Repairing vertical connectivity: what to do at the site and in the catchment

Repairing vertical connectivity: what to do at the site and in the catchment

CRC for
Water Sensitive Cities

Strategy 1. Repair the height of the watertable

Suitability of strategy: most suitable for waterways where the watertable is shallow – at least during the wet season (baseflow index of site is high).

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
1a. Repair the height of the watertable See *Repairing flow: what to do in the catchment* factsheet, actions 5a–5h for falling watertable, actions 5i–5p for a rising watertable	The height of the watertable affects surface water/ groundwater interactions.	Suitable in most locations except where the groundwater is contaminated. See *Repairing flow: what to do in the catchment* factsheet for the specific suitability of specific actions.	[1, 2] but not where groundwater is contaminated [3]	See associated factsheet

Strategy 2. Slow flow

Suitability of strategy: all sites, except those where flow has already been slowed (e.g. downstream of a flow regulating structure or in a weir pool).

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
2a. Slow flow by catchment-wide harvesting, infiltration and detention of stormwater See *Repairing flow: what to do in the catchment* factsheet, Strategy 1	Minimising the volume of stormwater inputs into the urban drainage network helps reduce the velocity of instream flows and increases the potential for water to downwell into the hyporheic zone.	See *Repairing flow: what to do in the catchment* factsheet, Strategy 1, all actions.	[4]	See associated factsheet

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
2b. Slow flow using existing dams and weirs	Dams or weirs can be used to trap and store high flows, moderating the velocity of water flow downstream and increasing the potential for water to downwell into the hyporheic zone.	Where there are significant inputs of stormwater upstream of the dam or weir, but relatively few stormwater inputs downstream of the water storage facility. This action does NOT advocate for the creation of new dams or weirs.		

Strategy 3. Promote hydraulic diversity

Suitability of strategy: suitable only once scouring urban flows have been repaired or if low flows occur for a protracted period each year. Most effective where the bed material is highly permeable.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
3a. Allow the channel to adjust naturally See *Repairing geomorphology: what to do at the site and in the catchment* factsheet, Strategy 3	More geomorphic diversity (beds, bars) occurs in naturally adjusted channels than channelised waterways. The increased geomorphic complexity promotes hydraulic diversity (e.g. deep and shallow waters), which promotes the vertical exchange of water.	Where the waterway is channelised at present, particularly where it is constrained by hard-lining (e.g. concrete, RIP RAP). Where the bed material is highly porous. See associated factsheet for the suitability of specific actions.		See associated factsheet
3b. Increase channel sinuosity	Reconfiguring the channel to increase sinuosity will slow flow and increase instream hydraulic diversity – both of which will promote the vertical exchange of water.	Where the waterway has been channelised. Where there is sufficient land around the stream for channel redesign. Where earthworks don't pose a significant risk to existing riparian vegetation.	[3-5]	[6-10] See also RVR Meander tool
3c. Establish a pool-riffle sequence	Pool-riffle sequences increase variation in hydraulic head (water pressure) along the stream, stimulating the vertical upwelling and downwelling of water.	Where bed material is highly porous. Where stream depth is shallow so that riffles can create marked hydraulic diversity. Where the stream channel is stable such that riffles won't get washed away. Where sedimentation is low so that riffles won't be buried.	[4, 5, 11-13]	[14] and River restoration manuals

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
3d. Install boulders and large woody debris (LWD)	Boulders and LWD create localised increases in surface water elevation that promote the downwelling of water into the hyporheic zone.	Where instream habitat complexity has been drastically simplified by urbanisation. Where bed material is porous. Placement of LWD will be most successful where logs are able to stretch across the channel. If concerns exist about the risk to urban infrastructure, we recommend using the Large Wood Structure Stability Analysis Tool <http://www.fs.fed.us/biology/nsaec/products-tools.html> [2-5, 15-18] [8, 10, 19-23]	[2-5, 15-18]	[8, 10, 19-23]
3e. Create artificial structures	Artificial structures (e.g. cross vanes, J-hooks, sub-surface boxes) can create localised variation in water depth and therefore promote upwelling and downwelling.	Where actions 3b, 3c and 3d are inappropriate due to any number of constraints. Care needs to be taken so that artificial structures do not reduce connectivity, e.g. fish passage, or create other environmental impacts downstream.	[4, 24, 25]	[25, 26]

Strategy 4. Improve the permeability of bed material

Suitability of strategy: most suitable for waterways where the bed material is highly permeable (cobble, gravel, coarse sand).

