Repairing geomorphology: what to do at the site and in the catchment

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CRC for
Water Sensitive Cities

Strategy 1. Reduce flow volume and velocity

Suitability of strategy: in general, this strategy is most appropriate for small- and medium-sized streams rather than large lowland rivers.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
1a. Reduce flow volume by harvesting, infiltrating, detaining and disconnecting stormwater in the catchment See *Repairing flow: what to do in the catchment* factsheet. Strategy 1 all actions	Minimising the volume of stormwater inputs into the waterway will reduce the volume and velocity of instream flows, reducing their erosive force on the waterway channel and reducing unnatural incision and widening.	Most effective where the catchment is small with relatively low imperviousness (< 10 per cent), such as in peri urban areas, because there are fewer impervious surfaces and therefore less stormwater that needs to be attenuated. See *Repairing flow: what to do in the catchment* factsheet for the suitability of specific actions.	[1-7]	See associated factsheet
1b. Use exsisting dams and weirs to trap water	Man-made structures such as weirs can be used to trap flashy urban flows and moderate outflow spikes, reducing the scouring of downstream flows and their erosive force on channel beds and banks.	Where there are significant inputs of stormwater upstream of the dam or weir and relatively few stormwater inputs downstream of the weir – at least for some way. Where the regulating structure has capacity to store high flows behind it.	[1-7]	[8, 10] See relevant WSUD guidelines and MUSIC tool
1c. Reduce the velocity of instream flow at the site See *Repairing flow: what to do at the site* factsheet, Strategy 1 all actions	Changing the shape of the channel and using instream structures (logs, w-weirs) can all slow the flow at a given site and reduce erosive forces on the channel. Note, these actions have much less influence than actions implemented at the catchment scale (i.e. action 1a this strategy).	Where catchment-wide implementation of water saving urban design (WSUD) has already occurred.		See associated factsheet

Strategy 2. Reduce fine sediment and promote coarse sediment

Suitability of strategy: most suitable for established urban catchments that are starved of coarse sediments (e.g. there are few bars or benches made of sand or gravel in the channel).

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
2a. Ensure that construction sites use sediment control measures	Urban construction can cause instream sedimentation to increase three-fold. Ensuring that developers put measures in place (e.g. sediment traps) to reduce sediment runoff from construction sites into stormwater drains will reduce the un-naturally high levels of fine sedimentation that during urban construction phases typically smother gravel beds, infill pools and create sediment slugs.	Where considerable construction activity is occurring in the upstream catchment, such that the urban waterway is in a state of sediment accumulation. Where roadside stormwater drains are directly connected to the waterway. Where fine sediments (silt, sand) are smothering the channel.	[8]	[8] and WSUD manuals
2b. Encourage the channel to naturally self-adjust See Strategy 3 all actions this factsheet	Many urban waterways are starved of coarse sediment. Channel banks can be a good source of coarse sediment for the channel. If the channel is allowed to naturally migrate across the floodplain then bank sediments can be transported downstream where they contribute to the construction of geomorphic units (riffles, banks, bars).	Where there is little construction in the upstream catchment, such that the urban waterway is in a state of sediment depletion. Where there is sufficient space in the riparian buffer for channel migration and/ or widening. See Strategy 3 for the suitability of specific actions.	[3, 9]	See Strategy 3 this factsheet
2c. Protect headwater sources of coarse-grained sediment	Headwater streams in relatively undeveloped catchments can provide a natural supply of coarse-grained sediments for downstream reaches and should be protected from development. If they are developed they should have wide riparian corridors and be allowed to adjust naturally so they can continue to deliver sediment downstream.	For waterways with relatively undeveloped headwaters (e.g. greenfield sites, or peri urban areas). Where headwaters sit in sloped landscapes – i.e. their flows have enough power to mobilise coarse sediment downstream.	[3]	
2d. Re-engage headwater sources of coarse sediment by removing stormwater pipes and removing instream barriers	Daylighting small streams (first order) will provide a source of coarse sediments for downstream receiving waterways. Similarly, removing barriers (such as weirs) should improve the delivery of coarse sediments to downstream sites.	Daylighting is most suitable for small brownfield waterways. Removing instream barriers is most suitable for lowland sites located downstream of an instream barrier that is preventing the passage of coarse sediment. Note that barrier removal may also increase stream power and exacerbate scouring and thus should be considered with caution. Decisions to remove barriers must be viewed holistically and consider the consequences for geomorphology, flow and biota.	[3]	

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
2e. Redesign GPTs or manage them so that coarse sediments are returned to the stream	Gross pollutant traps (GPTs) are designed to trap sediment; however, this contributes to sediment problems in streams. While fine sediments bond to pollutants and should be removed, coarse sediment (sand, gravel) should be put back into the channel to support the construction of geomorphic units (i.e. riffles, banks, bars).	Where the channel is starved of course-grained sediment – evidence of this is where the channel bed has been actively eroding. Where scouring urban flows have been managed by catchment-wide WSUD (otherwise gravel additions will be lost downstream).	[10-12]	
2f. Manually add coarse sediment (clean gravel) to stream	Many urban waterways are starved of coarse sediment. If clean coarse fill (e.g. gravel) is available it can be directly added to the channel.	In high value locations where the channel is starved of coarse sediment and modification by GPTs is not possible or insufficient to repair the coarse-sediment load. Where scouring urban flows have been managed by catchment-wide WSUD (otherwise gravel additions will be lost downstream).	[3, 10, 11]	Gravel can be added in one location and flow can naturally redistribute it [11]

