The missing link in Hydrologic Connectivity

Reconnecting riverine habitats, biodiversity, nutrient cycles, solute transport and temperature regulation through restoring hyporheic exchange

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Ecosystem Restoration webinar
27 September 2016

US Army Corps of Engineers
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Webinar Outline

- Review guiding ecosystem restoration policy and definition of significance and connectivity
- Define and describe the drivers, functions and ecological importance of "*hyporheic zones*"
- Discuss restoration methods to maximize ecosystem functions and services by incorporating "*hyporheic exchange*" into our concepts of riverine biodiversity and habitat connectivity

What is guiding our focus and evaluation of hydrologic connectivity?

- Annual Engineering Circular (EC) for Civil Works Direct Program Budget Development
- "Budget EC" guidance for Environment business line includes aquatic ecosystem restoration (ENR)
- Seven Performance Components that indicate "significance" of resources being restored

Hydrologic Connectivity and Significance

- *Habitat Scarcity, Connectivity, Special Status Species, Plan Recognition,* Hydrologic Character, Geomorphic Condition and Self-Sustaining
- National Significance requires top scores in Scarcity and Connectivity, with at least second scores in Species and Plan Recognition
- Regional Significance requires at least second scores in all four criteria

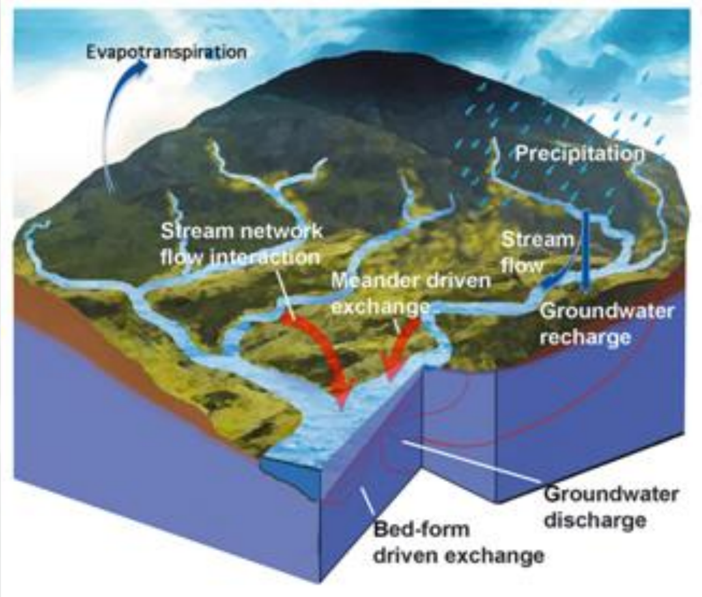
Defining and scoring Connectivity as a component of significance

- Facilitate movement of native organisms between and within critical habitat areas,
- *Or*, add "a critical component to an ecosystem and contribute to increased biodiversity."
- Scoring focuses on restoring physical habitat connection or a network of habitats connected by "travel habitat"

How are we applying these definitions conceptually to riverine ecosystems?

"Hydrologic connectivity is used here in an ecological sense to refer to water-mediated transfer of matter, energy, and/or organisms within or between elements of the hydrologic cycle." Pringle (2001)

Figure right, Boano et al. (2014)



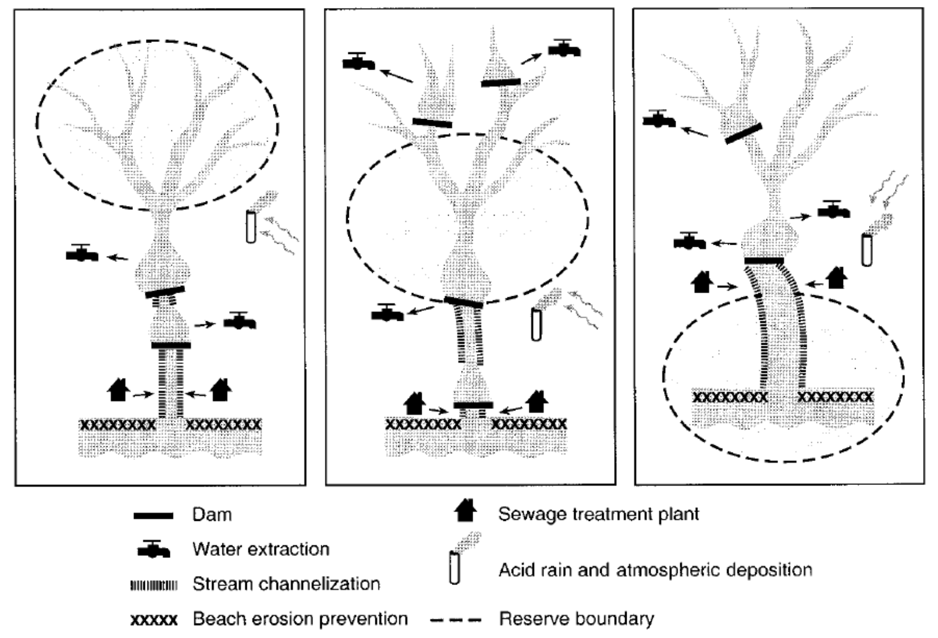
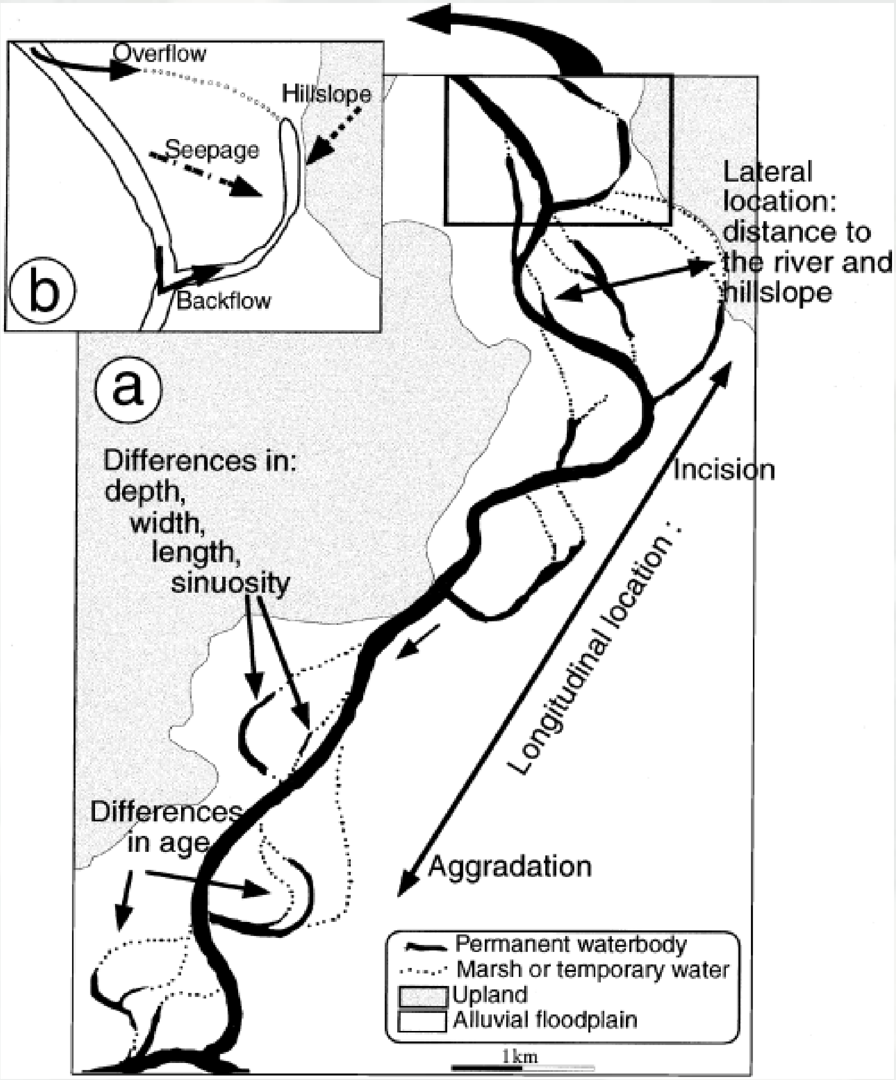


Figure right, Pringle (2001)

Broad conceptual definitions of connectivity in riverine ecosystems

Figure below, Amoros & Bornette (2002)

- surface water connectivity for riparian/terrestrial, water column, benthic aquatic species
- lateral (floodplain access), longitudinal (classic upstream/downstream river corridor migration), vertical (nutrients, oxygen, sediments, organisms or genetic material), temporal
- Site, reach, watershed, regional scales



How are we applying this concept practically?

- Increasing primary productivity or biodiversity depends on reconnecting physical ecosystem components within the river corridor – *primarily lateral and longitudinal*
- Partitioning/allocating surface water to create interconnected or proximal patch habitats for critical life stage development, (e.g., environmental flows, minimum flows, flushing flows) – *primarily lateral and longitudinal*

Physical or hydrological changes we make to explicitly influence connectivity

- Restoring networks of riparian corridors for migratory birds or other terrestrial species – *primarily longitudinal, can be lateral*
- Removing dams, weirs or grade control structures to restore flow-based corridors for animals, nutrients, substrate or genetic materials– *primarily longitudinal, can have vertical impacts*
- Removing or setting levees back to reconnect floodplains, benefitting riparian animals and vegetation – *primarily lateral, can be longitudinal, has vertical impacts in wetted areas*
- Constructing high flow or backwater channels to create connections to rearing, spawning or other habitat for aquatic or amphibious animals, or vegetation – *primarily lateral, can have longitudinal and vertical impacts*

Do we account for vertical connectivity explicitly?

- Lowering or terracing floodplain elevations to bring phreatophytes or hydrophytes in range of survival water table or vadose zone elevations
- Creation or enhancement of riparian wetlands
- Reconnecting groundwater sources in riparian or instream areas to create temperature refugia
- Replacing or enhancing instream substrate to maximize fish egg survival in spawning sites or redds
- Use of instream or floodplain structures to direct flows to increase groundwater recharge or subsurface flows