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
4a. Remove impermeable channel lining	An impermeable channel lining (e.g. concrete, compacted clay) prevents the interaction of surface water with shallow groundwater – limiting the vertical exchange of water, i.e. both groundwater upwelling and local recharge of the watertable by stream water.	Where the channel is lined with an impermeable material (e.g. concrete, clay). Where concrete removal is coupled with other restorative works such that it does not exacerbate channel incision.	[4, 27]	
4b. Add coarse gravel to the channel	Adding coarse sediment will increase the porosity of the stream bed, facilitating hyporheic exchange. If gravel is added to a concreted drain it will allow the creation of a hyporheic zone for nutrient processing (see *Reducing nutrients: what to do at the site* factsheet), but still not facilitate groundwater/surface water interactions. If gravel is added to a non-concreted channel, it will improve the development of a hyporheic zone and enable groundwater/surface water exchange.	At high value lacations. Where scouring urban flows have been repaired so they won't just simply wash the added bed material out of the site. Where gravel is a natural bed material. In most locations repairing sources or coarse sediment (see *Repairing Geomorphology: what to do at the site and catchment* factsheet, Actions 2c and 2d) and allowing the channel to naturally adjust will be more effective over the longer term.	[4, 5]	

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
4c. Use flushing flows to clean gravel beds	High levels of sedimentation can clog the top layer of channel sediments, reducing the permeability of the bed and the development of a hyporheic zone. A flushing flow from a dam/weir, a wastewater treatment plant or other urban water infrastructure (e.g. fire hydrant, water pipeline) can flush fine sediment downstream or overbank, cleaning gravel beds or other permeable bed material.	Where stream bed sediments are naturally porous (e.g. gravel, coarse sand) and covered with fine sediment. Where catchment land management is advanced such that fine sediment inputs will not immediately compromise this action.	[2-4, 28]	
4d. Support bioturbation by native fauna	Stream fauna that dig tunnels into the substrate (e.g. chironomids, worms) enhance the movement of water into and out of the hyporheic zone.	Where bioturbating fauna are naturally abundant.	[4, 29, 30]	
4e. Repair streamside riparian vegetation	Streamside vegetation can promote the infiltration of surface water into the hyporheic zone because roots create macropores that act as subsurface flow paths.	Where streamside vegetation has been largely cleared. Where tree and macrophyte roots extend into the hyporheic zone.	[4, 31]	

Supporting documents

1. Bhaskar, A., et al. (2016) Will it rise or will it fall? Managing the complex effects of urbanization on base flow. Freshwater Science, 35: p. 293-310.
2. Boulton, A.J. (2007) Hyporheic rehabilitation in rivers: restoring vertical connectivity. Freshwater Biology, 52: p. 632-650.
3. Hancock, P.J. (2002) Human impacts on the stream–groundwater exchange zone. Environmental Management, 29: p. 763-781.
4. Lawrence, J.E., et al. (2013) Hyporheic zone in urban streams: a review and opportunities for enhancing water quality and improving aquatic habitat by active management. Environmental Engineering Science, 30: p. 480-501.
5. Hester, E.T. and M.N. Gooseff (2010) Moving beyond the banks: hyporheic restoration is fundamental to restoring ecological services and functions of streams. Environmental Science and Technology, 44: p. 1521-1525.
6. WDF (2004) Channel modification, In: Stream habitat restoration guidelines, K. Saldi-Caromile, et al., Editors. Washington Department of Forestry, Olympia, Washington, US. Available from: https://www.wou.edu/las/physci/taylor/g407/restoration/WA_Dept_Forestory_2004_Channel_Modification_Techniques.pdf.
7. Sardi-Caromile, K., et al. (2004) Stream habitat restoration guidelines: final draft. Co-published by the Washington Department of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington. Available from: http://wdfw.wa.gov/publications/00043/wdfw00043.pdf.
8. Erskine, W., et al. (2007) River restoration based on natural channel characteristics: how to develop restoration designs for different rivers and riparian plant communities. In: 5th Australian Stream Management Conference. Thurgoona, NSW.
9. Brookes, A. (1987) Restoring the sinuosity of artificially straightened stream channels. Environmental Geology and Water Sciences, 10: p. 33-41.
10. Rutherford, I.D., et al. (2000) A rehabilitation manual for australian streams: volume 2. Cooperative Research Centre for Catchment Hydrology. Land and Water Resources Research and Development Corporation. Available from: http://www.engr.colostate.edu/~bbledsoe/CIVE413/Rehabilitation_Manual_for_Australian_Streams_vol2.pdf.
11. Kasahara, T. and A.R. Hill (2006) Hyporheic exchange flows induced by constructed riffles and steps in lowland streams in southern ontario, canada. Hydrological Processes, 20: p. 4287-4305.
12. Brunke, M. and T.O.M. Gonser (1997) The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology, 37: p. 1-33.
13. Storey, R.G., et al. (2003) Factors controlling riffle-scale hyporheic exchange flows and their seasonal changes in a gaining stream: a three-dimensional groundwater flow model. Water Resources Research, 39
14. BCSRTB (unknown) Restoration of riffle:pool sequences in channelised streams. British Columbia's Stream Restoration Technical Bulletin.
15. Mayer, P.M., et al. (2010) Nitrogen dynamics at the groundwater–surface water interface of a degraded urban stream. Journal of Environmental Quality, 39: p. 810-823.

