following table further outlines some benefits of incorporating hyporheic exchange in stream restoration, which are then discussed in greater detail in the next section.

Table 1

Benefit	Description
Improve Nutrient Processing[1]	Abiotic and biotic chemical transformations of nutrients due to greater surface area capture/transformation by substrate material benefits water quality through increased nutrient processing.
Reduce Toxin Concentrations[1]	Presence of aerobic and/or anaerobic conditions, as well as greater carbon availability allow greater toxin capture/transformation of hydrocarbons, metals, and other harmful chemical species.
Buffer Surface Water Temperatures[1]	Increased mixing of surface and groundwater, promoting a more consistent surface water temperature. This in turn can improve habitat quality.
Improved Aquatic Habitat[1]	From microbes to fish, less impaired water and stable water temperatures provide improved wildlife habitat, which has far reaching effects on both the aquatic and terrestrial environment.
Increase Dissolved Oxygen Concentrations [1, 2]	A common measure of water quality, other hyporheic exchange restoration efforts have the added impact of increasing DO. Again, this improves aquatic habitat quality, and in turn terrestrial habitats.
Improved Riparian Habitat[2]	Reduced fine sediment loading while improving bank stability, vegetative cover, and habitat quality. This has positive impacts both for water quality and the wider watershed area.
Flood Attenuation[2]	Increased floodwater storage and residency time through increased channel planform complexity, addition of bordering wetlands. This provides a valuable ecosystem service.
Reduce fine sediment loading[2]	Reduces infilling of interstitial spaces in stream substrates and decreases fine organic material which can in some cases, which can decrease Sediment Oxygen Demand.

[1] Hester & Gooseff (2011)
[2] Buss et al. (2009)

Nutrients – Due to the unique biogeochemical conditions found within them, hyporheic zones benefit stream systems through increased nutrient processing (Hester et al., 2011). This is a result of the high interstitial surface area, increased available labile carbon, and slower flow velocities (Hester et al., 2011). The outcome of these conditions is an increase in biotic and abiotic chemical activity compared to surface and groundwater. In the case of nitrogen, this increased chemical processing in aerobic zones of hyporheic exchange can benefit in ways such as ammonification and nitrification. In hyporheic zones with dominant anaerobic conditions, we can see denitrification, as well as these zones acting as nitrogen sinks. However, there is research which shows that nitrogen rich streams store more nitrate in surface waters than in the hyporheic zone, despite high rates of denitrification in shallow streambed substrates. While the denitrification rate within these shallow sediments is high, greater exchange between the water column and the hyporheic zone is required to increase hyporheic nitrate retention (Storey et al., 2004).

There is also the potential for phosphorus capture in hyporheic zones through abiotic sorption to oxides and bacterial metabolization. Where phosphorus is frequently a limiting nutrient/reactant in stream systems, this is an important interaction to research further. Human activities such as channel alteration or sediment loading, such as we see with agriculture, impair this ability to capture nutrients through reduced substrate surface area, reduced carbon substrates for reaction sites, and nutrient subsidies from anthropogenic activities (Hester et al., 2011).

Toxins – Like nutrients, different toxins can undergo sorption or degradation depending on whether aerobic or anaerobic conditions are found and the availability of carbon substrate. Where aerobic conditions are present, aromatic hydrocarbons and phenols may be mineralized. When given enough organic carbon in anaerobic hyporheic zones, chlorinated solvents, fuel oxygenates, and organic pollutants may be metabolized or sequestered. Redoximorphic conditions can lead to precipitation or sorption of metals. These conditions can exist along varying gradients, improving water quality for both surface water and groundwater entering the hyporheic zone and stream system (Hester et al., 2011).

Temperature – Groundwater temperature remains relatively constant year-round, while surface water temperatures fluctuate with seasons and rainfall events. The hyporheic zone acts as a heat exchanger between surface and groundwater to buffer these heat fluctuations in surface water at reach and basin scales. This stabilizing effect on surface waters can improve habitat conditions for macroinvertebrates and fish in the water column and the benthic zone and can also mitigate the growth of cyanobacteria (Savadova et al., 2018).