Examples from the Middle Rio Grande, NM

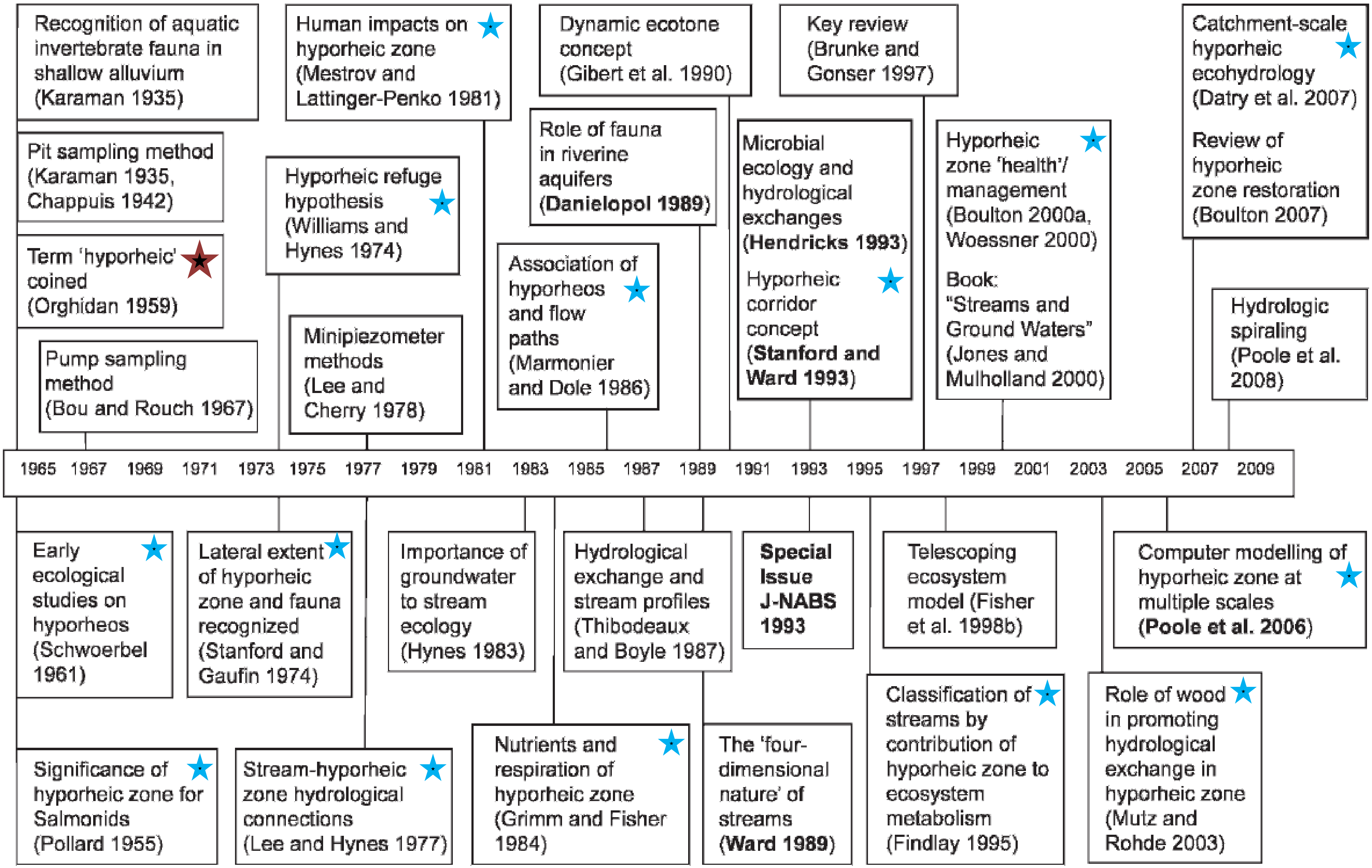
Examples from the Middle Rio Grande, NM

Can we refine our concept of riverine connectivity?

- A unit of river study beyond bed, banks, floodplain and riparian areas that better integrates longitudinal, lateral, vertical and temporal aspects (Kondolf, et al., 2006)
- Harvey and Gooseff (2015) define river corridor as the meaningful hydrologic unit "*that integrates downstream transport with lateral and vertical exchange across interfaces*"
- They define the river corridor hydrologic cycle with the term ***"hydrologic exchange flows"*** where *"lateral and vertical exchanges of water, materials, and energy between rivers and their surrounding marginal surface and subsurface waters."*

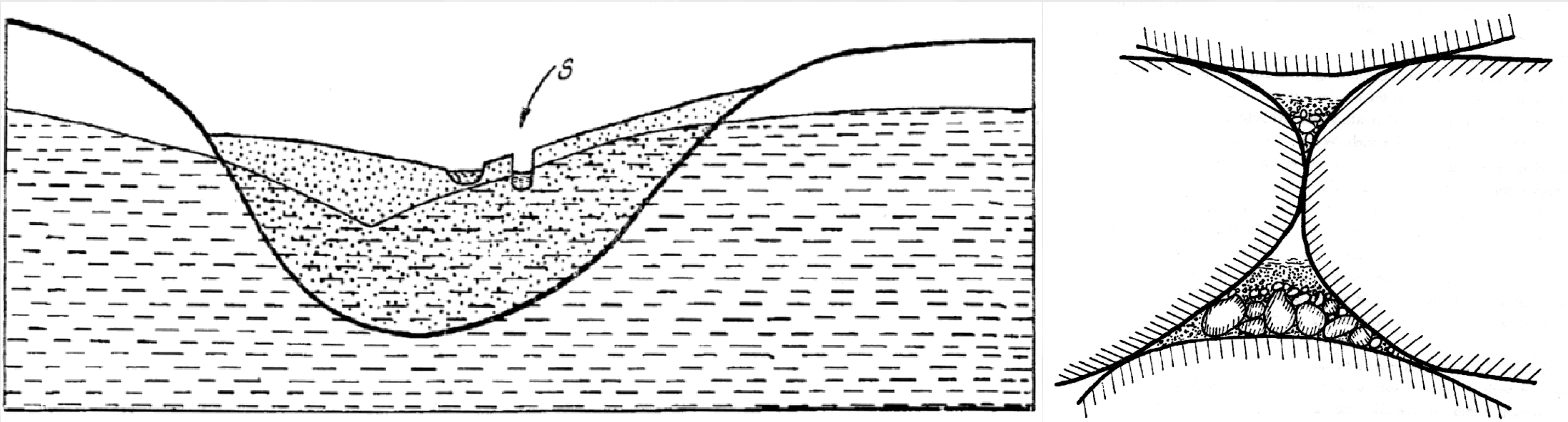
A brief history of surface/groundwater functional research

Table from Boulton et al., 2010



Marginal subsurface waters: the Hyporheic Zone

- First defined and described in the 1950's by Romanian Hydrobiologist, Traian Orghidan
- *"This [hyporheic] biotope is formed by the water-saturated interstices of riverbed deposits."* (Kaeser, 2010, English translation of Orghidan, 1959)



Figures above, Orghidan 1959. Left, valley cross section showing hyporheic sampling pit at *S*. Right, hypothetical profile through two interstitial pore chambers

Defining the Hyporheic Zone and how it works

Among the components and functions of the hyporheic zone (HZ) Orghidan (1959) described:

- The "hyporheic biotope" is an *ecotone*, a combination of surface water (SW), groundwater (GW) and the area between the two sources.
- Organisms move between SW, GW and HZ, showing connectivity between these three ecosystem units.
- There is great heterogeneity in HZ in space and time.
- Fauna community densities and composition are related to detritus and bacteria abundance.

What is Hyporheic Exchange?

- *Hyporheic exchange* is water-mediated exchange in the HZ
- >10% surface water content to meet the HZ definition

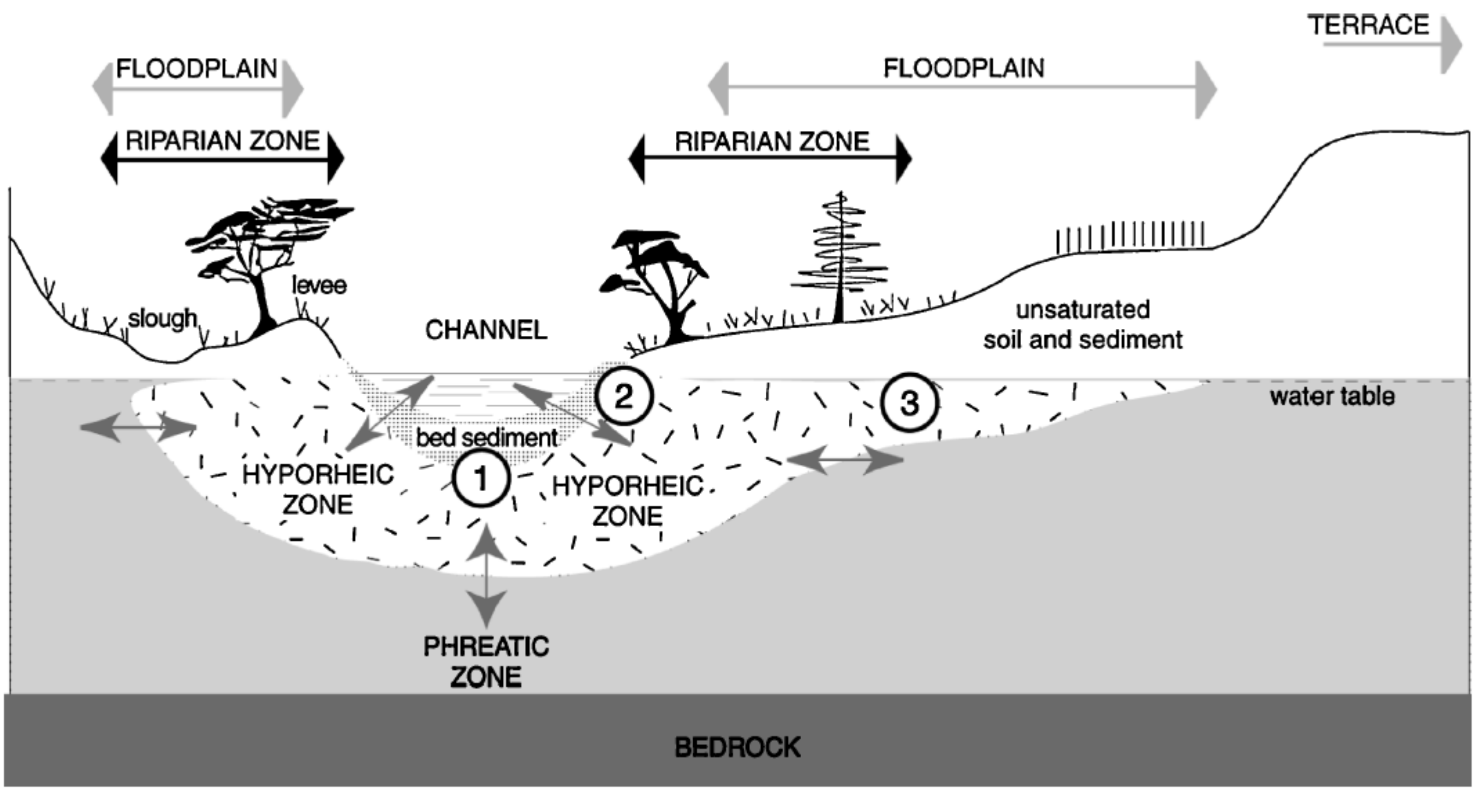


Figure 1. Schematic diagram of the vertical and lateral structure of a channel–floodplain–aquifer system. (1) Wetted channel hyporheic, (2) parafluvial hyporheic and (3) floodplain hyporheic according to Naiman *et al.* (2000) (modified from Ward, 1998)

(Figure above, Steiger et al. 2005)

How does Hyporheic Exchange work?

- At its simplest hydrodynamic definition, *"hyporehic flow is the transport of surface water through sediments in flow paths that return to surface water,"* (Boano et al., 2014).
- Inherent in this definition is the concept of the *"bidirectional exchange of water between the channel and alluvial aquifer"* Poole et al (2008).
- Downwelling = hyporheic recharge
- Upwelling = hyporheic discharge

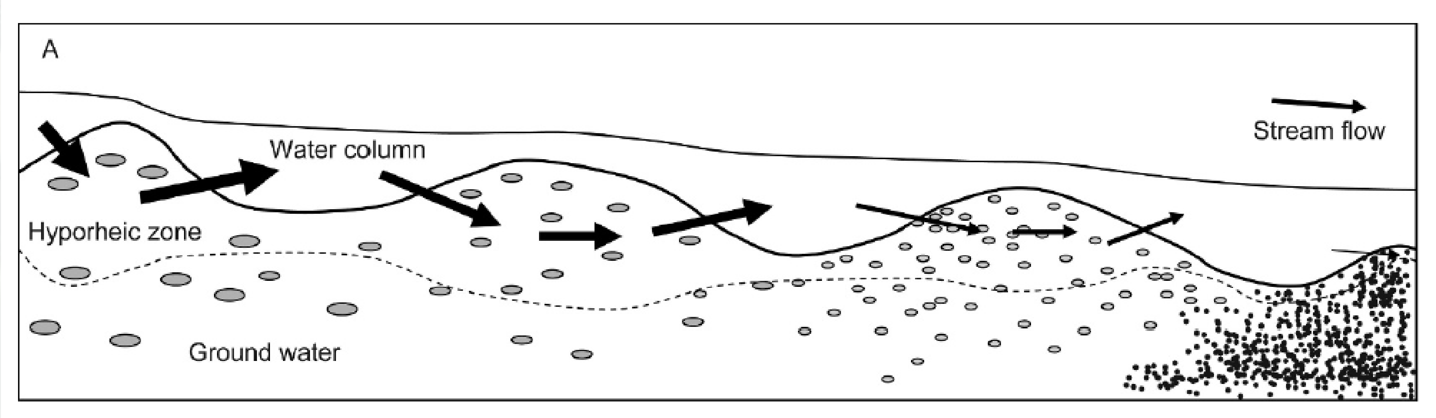


Figure excerpt, Boulton et al., (2010)

What drives hyporheic flow and functions?