16. Groffman, P.M., et al. (2005) N processing within geomorphic structures in urban streams. Journal of the North American Benthological Society, 24: p. 613-625.

17. Hester, E.T. and M.W. Doyle (2008) In-stream geomorphic structures as drivers of hyporheic exchange. Water Resources Research, 44.

18. Krause, S., et al. (2014) The potential of large woody debris to alter biogeochemical processes and ecosystem services in lowland rivers. Wiley Interdisciplinary Reviews: Water, 1: p. 263-275.

19. Treadwell, S., et al. (2007) Wood and other aquatic habitat. Available from: https://arrc.com.au/wp-content/uploads/2015/08/Wood%20and%20other%20aquatic%20habitat.pdf.

20. Brooks, A.P., et al. (2006) Design guideline for the reintroduction of wood into australian streams. Land and Water Australia Canberra. Available from: https://arrc.com.au/wp-content/uploads/2015/08/Design%20guideline%20for%20the%20reintroduction%20of%20wood%20into%20Australian%20streams.pdf.

21. Beesley, L., et al. (2017) Riparian design guidelines to inform the repair urban waterways. Cooperative Research Centre for Water Sensitive Cities. Melbourne Australia.

22. Rafferty, M. (2017) Computational design tool for evaluating the stability of large wood structures. Department of Agriculture, National Stream and Aquatic Ecology Centre. Fort Collins, Colorado, USA. Available from: https://www.fs.fed.us/biology/nsaec/assets/rafferty_usfs_nsaec_tn-103-2_stabilitylargewoodstructurestool.pdf.

23. Wohl, E., et al. (2016) Management of large wood in streams: an overview and proposed framework for hazard evaluation. JAWRA Journal of the American Water Resources Association, 52: p. 315-335.

24. Kasahara, T. and A.R. Hill (2008) Modeling the effects of lowland stream restoration projects on stream–subsurface water exchange. Ecological Engineering, 32: p. 310-319.

25. Ward, A.S., et al. (2011) How can subsurface modifications to hydraulic conductivity be designed as stream restoration structures? Analysis of vaux's conceptual models to enhance hyporheic exchange. Water Resources Research, 47

26. Rosgen, D.L. (2001) The cross-vane, w-weir and j-hook vane structures: their description, design and application for stream stabilization and river restoration. In: Wetlands Engineering and River Restoration Conference. Reno, Nevada.

27. Bernhardt, E.S. and M.A. Palmer (2007) Restoring streams in an urbanizing world. Freshwater Biology, 52: p. 738-751.

28. Hancock, P.J. and A.J. Boulton (2005) The effects of an environmental flow release on water quality in the hyporheic zone of the hunter river, australia. Hydrobiologia, 552: p. 75-85.

29. Covich, A.P., et al. (1999) The role of benthic invertebrate species in freshwater ecosystems: zoobenthic species influence energy flows and nutrient cycling. BioScience, 49: p. 119-127.

30. Song, J., et al. (2010) Observation of bioturbation and hyporheic flux in streambeds. Frontiers of Environmental Science & Engineering in China, 4: p. 340-348.

31. Dosskey, M.G., et al. (2010) The role of riparian vegetation in protecting and improving chemical water quality in streams. JAWRA Journal of the American Water Resources Association, 46: p. 261-277.

River restoration manuals

Rutherford, I.D., et al. (2000) A rehabilitation manual for Australian streams: Volume 2. Cooperative Research Centre for Catchment Hydrology. Land and Water Resources Research and Development Corporation. Available from: http://www.engr.colostate.edu/~bbledsoe/CIVE413/Rehabilitation_Manual_for_Australian_Streams_vol2.pdf.

WRC (2002) River restoration. Water and Rivers Commission. Perth, Western Australia. Available from: http://www.water.wa.gov.au/water-topics/waterways/managing-our-waterways2/river-restoration-manual.

Sardi-Caromile, K., et al. (2004) Stream habitat restoration guidelines: final draft. Co-published by the Washington Department of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington. Available from: http://wdfw.wa.gov/publications/00043/wdfw00043.pdf.

Cramer, M.L. (ed) (2012) Stream habitat restoration guidelines. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnerships and the US Fish and Wildlife Service, Olympia, Washington

Harman, W., et al. (2012) A function-based framework for stream assessment and restoration projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006. Available from: https://www.fws.gov/chesapeakebay/StreamReports/Stream%20Functions%20Framework/Final%20Stream%20Functions%20Pyramid%20Doc_9-12-12.pdf.