Aquatic/Benthic Habitat – The benthic and hyporheic zone are habitat for a wide variety of organisms. Macroinvertebrates are key residents of this zone, with some inhabiting the hyporheic zone for their entire life cycle, while others depend on it for certain stages of development. Where some of these species are also residents of the terrestrial, both environments benefit. For example, some species such as Mayflies and Caddisflies spend their larval stages on or in the benthic layer, while emerging to spend adulthood in the terrestrial environment, supporting food webs of vertebrates in both. Many fish species lay eggs in the substrates of rivers and are highly susceptible to sediment load, water temperature, and water quality issues such as eutrophication. So, improving hyporheic exchange can have far reaching impacts along stream systems and beyond that are of clear economic importance.

Dissolved Oxygen – Through direct impacts like water oxygenation through increased turbulence, or as a function of improving water quality through nutrient capture, temperature management, and improved benthic habitat, increased levels of dissolved oxygen are an easily measured benefit of increased hyporheic exchange. Increased dissolved oxygen in upstream reaches can promote increased hyporheic exchange in sediment layers downstream through increased oxygenation of the benthic zone resulting in increased aerobic microbial processing (Buss et al., 2009).

Terrestrial Habitat – Efforts along the riparian zone and beyond offer several benefits through increased hyporheic exchange directly within stream banks and indirectly such as reduced sediment loading. Simply restoring or improving vegetative cover along the riparian zone both reduces fine sediment loading which can impact stream substrates, and by providing carbon sources for reaction and capture of nutrients and toxins. Root systems can also sequester excess nutrients and toxins and fallen trees can provide both hydraulic gradients and habitat in stream. Policy based efforts such as educating agricultural stake holders on the impacts of over fertilization and sediment control can also impact hyporheic exchange through reduced sediment load and reduced nutrient load (Buss et al., 2009).

Flood Attenuation – Hyporheic exchange improvements such as restoring/increasing flood plains and bordering vegetated wetlands, increased stream sinuosity, adding stream channels, and in channel features such as step logs all serve to slow the peak discharge from storm events (Buss et al., 2009). This benefits not just water quality but has an obvious economic benefit to the communities around and downstream of restoration efforts.

Reduce Fine Sediments – Reducing fine sediment loads through various restoration techniques both in stream and on land improves water quality for both human use and as habitat. Reducing fine sediment loading also has positive feedback on hyporheic exchange at the basin scale as high sediment loads lead to infilling of interstitial pore space in stream substrates, blocking the flow of surface water into the hyporheic zone (Buss et al., 2009).

APPLICATIONS IN FLORIDA

Florida's hydrology is primarily influenced by its marine geological history and topography. For most of its recent geological history, carbonate marine sediments built up over millions of years to create the karst limestone "basement" of the Florida plateau. Other marine deposits of sand and gravel were deposited on top of the karst formations later in the states' geological development. This has led to the most common river substrates in the state being sand, gravel, and limestone. These karst formations now hold vast aquifers which feed many Florida streams and rivers through springs. These karst formations and aquifers can present challenges when trying to incorporate hyporheic exchange into stream restoration plans. In some parts of the state, rivers can disappear into underground karst formations through sinks, re-emerging closer to the coast. In other areas, karst conduits containing sand and gravel provide surface water the means of entering groundwater systems. Depending on the level of water quality impairment and the level of aquifer use, this could either see long term "filtering" of water, or risk spreading water quality issues to new areas and users, depending on seasonal flow (Wu et al., 2013).

Most of Florida's natural rivers and streams have relatively small gradients, creating slow, meandering waterways with low stream velocities and slow discharge rates. Many of Florida's rivers are also subject to tidal flows near the coast, which further reduces discharge rates and can also experience tidal backflow.

Despite the challenges of working with the unique nature of Florida's rivers and streams, there are methods of inducing and improving hyporheic exchange that should provide the benefits and avoid the risk of directing impaired surface water into aquifers. The low energy, meandering nature of the state's streams becomes beneficial for inducing hyporheic exchange in riparian zones.