- Ecosystem drivers as large scale processes or components (e.g., climate, land use, geology)
- Landscape scale drivers (interdependent)
  - Subsurface heterogeneity (e.g., glacial/fluvial deposits, floodplain morphology, geology)
  - Sediment characteristics (e.g., permeability, hydraulic conductivity, porosity)
  - River morphology (e.g., planform, bedform topography)
  - Hydraulic/hydrologic characteristics (e.g., head gradient, velocity, flood frequency)
  - Bioturbation (e.g., burrowing, nutrient and chemical processing, impoundments)

Subsurface heterogeneity

- Large interstitial pathways can develop by layering of fluvial deposits, glacial deposits, paleochannels, floodplain morphology and surficial land form
- Creates preferred flow paths that can expand or extend hyporheic path lengths and residence time laterally, vertically and longitudinally

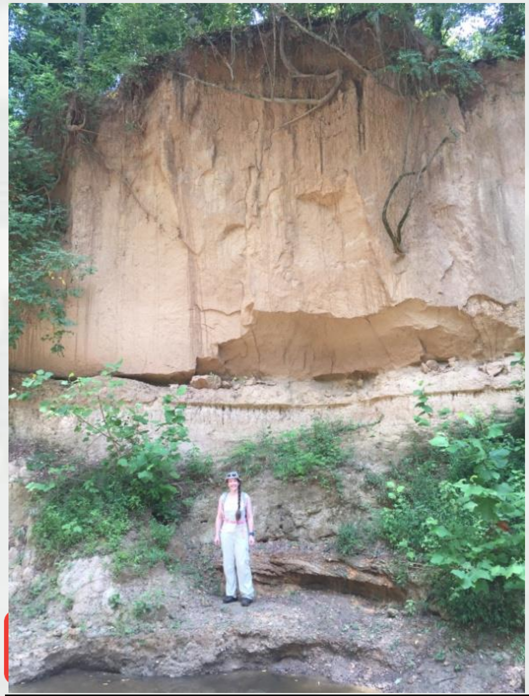
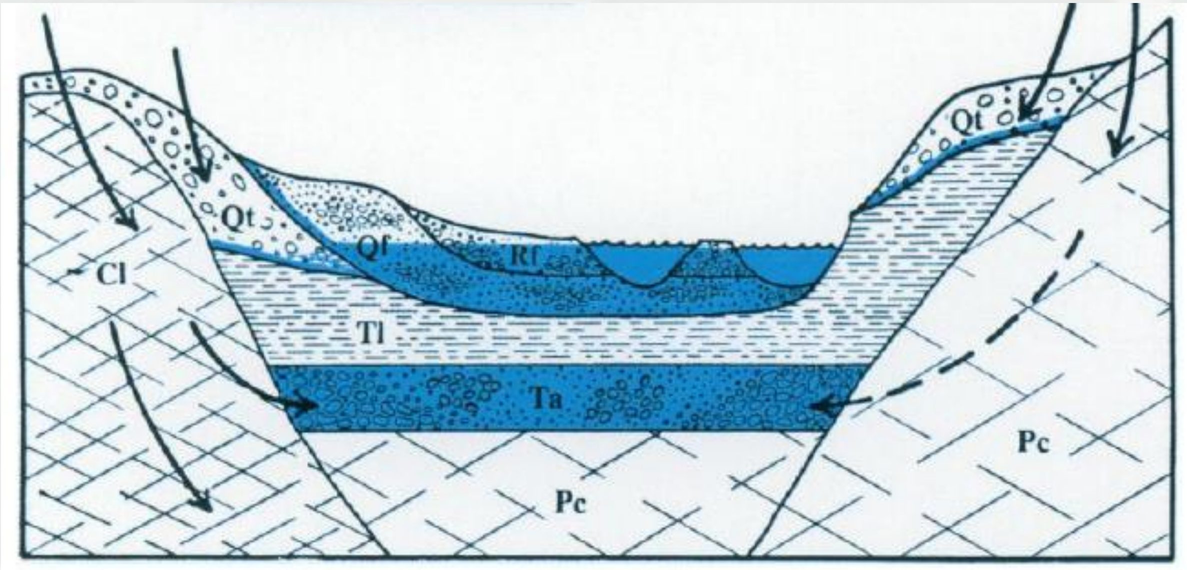


Figure right, Little Sand Creek, MS

Figure excerpt below, Orghidan (1959)



Subsurface heterogeneity

Malard et al. (2002) show variations in cross-sectional relationships between channel, ground, and hyporheic waters (figure right). Arrows indicate dominant flow direction.

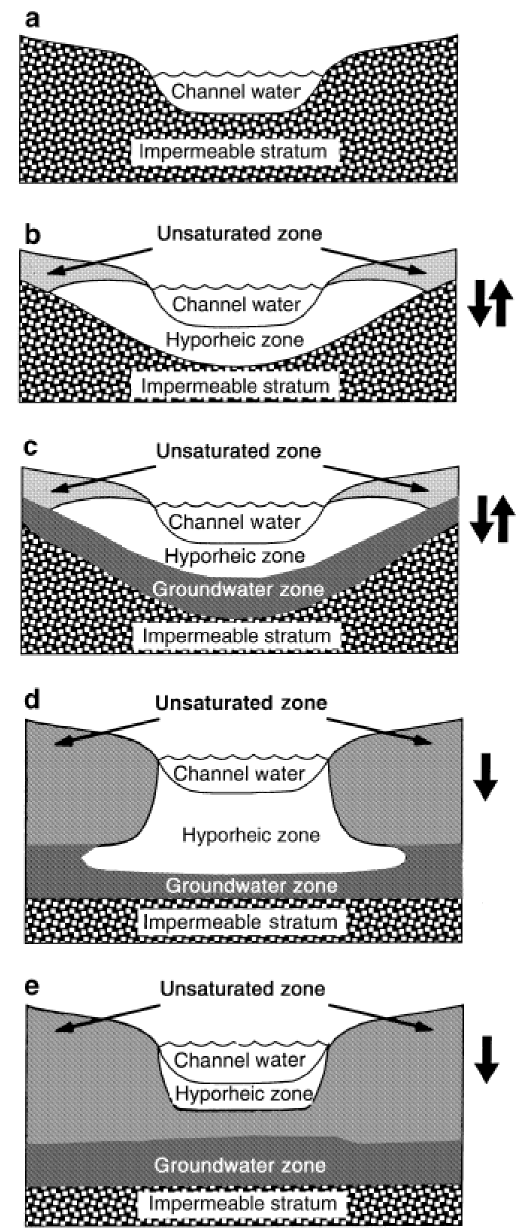
(a) No hyporheic zone

(b) Hyporheic zone with advected channel water only

(c) Hyporheic zone with advection from channel and ground water

(d) Hyporheic zone created by infiltration of channel water (no parafluvial flow)

(e) Perched hyporheic zone created by infiltration of channel water



Subsurface heterogeneity, sediment characteristics

Interaction between groundwater and hyporheic exchange mediated by subsurface heterogeneity – drives flow path direction, length and residence time at reach and bedform scales

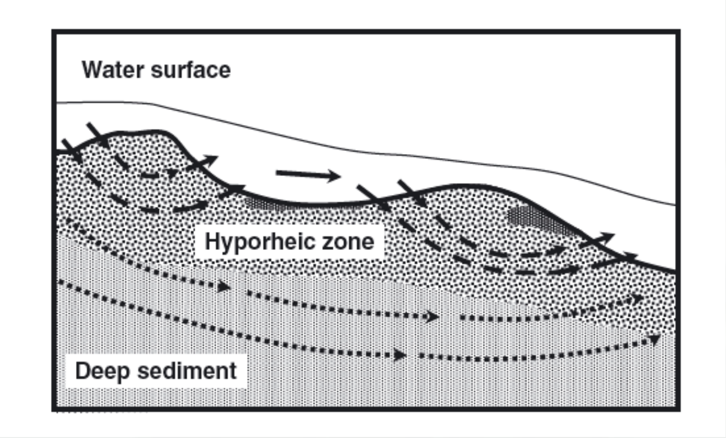


Figure above, Boulton et al. (2007)

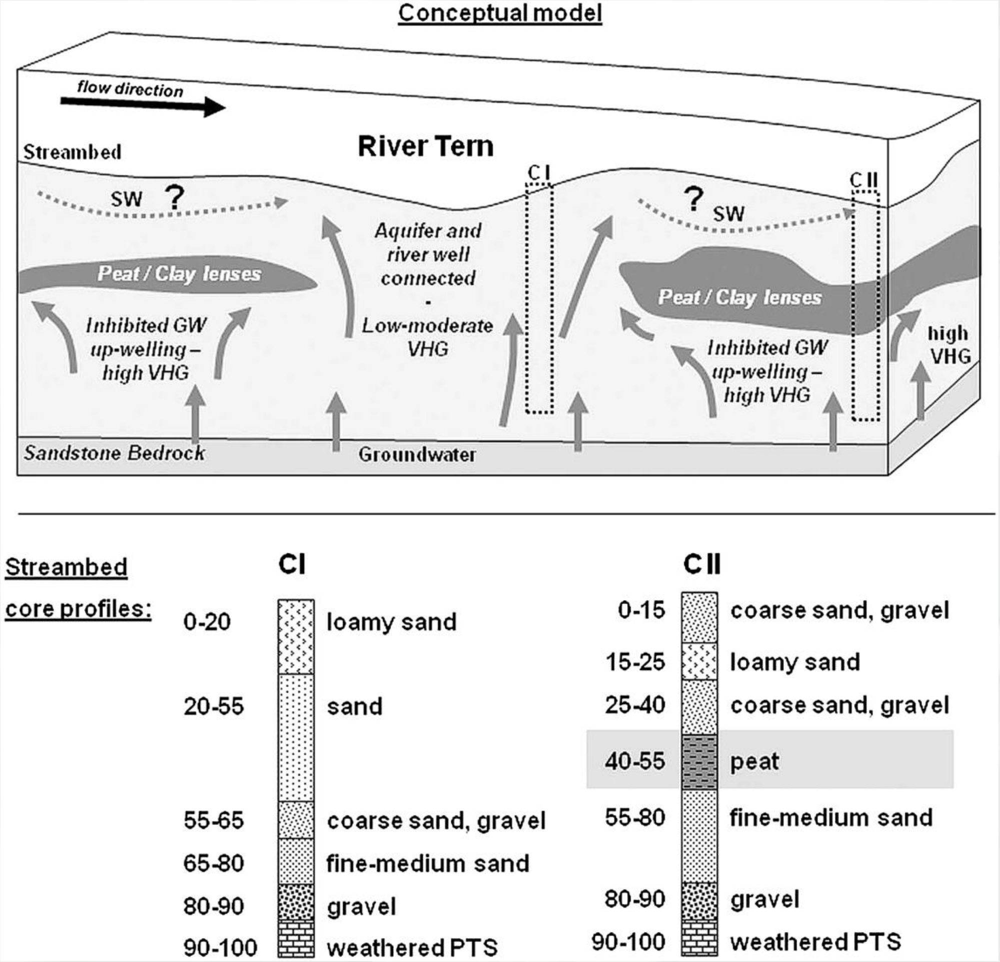
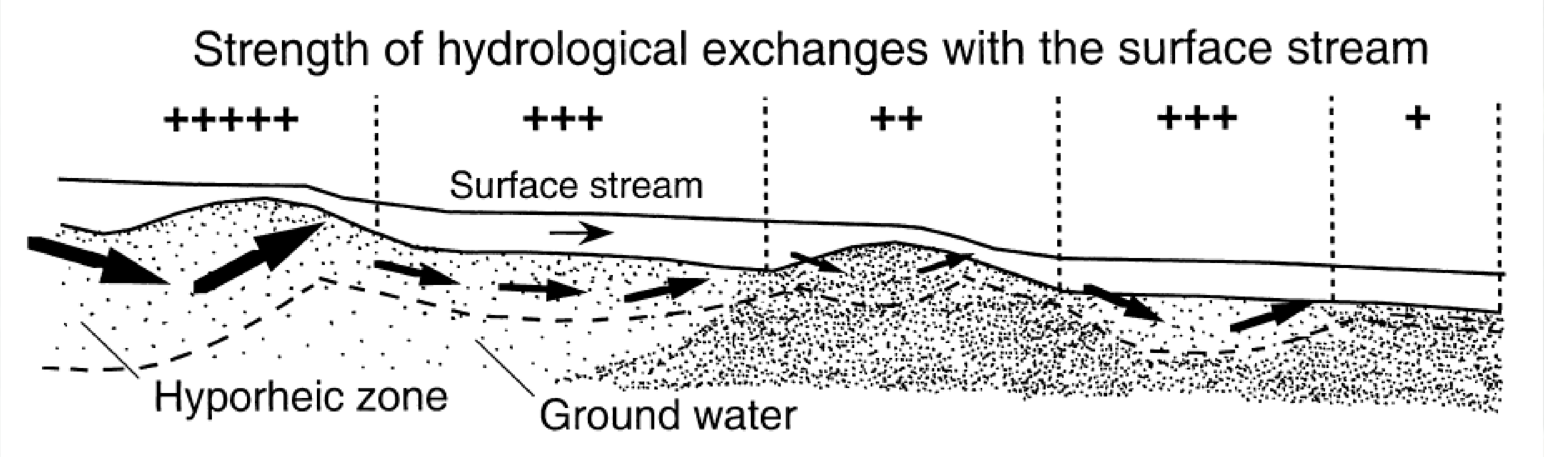