Other useful tools

Abad, J.D. and M.H. Garcia (2006) Rvr meander: a toolbox for re-meandering of channelized streams. Computers & Geosciences, 32(1): p. 92-101

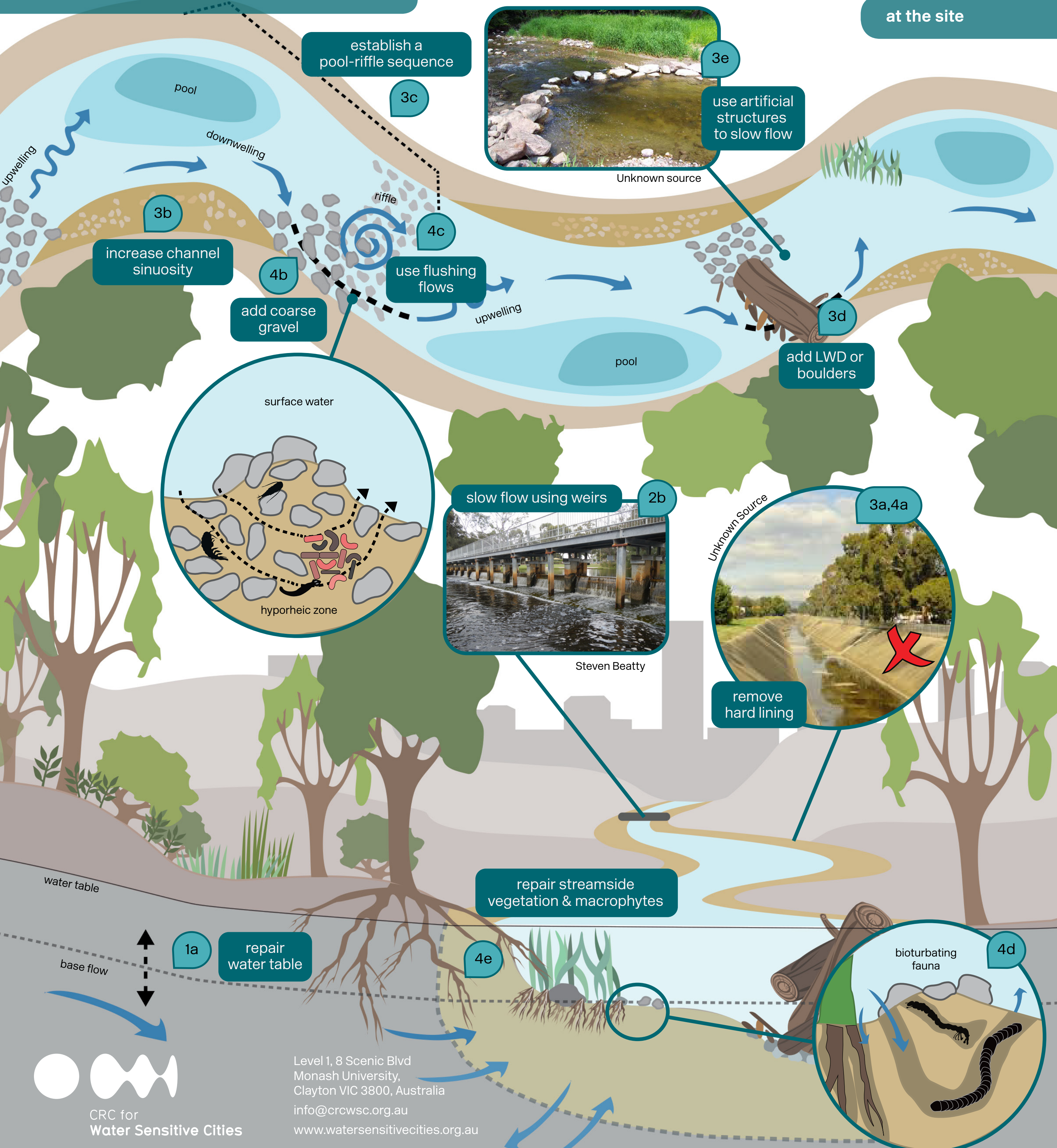
Repairing vertical connectivity: what to do at the site and in the catchment

Strategy 1. Repair the height of the water table

Strategy 2. Slow flow

Strategy 3. Promote hydraulic diversity

Strategy 4. Improve the permeability of bed material



CRC for Water Sensitive Cities

Level 1, 8 Scenic Blvd
Monash University,
Clayton VIC 3800, Australia

info@crcwsc.org.au

www.watersensitivecities.org.au