The low energy nature of Florida's streams has meant that most of them are unaltered, with some notable exceptions like the Kissimmee River, which was straightened to facilitate drainage. Low energy meandering is a benefit for hyporheic exchange in riparian sediments. By focusing efforts on fostering/increasing hyporheic exchange in the riparian zone and terrestrial environment, including policy initiatives, it should be possible to foster or improve hyporheic exchange while maintaining surface water flow. These efforts could also provide additional benefits such as flood attenuation.

Other in-channel methods that do not greatly alter hydraulic gradient between surface and groundwater are still viable, such as substrate coarsening and increasing organic substrate availability.

Due to its impact at large scales, reducing fine sediment loading is key to hyporheic restoration. Reducing fine sediment loading can be achieved in several ways, including revegetating riparian zones and policy changes such as creating/legislating riverfront buffer zones to manage sediment generating activities. The following table provides some restorations techniques as they might be applied in Florida and some possible challenges.

Table 2

Approach	Description	Benefits	Challenges
Increase Stream planform complexity	Increasing the channel bank surface area and/or permeability along the sides of the channel available for hyporheic exchange to take place	Creates hyporheic exchange in riparian areas such as meanders and point bars, without forcing surface water into channel bottom highly permeable substrates and ground water. Sequestration of excess nutrients and toxins in sediments and vegetation.	Potentially cost prohibitive if done at a large scale. Land may be in anthropogenic use, requires landowner cooperation.
Riparian zone restoration	Restoring/enhancing riparian zone functions such as increasing native vegetation	Reduce fine sediment loading, increase available particulate organic carbon in stream substrate. Sequestration of excess	Land may be in anthropogenic use, landowner cooperation.

		nutrients and toxins in sediments and vegetation. Secondary benefit of providing habitat and increased terrestrial biodiversity.	
Large woody/organic debris	Placement of logs parallel to current direction, and other sources of carbon such as woven mats in streams or on channel sides and bottom	Increase organic carbon availability, provide habitat for vertebrates/invertebrates	Ensuring placement so as not to create hydraulic head in stream flow
Creation/restoration of bordering vegetated wetlands	Restoring impacted wetland function or creating new wetlands along stream channels	Creates areas where surface water interacts with hyporheic zone in a low energy environment. Secondary benefit of flood attenuation.	Land may be in anthropogenic use, landowner cooperation.

There is overlap between the techniques, as well as their benefits and challenges that highlights an interconnection between various stream functions and their restoration. Increasing stream planform complexity can involve returning a straightened stream to a more natural meandering condition, increasing stream channel braiding, or increasing the flood plain width. These in turn increase not only the permeable sediments available for hyporheic exchange, but also the available riparian zone. This in turn reduces fine sediment loading, the benefits of which loop back to increased hyporheic exchange in stream banks. These efforts need not be complex. In the case of riparian habitat in urban and semi urban areas, this could be as simple as a no mow policy for grass banks.

FLORIDA POLICY

Florida has not yet introduced any formal legislative standards for hyporheic exchange, either stand alone or as part of a wider effort. Adding some best management practices for inducing hyporheic exchange in our waterways, especially those that were historically straightened, are subject to sediment loading, or have had their riparian zones reduced through agriculture and urbanization could provide an important additional tool without greatly increasing cost. Further research will most likely be required to come up with effective strategies of stream restoration that create the desired effect. The ongoing efforts at restoration along the Kissimmee River give an opportunity to do just that, as meanders of varying size and channel width are options during the reconstruction/restoration.

With the unique nature of Florida's rivers, this may be best done by creating guidance for hyporheic exchange specific to the state, or at a local level by allowing the state's water management districts to develop their own best management practices and restoration techniques to encourage hyporheic exchange. By focusing on local efforts, rather than approaching the issue from a Federal or state level, it may be easier to engage managers, landowners, and stakeholders to create "made in Florida" solutions. We can see from the challenges column of table 2 that getting support from landowners and other stakeholders will be key in the success of any wider attempts at incorporating hyporheic exchange into Florida stream restoration policy.

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