Figure excerpt above, Boano et al. (2014)

Subsurface heterogeneity, sediment characteristics

Mosaic model of surface–subsurface exchange (figure below from Malard et al., 2002)

- Patches induced by spatial variation in streambed topography and sediment permeability
- Dark areas represent fine sediments, arrows indicate direction of flow flux rate of surface water into sediments
- Ground water flux upward into the HZ occurs at the downstream end of hyporheic flow paths.



Morphology overview

- Planform geometry influences lateral (cross-channel) and longitudinal (down-valley) flow paths
- Bedform geometry interacts with planform geometry to create complex reach-scale flow field interactions

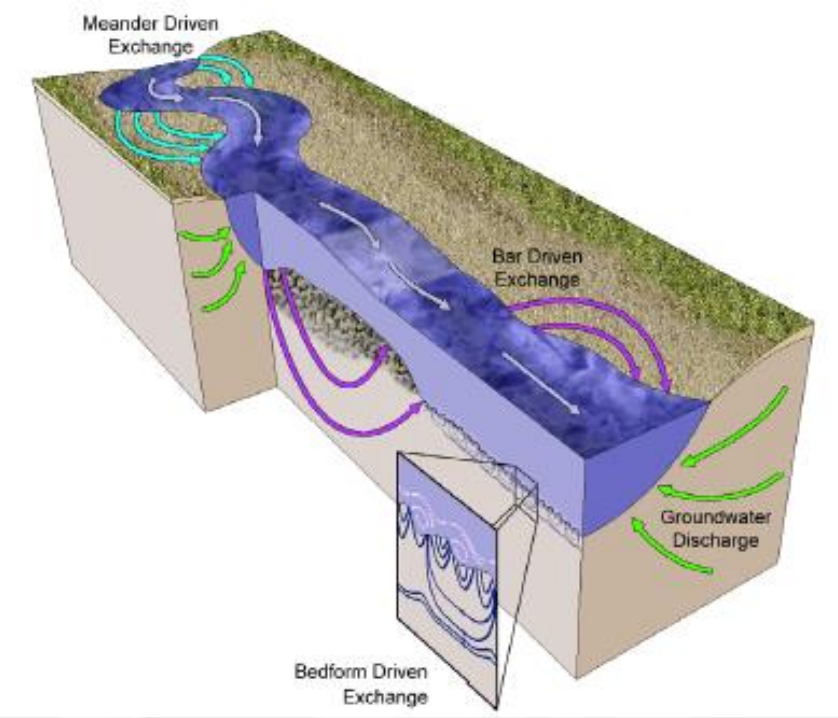


Figure right, Stonedahl et al. (2010)

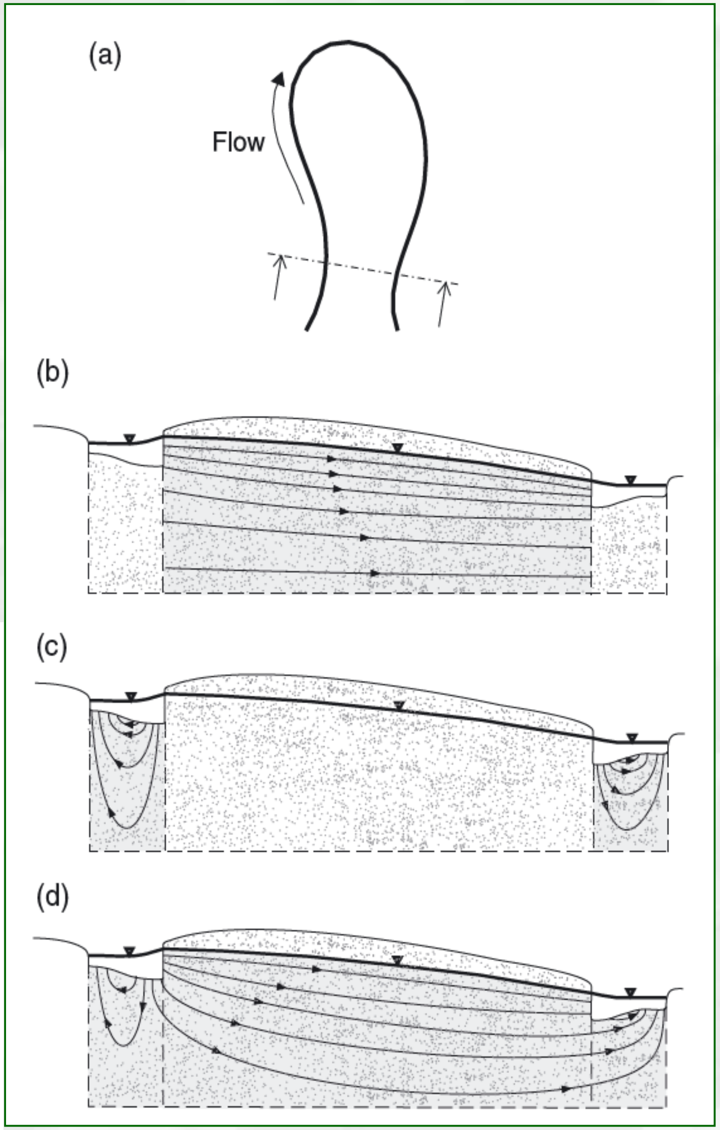
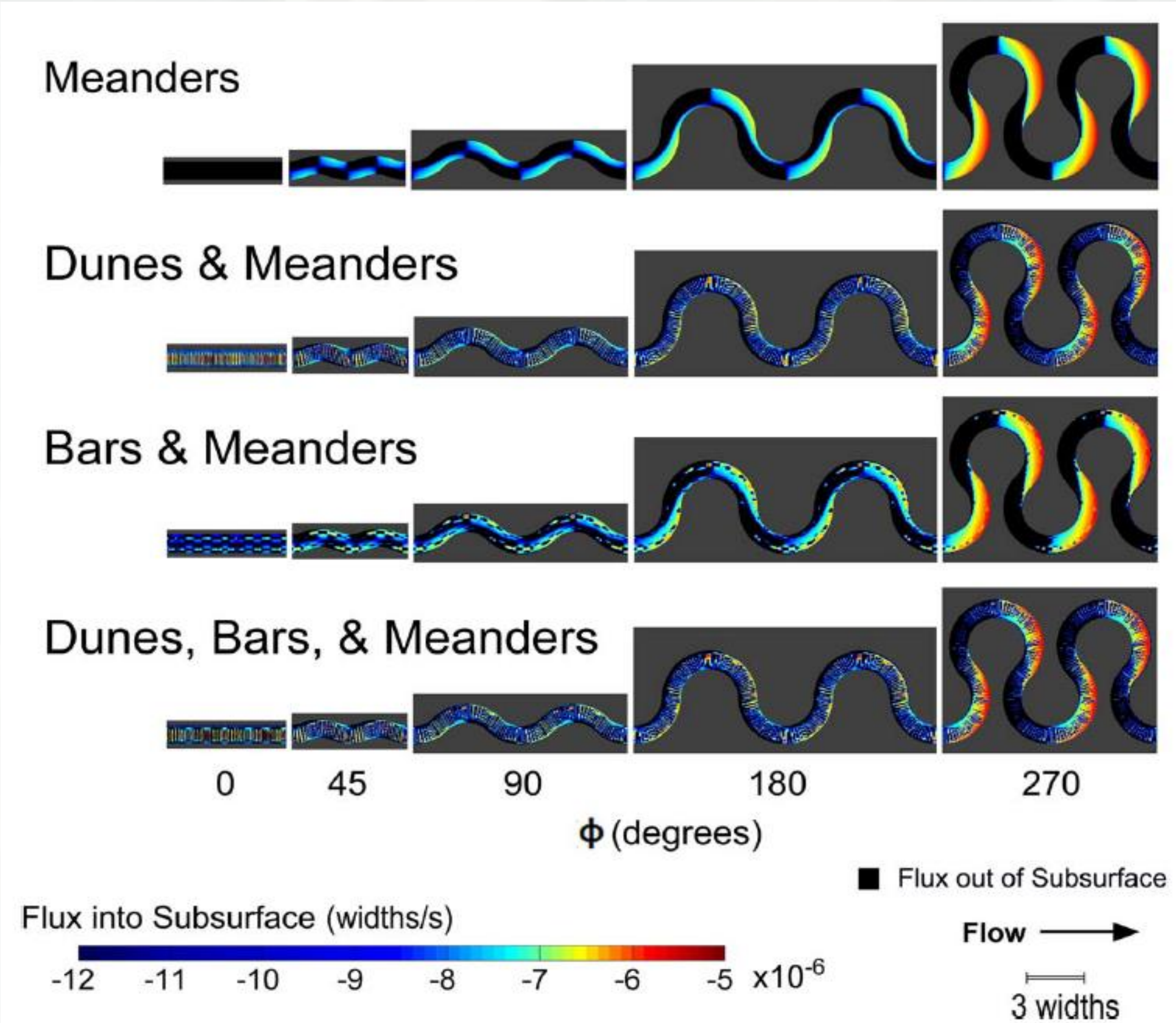


Figure above, Boano et al. (2014)

Hydrologic and Hydraulic drivers: *very* brief review

- Hyporheic exchange is a flux = exchange of water across stream bed
- Energy gradients drive fluxes
- Hydraulic gradients measured in *hydraulic head* units (energy per unit weight)
- Static and dynamic components drive flux in moving waters
- *Hydrostatic* = elevation head and hydrostatic pressure head (basically water depth) – not dependent on flow, reach scale
- *Hydrodynamic* = velocity head and hydrodynamic pressure head – dependent on flow, roughness element scale
- Water depth and slope are most influential at reach scales, velocity most influential at sub-channel-width scales
  - Meander geometry and larger bedforms vs. smaller bedforms and roughness elements
  - Above and below water elements
  - Sinuosity and height of channel-spanning topo features
  - Steeper slopes yield greater head gradients

Morphology – channel flux modeling



Flux in = downwelling = recharge
blue is slow
red is fast

Flux out = upwelling = discharge
black

Number (0,45, etc.) = degrees of bend

Figure left, Stonedahl et al. (2013)

Morphology – planform model results

- Before the reversal meander pattern (270 degrees), the trend is for increasingly longer paths with slightly steeper gradients with increasing sinuosity
- straighter channels produce shorter, flatter paths
- more sinuous channels produce longer, flat paths
- Greater than 180 degrees curvature produces short, steep paths with some longer, more gently graded paths.

Figure below, Stonedahl et al. (2013)

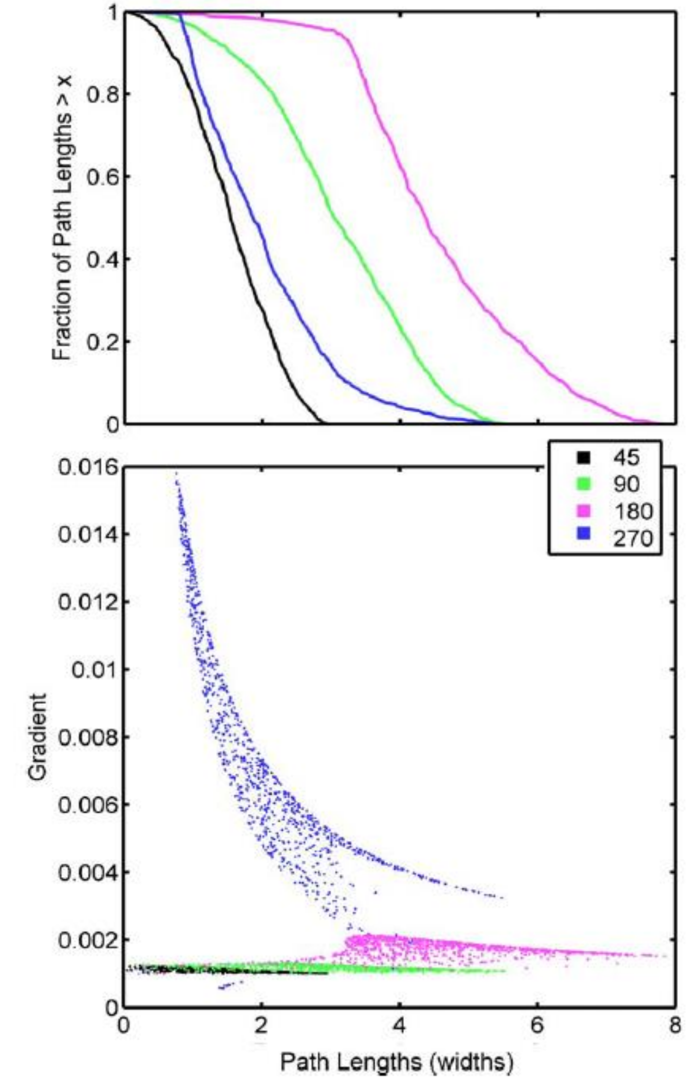


Figure 8. (top) Cumulative distribution of path lengths associated with each planform of the meanders case. (bottom) Gradient versus path length for each planform of the meanders case.

Bioturbation

- Animals (algae to mammals) near and within hyporheic zone influence and produce important hyporheic functions and structure
- *Hyporheos* (e.g., clams, worms, macroinvertebrates) that live in the HZ create burrows, build nests, physically/chemically process organic matter and solutes
- Vertebrate aquatic and terrestrial animals create burrows, nest sites, impoundments

- Vegetation can influence structure and function, cause preferential flow pathways, root holes, macropores, fractures, pipe flow, diurnal and seasonal transpiration

Table 1 Functional roles and linkages of hyporheic meiofauna and macrofauna in streams

Activity	Potential or demonstrated effects
Burrowing	Bioturbation, modifying interstitial pore size and water velocity, altering redox gradients, aerating sediments, dispersing bacteria and fungal spores, transport of organic matter
Egestion of coarse faecal pellets	Modify pore size (as above), compact fine sediments, generate particulate organic matter, transportation and inoculation of bacteria and fungal spores
Excretion	Generate labile dissolved organic carbon, source of ammonium and other nutrients, promote microbial growth
Grazing microbial biofilms	Promote biofilm activity, change in microbial composition
Breakdown of buried particulate organic matter	Shredding of buried leaf litter and other particulate organic matter increase surface area for bacterial attack
Secondary production and hyporheic metabolism	Secondary production and growth of hyporheic invertebrates, faunal contribution to metabolism of hyporheic zone
Movement between hyporheic zone and sediment surface	Migration by occasional hyporheos, accidental export of permanent hyporheos in upwelling zones, 'washout' of hyporheos during floods
Emergence of amphibites	Removal of matter and energy from hyporheic zone and supply to surface stream and terrestrial environment, provision of food for riparian predators

Table excerpt, Boulton, 2007

Beaver activity, Batavia Kill, NY. Clipboard for scale.

Beaver paw print, Batavia Kill, NY. Human paw for scale.

Biogeochemical functions of hyporheic exchange

- Can strongly modify surface water chemistry through important biochemical processes
- Mediated by “microbial biofilms” that break down detritus, create bioavailable organic carbon, provide important N cycling and process other solutes
- Order and extent of these reactions depends on *flow path length* and *residence time*.
- Overbank flows, flood pulses increase wetted areas and process opportunities
- Can also promote interstitial deposition through settling and filtration, retaining particle associated constituents (i.e., sorbed to clay particles) such as metals, sequestering these from surface waters

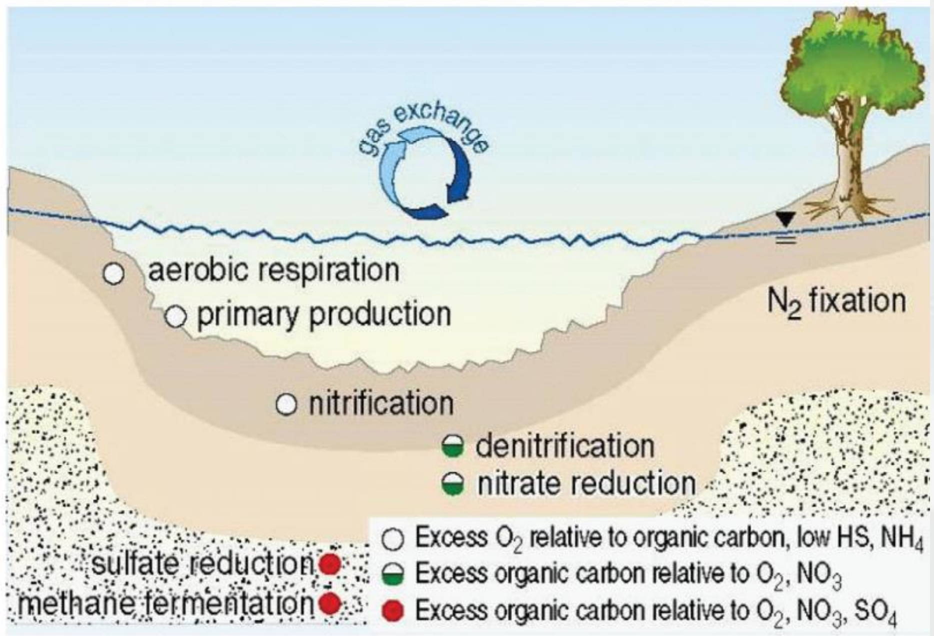


Figure above, Harvey and Gooseff, 2015

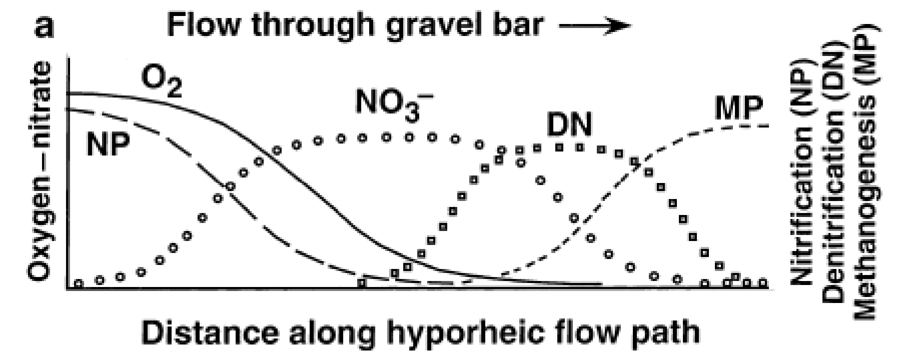


Figure excerpt above, Malard et al., 2002

Thermal/chemical functions of hyporheic exchange

- Thermal cooling, buffering or regulation of surface waters
- Convection with mixing of warmer surface water with cooler groundwater
- Conduction and diffusion through contact with cooler subsurface media
- Downwelling zones: Generally warmer, more oxygenated, possibly higher NO_3^-
- Upwelling: Generally cooler, containing more bioavailable C, lower DO and NO_3^-

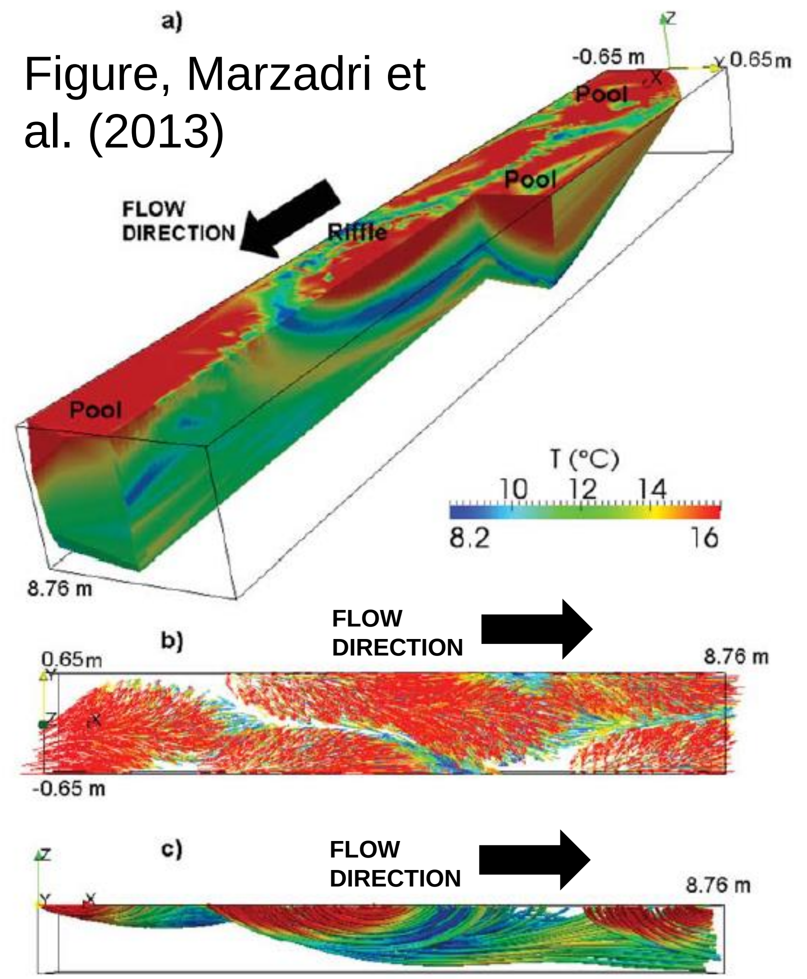
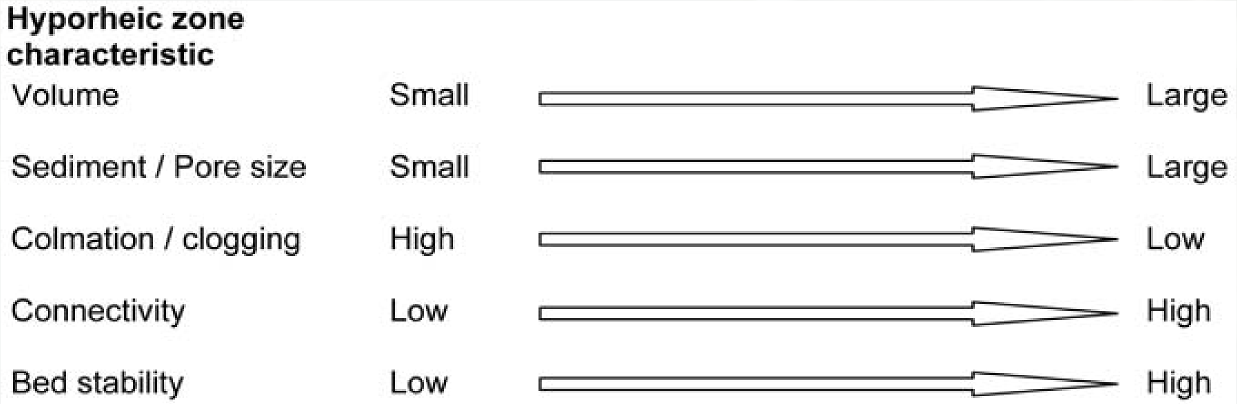


Figure 11. Temperature evolution in the streambed and at the streambed interface in the case of the small steep stream. (a) 3-D view of temperature distribution within the hyporheic sediments, (b) planar view of temperature flow field, and (c) longitudinal view of streamtube distribution.

Ecological/biological functions in the hyporheic zone

- Hyporheos – Fauna that live in these environments
  - Life-stage specific – egg incubation, larval stages or instars – reproductive niches
  - Resident populations – typically smaller invertebrates, algae and other microbiological folks
  - Refuge-seekers – some types of benthic and aquatic organisms (e.g., fish, macroinvertebrates, amphibians) use the HZ to escape flooding, drought, thermal or other disturbance or perturbations
- Refuge use is especially critical in arid-region streams where subsurface flow can sustain communities in ephemeral or intermittent streams
- Extent and health of HZ have direct and indirect impacts on primary/secondary productivity, benthic, aquatic, riparian and river corridor dependent biodiversity
- Measures of HZ suitability for various organisms include
  - Volume of substrate pore size, extent of pore clogging, connectivity in pore spaces
  - Bed stability
  - Organism size



Arrows indicate direction of increasing refugial effectiveness for the characteristics shown

Figure left, Robertson and Wood (2010)

Can we refine our model of riverine connectivity to include hyporheic zone and exchange processes?

If the Hyporheic zone is defined by three-dimensional connectivity below the bed, banks and floodplain areas of the river corridor…

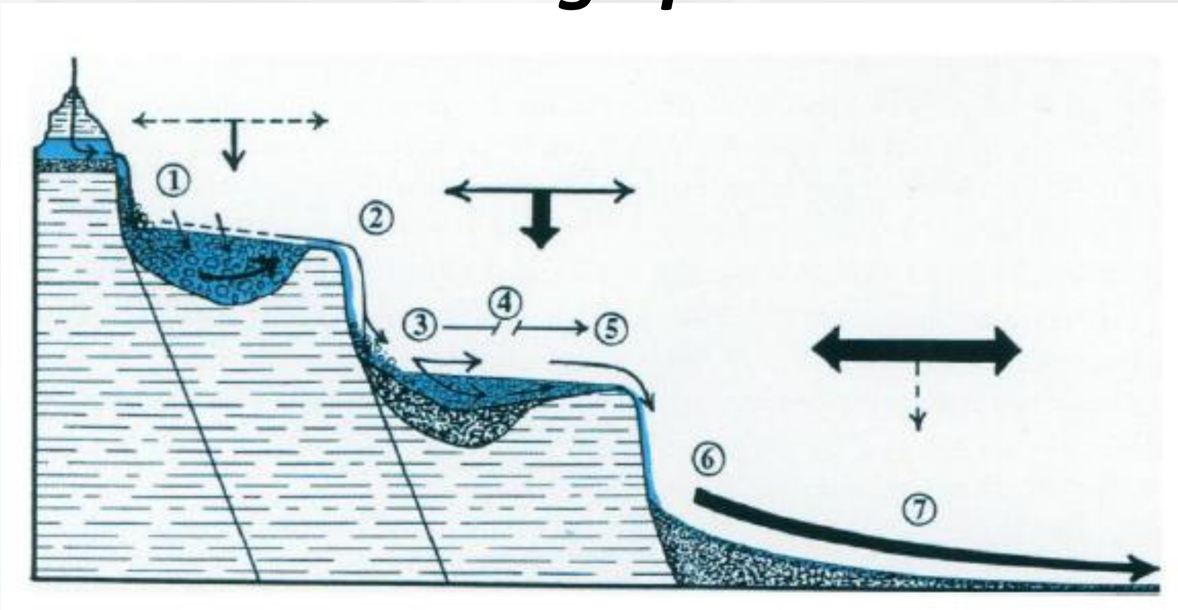


Figure above, Stanford and Ward, 1993. Longitudinal river profile; relative volumes of surface and interstitial (hyporheic) flows shown by arrows. Horizontal and vertical hovering arrows represent floodplain flows (overland or into hyporheic zone). Curved arrows represent stream flow and hyporheic flow relative volume and direction. Numbers correspond to next Fig.

Restructuring the river corridor perspective, hydrologic exchange flows and the hyporheic zone

…Then we can incorporate the Hyporheic Corridor concept proposed by Stanford and Ward (1993) for systems with large and discontinuous constrictions, serial discontinuities and variable size/length of interstitial pathways

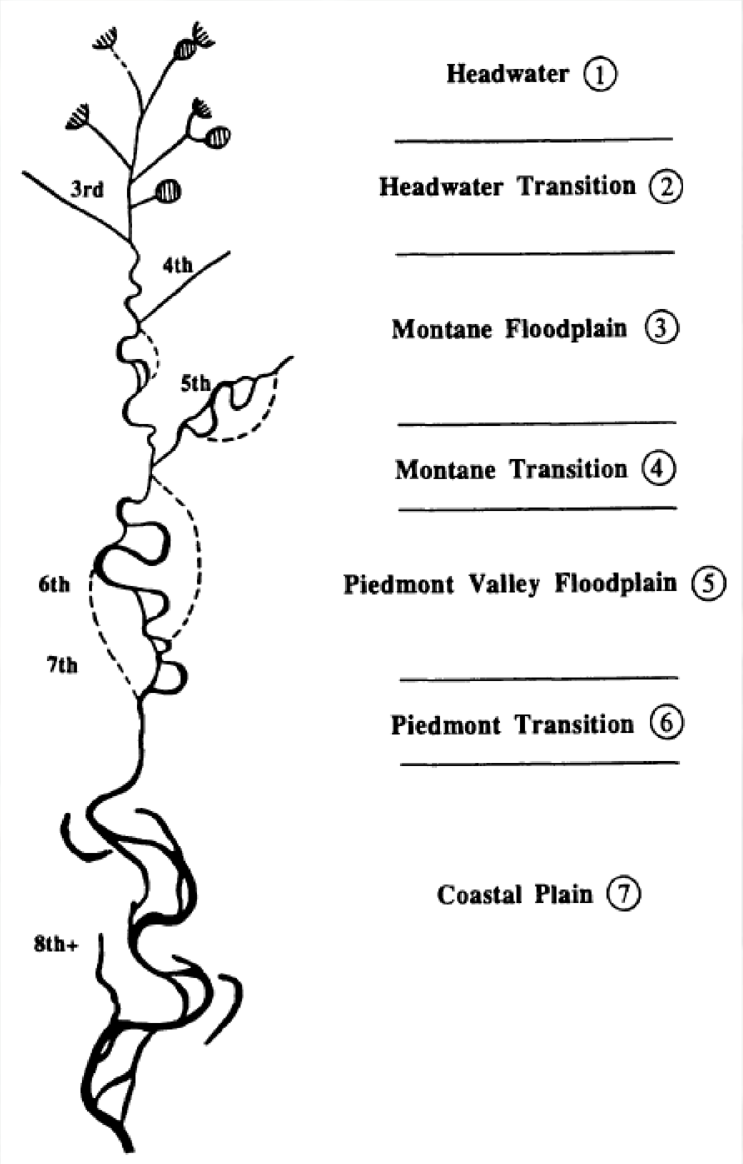
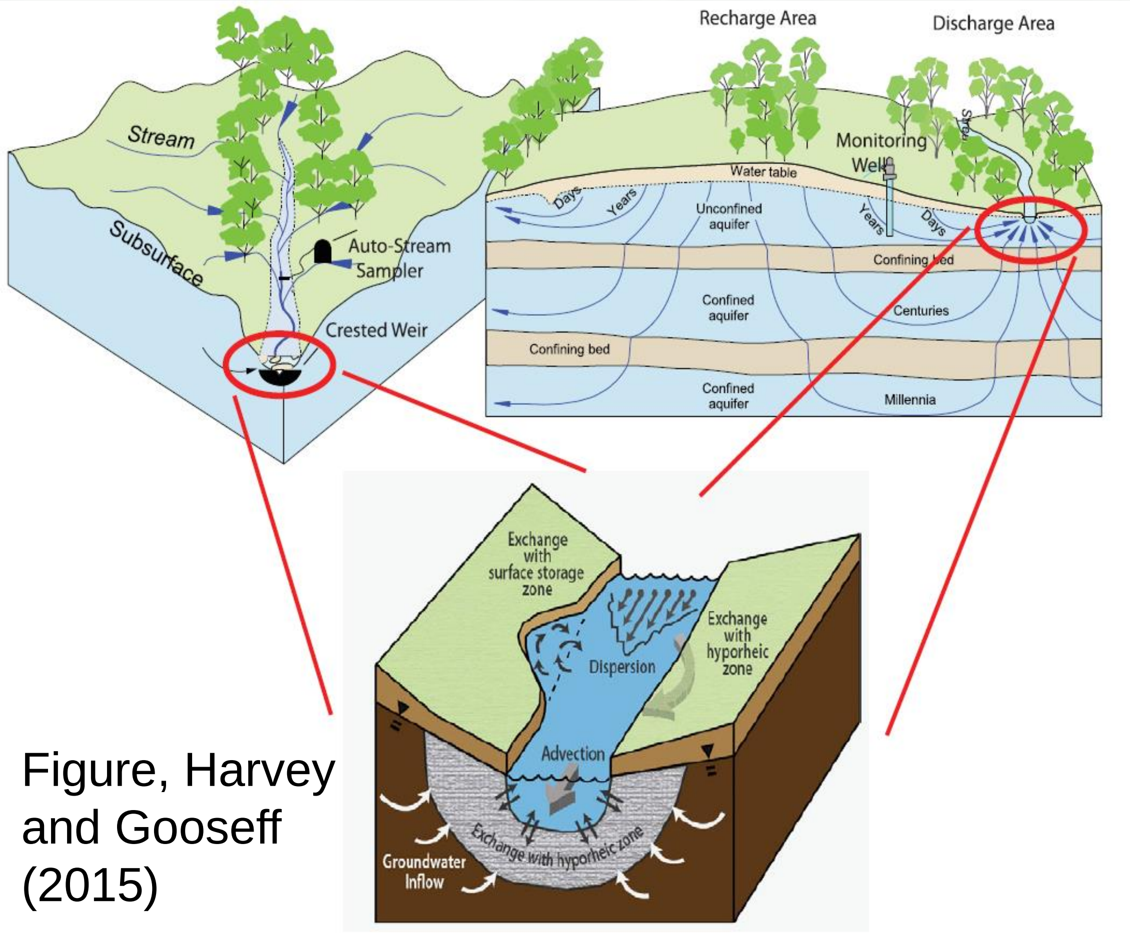


Figure at right, Stanford and Ward, 1993. Strahler stream order shown.

Hydrologic connectivity in the context of both river and hyporheic corridors as a unit



Figure, Harvey and Gooseff (2015)

A process-based definition of hydrologic connectivity that includes these hydrologic exchange flows, "*main channel exchange with recirculating marginal waters, hyporheic exchange, bank storage, and overbank flow onto floodplains*" (Harvey and Gooseff, 2015)

Review – how do riverine (corridor) ecosystems benefit from hyporheic connectivity?

- Mediates flood and drought disturbances by providing physical refugia for micro- and meiofauna
- Provides primary and secondary production values through biofilms and interstitial fauna
- Helps regulate diurnal or average stream water temperatures, sometimes providing critical thermal refugia
- Provides microbial processing – bioavaiable C sources, active in N cycling, reaction sites for organic and inorganic pollutants
- Can even have geomorphic impacts by preferential flow paths, piping, sapping, paleochannel or layered alluvial flow
- Works at many river corridor scales, from individual substrate elements, to geomorphic features (pools, riffles, bars), to parafluvial and floodplain areas, to valley-scale connections

Limitations of hyporheic or hydrologic connectivity

- Greater access to floodwaters can stress existing riparian vegetation or mobilize stable floodplain sediments
- Connecting oxbow lakes or riparian wetlands can likewise destabilize bed sediments or limit establishment of aquatic vegetation
- Increased hyporheic inflows from agricultural areas may stress hyporheos or result in a shift in hyporheic communities
- Higher nutrient content that stimulates hyporheic productivity may decrease benthic or aquatic biodiversity if overgrowth of certain algal species results
- Sediment coarsening or reduction of siltation may limit establishment of aquatic or riparian plants
- Changes in reservoir management or routing of point discharges – adding, treating, rerouting – may cause sudden changes in hyporheos if solute loads change, or changes in hyporheic exchange if flows and sediment loads change

Hydrologic exchange in ecosystem restoration

- Explicitly including hyporheic goals and ecosystem benefits in our restoration connectivity accounting
- Design guidance for hyporheic flux objectives, Ward et al., 2011
  - Thermal cooling or buffering of surface waters by heat exchange – requires rapid contact and return, high hydraulic conductivity and low residence time
  - Thermal regulation by creating lag in diurnal return – requires more control of residence time, variable hydraulic conductivity
  - Restoration of salmonid spawning habitat – requires cool, well-oxygenated gravel substrate, high hydraulic conductivity
  - Biogeochemical cycling – requires maximized exchange and delivery of limiting constituents (to or from), residence time control and variable hydraulic conductivity depending on process

Morphologic alterations

- Create terraced floodplains, backwater or high flow channels
  - Gets plants closer to the parafluvial hyporheic zone, vadose zone or phreatic flow
  - Expands wetted area during floods, allowing greater area for all hyporheic functions
- Create pools, riffles, steps, meander bends – generate hydraulic head gradients to induce exchange, trap additional CPOM, induce temperature controls
- Create complex bed morphology –
  - many small bars provide more hyporheic refugia because benthic organisms accumulate preferentially in sediments at the downwelling edges of bars during floods, though larger bars may provide the more stable refugia in larger events (Malard et al., 2002; Poole, 2002; Boulton, 2007)
  - Coarser, more permeable bar formations increase denitrification potential of vertical hyporheic exchange over bars and meanders (Gomez-Velez et al., 2015)

Morphologic alterations

Figure excerpt below, USBR and ERDC, 2016

- Install large wood, boulders or other specific habitat elements – see especially USBR and ERDC (2016)
- Creates localized roughness elements that generate hydraulic head gradients (hydrodynamic driver)
- Adds coarse particulate organic matter and can act as a trap for additional CPOM
- Nutrient source and morphological influence can persist for decades

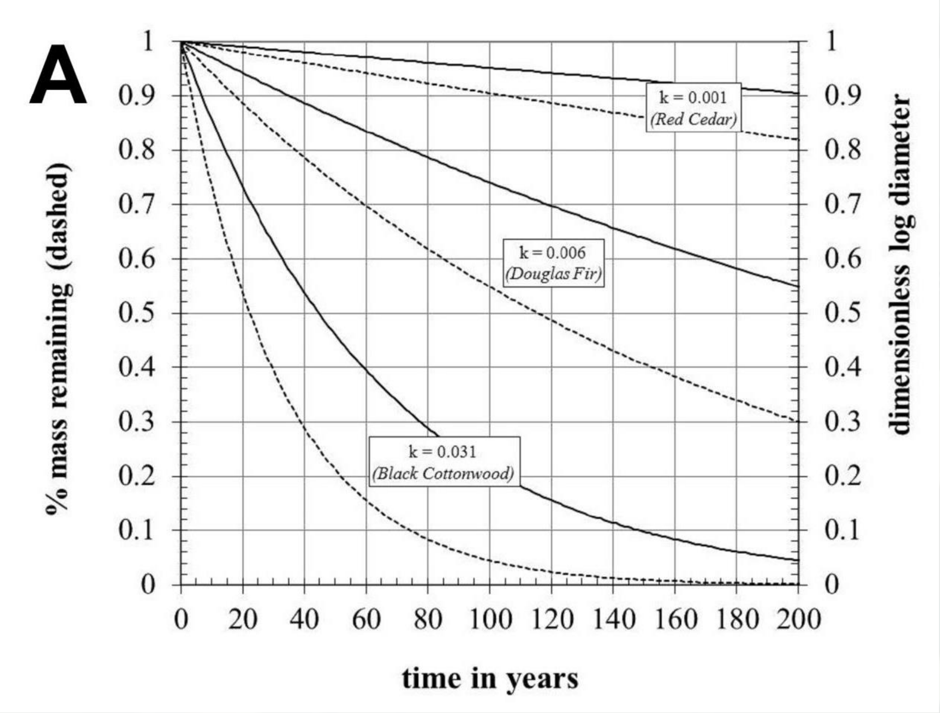
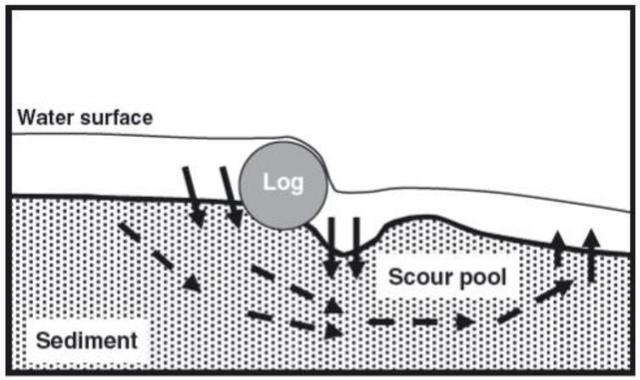


Figure right, Boulton, 2007



Sediment – control, augmentation, restoration

- Coarsen sediments – add sediment directly to downwelling areas or prevent impoundment of coarser grains – this can be especially helpful in restoration of spawning habitats for species with long egg incubation periods requiring oxygenated water (downwelling areas)
- Remove or stabilize sources of fine sediments, especially in urbanized or coarse systems – siltation might be the most damaging anthropogenic impact to hyporheic exchange, as sediment permeability is a critical determinant (Boulton, 2007)
- Remove impermeable revetments, particularly in areas where floodplain geomorphology can be restored to allow parafluvial and alluvial floodplain areas to re-enter the hyporheic zone (Faulkner et al., 2012)

Hydrology and vegetation

- Introduce flushing flows to mobilize fines or break up armor layer (in relatively stable settings, generally requires controlled releases or limitations on withdrawals)
- control quantity (release rate) and quality of stormwater flows (generally requires rerouting and/or treatment BMPs)
  - In areas subject to low hydraulic conductivity in hyporheic zone sediments
  - In areas subject to ongoing siltation or sedimentation from urbanization or legacy sediments (Hester and Cranmer, 2014)
  - In agricultural areas with heavy sediment and sorbed pollutant loads
- Plant (restore) riparian areas (generally requires native veg.)
  - Nutrient sources
  - Shade for near-surface cooling
  - Preferential flow paths (roots and animal burrows)
  - Localized roughness elements induce local downwelling

Taking advantage of techniques we already use

- Retrospective Evaluation of Aquatic Ecosystem Restoration Projects Completed by the USACE http://cw-environment.usace.army.mil/retro/index.cfm
- Advanced Search on selected Restoration Intents for riverine projects

Restoration Intent:

- ❑ Aquatic Habitat Improvement (*surface longitudinal and lateral*)
- ❑ Aquatic or Wetland Plant Management
- ❑ Bank/Shoreline Stabilization
- ❑ Beneficial Uses of Dredged Material
- ❑ Channel Reconfiguration (*surface longitudinal and lateral*)
- ❑ Dam Removal/Retrofit (*surface longitudinal*)
- ❑ Fish and Wildlife Management
- ❑ Fish Passage (*surface longitudinal*)
- ❑ Floodplain/Tidal/Backwater Reconnection (*both, primarily lateral*)
- ❑ Flow Modification (*both, primarily longitudinal*)
- ❑ Land Acquisition
- ❑ Land Creation/Restoration
- ❑ Riparian or Shoreline Management
- ❑ Water Quality Management (*surface longitudinal and lateral*)

Selected Restoration Practices in Retrospective

Restoration Practices	Restoration Practices
Channel creation, rehabilitation, restoration, stabilization	Invasive species control and management
Contaminant remediation, removal	Large woody debris placement
Culvert addition, modification, removal, replacement	Native plantings and revegetation - aquatic
Dam modification, removal, replacement	Native plantings and revegetation - terrestrial
Debris or fill removal	Nutrient and D.O. management
Dike and levee breaching, construction, improvement, removal	Placement of dredged material
Dredging and excavation	Sediment diversion
Fish and aquatic species passage or barrier installation, modification, removal	Species reintroductions and translocating (animal)
Freshwater land creation, restoration	Storm water runoff control and management
Habitat development and improvement	Stream channel rehabilitation or creation
Impoundment construction and repair	Tile disablement
In-stream construction and repair	Water control structure installation, modification
In-stream construction, flow modification	Weir construction, modification, removal

Retrospective Evaluation of Aquatic Ecosystem Restoration Projects Completed by the USACE – 132 Projects from search

Retrospective Evaluation of USACE Aquatic Ecosystem Restoration Projects

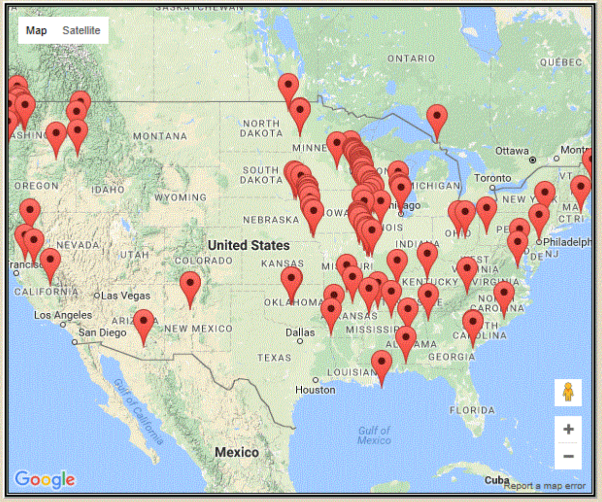
US Army Corps of Engineers

Home About Maps Select an Ecosystem Restoration Project Search: Simple / Advanced

Advanced Search

Search Results:

- Albuquerque Biological Park Wetland Restoration Project *New Mexico - Albuquerque District*
- Ambrough Slough *Wisconsin - St. Paul District*
- Anacostia Habitat Improvement *Maryland - Baltimore District*
- Anacostia River and Tributaries *Maryland; Washington D.C. - Baltimore District*
- Andalusia Refuge *Illinois - Rock Island District*
- Bay Island *Missouri - Rock Island District*
- Bertom and McCartney Lakes *Wisconsin - Rock Island District*
- Big Escambia *Alabama; Florida - Mobile District*
- Big Timber Refuge *Iowa - Rock Island District*
- Blackhawk Park *Wisconsin - St. Paul District*
- Boyer Chute *Nebraska - Omaha District*
- Boyer Chute Backwater and Chute Restoration *Nebraska - Omaha District*
- Brown's Lake *Iowa - Rock Island District*
- Buck Run *Missouri - Rock Island District*
- Bull Shoals Tailwater *Arkansas - Little Rock District*
- Bussey Lake *Iowa - St. Paul District*
- Calhoun Point *Illinois - St. Louis District*
- California Bend *Nebraska - Omaha District*
- Camp Creek *Oregon - Walla Walla District*
- Cape Fear River *North Carolina - Wilmington District*
- Capoli Slough - Restoration project not complete *Wisconsin - St. Paul District*
- Cherry Creek Restoration *Idaho - Seattle District*
- Chester North Fork *California - Sacramento District*
- Chicago Botanic Garden *Illinois - Chicago District*
- Clarksville Refuge *Missouri - St. Louis District*
- Codiga Farm *Washington - Seattle District*
- Cold Springs *Wisconsin - St. Paul District*
- Collins Creek *Arkansas - Little Rock District*
- Cottonwood Island *Missouri - Rock Island District*
- Cuddebackville Dam Removal *New York - Philadelphia District*
- Cuivre Island *Missouri - St. Louis District*
- Cuneo Press *Illinois - Chicago District*
- Deepwater Slough *Washington - Seattle District*
- Deroin Bend Restoration Project *Missouri - Omaha District*
- Dresser Island *Missouri - St. Louis District*
- Duck Island *Kentucky - Nashville District*
- East Birch Creek *Oregon - Walla Walla District*



Middle Rio Grande, Albuquerque District, NM

Riparian; Wetland; Bosque

- **Environmental resource issues:** Biodiversity; Environmental Flows; Habitat Loss and Fragmentation; Native Plant Communities; Recreation; Sediment Management; Threatened and Endangered Species
Threatened and Endangered Species: Rio Grande silvery minnow (*Hybognathus amarus*); Southwestern willow flycatcher (*Empidonax taillii extimus*)
- **Project purpose:**
1. Enhance native cottonwood-willow communities within the bosque.
2. Enhance and increase the number of water-related habitat features in the bosque.
3. Implement limited measures to rehabilitate some hydraulic connection between the bosque and the river consistent with operational constraints.
4. Protect, extend and enhance areas of potential habitat for listed species within the existing bosque.
5. Prevent catastrophic fires in the bosque through the reduction of fuel loads identified as hazardous.
- **Project features:** The Route 66 Project would include removal of jetty jacks and non-native vegetation across 121 acres of bosque north and south of Central on the west side of the river and north of Central on the east side of the river. Non-native vegetation to be removed would include salt cedar (*Tamarix ramosissima*), Russian olive (*Elaeagnus angustifolia*), Tree of Heaven (*Ailanthus altissima*) and Siberian elm (*Ulmus pumila*). The proposed action also includes recreating 3 high-flow channels, and enhancing one outfall wetland at the Gonzales Drain. Further restoration features include planting of native vegetation throughout the project area (121 acres) and creation of a number of willow swales. Improvements of existing facilities for educational, interpretive and low-impact recreational uses have also been incorporated into the Route 66 Project.
- **Restoration Practices Employed:** Channel creation, rehabilitation, restoration, stabilization; Debris or fill removal; In-stream construction, flow modification; Native plantings and revegetation - aquatic; Native plantings and revegetation - terrestrial; Other (Specify); Vegetation removal

Thornton Creek, Seattle District, WA
Stream; Riparian; Wetland

- **Environmental resource issues:** Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*)
- **Project purpose:**

1. Restore native fish and wildlife habitat at Matthews Beach as much as possible within the project area while not increasing flood risk or risk to public safety by creating rearing habitat for juvenile native (salmonid) fish and restore native riparian habitat in defined habitat zones;
2. Provide wetland function at Matthews Beach by configuring surface water bodies to create wetland areas adjacent to them
3. Remove non-native plants and restoring the riparian plant community in the project area to a native assemblage as much as possible.

- **Project features:** The design included construction of a 3,500 ft^2 fish rearing pond fed by a diverted natural stream channel. The pond was excavated from upland, achieving depths of 5-7 ft with shallow gradient side slopes. A clay layer was placed for the pond bottom. To create the impoundment, a naturalistic weir was constructed of logs, clay, and rocks at the outlet leading to Thornton Creek. Following construction, the pond perimeters and buffer were planted with native emergent and woody vegetation. Sedimentation ponds were incorporated into the stream design upstream of the main rearing pond to trap stormwater-fed sediments before they entered the rearing pond. Additionally, native species will be planted to replace the existing nonnative riparian vegetation along the existing creek banks and wetlands. An access trail, pond observation area, and interpretive signage will be included to meet public (including handicapped) access, educational, m
- **Restoration Practices Employed:** Channel creation, rehabilitation, restoration, stabilization; Dredging and excavation; Habitat development and improvement; Impoundment construction and repair; Invasive species control and management; Native plantings and revegetation - aquatic; Native plantings and revegetation - terrestrial; Weir construction, modification, removal aintenance, and safety requirements of the sponsor.

Watauga Aquatic Restoration, Huntington District, NC *Riparian; Bottomland hardwood*

- **Environmental resource issues:** Erosion; Habitat Loss and Fragmentation; Storm Water
- **Project purpose:**

The overall goal of the Watauga Aquatic Restoration Project is to restore ecosystem functions that are currently lost or degraded along this reach of the South Fork New River.

- **Project features:** The Preferred Action Alternative focuses on the development and expansion of a riparian corridor, improvements to eroding streambanks including overbank plantings, bank protection using woody material, and the construction of bend way weirs. In addition, new wetland areas will be created, an established wetland will be rehabilitated and areas adjacent to the river that are currently overgrown with invasive plants will be replanted with native species.
- **Restoration Practices Employed:** Habitat development and improvement; Native plantings and revegetation - terrestrial; Shore and erosion control structures; Weir construction, modification, removal

Big Timber Refuge, Rock Island District, IA
Backwater; Bottomland hardwood

- **Environmental resource issues:** Fish and Wildlife Populations and Communities; Habitat Loss and Fragmentation; Sediment Management; Water Quality
- **Project purpose:**

1. Increase fish habitat in the backwater area off Coolegar Slough
2. Increase habitat available to wintering fish not subject to freeze-out
3. Increase diversity of the fish habitat
4. Increase diversity of the bottomland hardwoods
5. Enhance duck habitat.

- **Project features:** Hydraulically dredge a channel 5,070 ft long, 50 ft wide, and 8 ft deep; Mechanically dredge a channel 327 ft long, 35 ft wide, and 8 feet deep through Timber Chute; Mechanically dredge a channel 9,400 ft long, 40-50 ft wide, and 3.5 ft deep of which 3,900 ft is located adjacent to the hydraulically dredged channel; Create 10 potholes in areas of willow thickets; Place barriers to prevent boat access to Little Denny; Plant mast trees on the placement sites; and, Construct check dams using dredged material.
- **Restoration Practices Employed:** Channel creation, rehabilitation, restoration, stabilization; Dredging and excavation; Native plantings and revegetation - terrestrial; Other (Specify); Placement of dredged material

Nine Mile Run, Pittsburgh District, PA *Urban Stream, Floodplain*

- **Environmental resource issues:** Contaminant Material; Habitat Loss and Fragmentation; Water Quality
- **Project purpose:** The principal goal of this aquatic ecosystem restoration project is to restore the habitat to promote the biological diversity of Nine Mile Run.
- **Project features:** Reach 1 a. Install trash rack; b. Armor right bank toe and re-vegetate eroded banks; c. Remove right bank and bottom of concrete channel and install step/pool channel; and, d. Grout boulders to left bank side wall. Reach 2 a. Raise stream invert and meander the stream into the ball field; b. Lower floodplain and increase sinuosity; c. Construct maintenance roads for sewer line; d. Manage invasive species; e. Provide trash rack and armor outfall from box culvert; and, f. Construct an emergent scrub-shrub wetland. Reach 2A a. Daylight Falls Ravine and construct an emergent scrub-shrub wetland in Fern Hollow; b. Modify parking area; c. Construct replacement soccer field; d. Provide Educational signage; and, e. Provide pedestrian recreational trails on maintenance roads. Reach 3 a. Construct low flow baffles within the culvert; b. Remove a portion of Belgian block stream bottom; c. Construct a step/pool at the end of the Belgian block channel; d. Lower floodplain on the right bank; e. Reconfigure channel above sewer line crossing; f. Construct a replacement ball field adjacent to Commercial Street; g. Construct a vegetated berm between the proposed ball field and Commercial Street; h. Control invasive plant species; i. Construct maintenance access roads; and, j. Armor channel leading from storm water/sanitary overflow outfall and eliminate ponding. Reach 4 a. Enhance in-stream habitat with veins, wing deflectors, weirs and rock boulder placements; b. Manage for invasive species and revegetate the riparian zone along toe of slag slopes; c. Construct step pools over sewer lines; d. Retrofit storm water outfalls and armor stream channel; and, e. Provide maintenance access. Reach 5 a. Construct step pools; b. Construct an emergent wetland on left bank; c. Enhance in-stream habitat by constructing veins, wing deflectors, weirs and rock boulder placements; d. Reroute outfall of slag leachate pipe into ALCOSAN sewer main; e. Enlarge the existing embayment by grading back the left bank.
- **Restoration Practices Employed:** Channel creation, rehabilitation, restoration, stabilization; Contaminant remediation, removal; Culvert addition, modification, removal, replacement; Dike and levee breaching, construction, improvement, removal; Dredging and excavation; Earthen berm construction; Fish and aquatic species passage or barrier installation, modification, removal; Habitat development and improvement; In-stream construction and repair; In-stream construction, flow modification; Invasive species control and management; Large woody debris placement; Native plantings and revegetation - aquatic; Native plantings and revegetation - terrestrial; Placement of dredged material; Shore and erosion control structures; Storm water runoff control and management; Stream channel rehabilitation or creation; Water control structure installation, modification; Weir construction, modification, removal

Questions…? Contact me any time – Thank You!

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