Strategy 3. Allow the channel to naturally self-adjust to altered flow

Suitability of strategy: suitable for sites where enough space exists to allow channel migration in relation to altered flows, where the bed and bank material is erodible (i.e. gravel, clay, sand, NOT bedrock). Note, this strategy may result in wider, shallower waterways that may exacerbate water temperature increases, thus it is recommended that natural channel adjustment is combined with riparian restoration to limit temperature rises.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
3a. Remove channel hard-lining	Removing the hard surface of urban channels, such as concrete lining and various forms of revetment, is a prerequisite to allowing the channel to self-adjust. Many geomorphologists consider that simply removing hard linings is a more efficient and cost-effective approach to channel self-adjustment than channel reconfiguration.	Where the channel is lined with hard surfaces (e.g. concrete).	[3, 13, 14]	
3b. Recreate channel sinuosity	If the urban channel is very straight and has uniform bank sediment, it may be necessary to give channel self-adjustment a helping hand by using earth-moving equipment to add some sinuosity. This man-made sinuosity will support the channel to create patches of erosion and deposition and start to adjust in a more natural fashion.	Creating sinuosity is inappropriate where the waterway slope is > 2 per cent.	[15]	[15-18]

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
3c. Increase the width of the riparian buffer	For natural adjustment to succeed, there must be enough land on either side of the waterway for the channel to migrate or widen into. Increasing the width of the riparian buffer ensures there is sufficient space for lateral channel migration.	Where there is sufficient available land surrounding the waterway. Where the development is greenfield and in the planning stage. In brownfield areas where it is difficult to widen riparian buffers, it may be possible to widen the buffer in discrete patches.	[3, 9, 13, 19]	[20]

Strategy 4. Mitigate erosion caused by urban infrastructure or head-cutting

Suitability of strategy: suitable for most sites, particularly sites where stormwater pipes or roads are present. Most effective if scouring flows have already been repaired at the catchment scale. The strategy is not appropriate if the channel is hard-lined with concrete.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
4a. Relocate/ redesign stormwater drainage inputs	Stormwater pipes that feed directly into the waterway create a hotspot of bank and bed erosion. Stormwater pipes should be disconnected from the waterway. They should terminate at swales or biofilters on the distal edge of the riparian zone.	All sites, particularly where the riparian buffer is wide enough to facilitate retrofitting and the establishment of a biofilter or swale.	[2, 3]	See WSUD manuals
4b. Redesign culverts	Culverts (i.e. pipes beneath road crossing) concentrate stream flow and often cause localised incision downstream. Open-bottom culverts can prevent this.	Where the site includes a road crossing with a culvert.	[21]	[21]

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
4c. Employ grade control structures (boulder weirs – cross vane, w-weir, j-hook; rigid weirs)	Knick points are abrupt changes in the slope of a stream caused by erosion. These geomorphic features typically erode upstream (i.e. head cutting) and can exacerbate incision problems in urban waterways. Grade control structures can be used to protect these areas and limit incision from spreading upstream.	At the downstream end of a restoration site. Where knick points exist downstream of the restoration site. Where natural changes in channel profile are causing unwanted scouring of the stream bed. Care needs to be taken so that grade-control structures do not reduce connectivity, i.e fish passage.	[22]	[22]

Strategy 5. Stabilise the bank, particularly erosion hotspots

Suitability of strategy: typically this strategy will be suitable where the stream bed is no longer undergoing marked adjustment to urban flow; that is, where the channel has already self-adjusted (Strategy 1 this factsheet) or where catchment hydrology has been repaired (see *Repairing flow: what to do in the catchment* factsheet, all strategies). The strategy is not appropriate if the channel is hard-lined with concrete.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
5a. Plant deep-rooted trees and a range of vegetation in the stream-side zone	Deep-rooted vegetation (e.g. trees) reduce the likelihood of bank collapse because they anchor the riverbank to the surrounding land. Trees also reduce the chance of the bank collapsing because they intercept rain and improve soil drainage, which keeps the bank drier and lighter and less likely to collapse. Grasses and sedges reduce the likelihood of bank collapse because their roots and rhizomes increase the tensile strength of soil matrices.	Most suitable when bank material is erodible (e.g. sand, clay) but relatively unimportant when it is non-erodible (e.g. bedrock). Trees are less effective for bank stabilisation if the watertable is very shallow as the tree roots are unlikely to be deep. Importantly, stream-side vegetation will exert relatively little influence on bank stability when channel width is > 50 m and when banks extend beyond the root zone (i.e. bank > 2 m depth).	[23-25]	[23, 24] – and see summary in [19]

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
5b. Line the stream bank with macrophytes (i.e. semi-aquatic plants such as sedges)	Macrophytes and other groundcover vegetation reduce bank erosion during high flows by flattening against the bank and reducing the scouring of bank material.	Where the stream bank is low (< 1 m high) and the bank slope is low (< 45° angle with stream). Where the macrophytes are planted in areas not subject to highly scouring flows; that is, they aren't likely to be just washed away. Macrophyte establishment will be more successful in some areas if the plants are supported by geofabric.	[23, 26, 27]	[19, 24]
5c. Add large woody debris (LWD) to the channel	LWD can deflect scouring flows away from the bank.	Most effective where the channel is narrow. Where LWD is placed in the correct location; that is, downstream of meander bends or on the toe of eroding banks. Most effective for bank stabilisation where density of LWD placed into the channel is large and where the logs are complex (rootwads, branches attached). 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> [28]. The associated resource [29] describes the process and may also be useful.	[24, 30, 31]	[31-34] See synthesis by [19]
5d. Use bank-hardening techniques (revetment)	Bank hardening techniques, such as RIP RAP, tree revetment, geotextiles, gabions or retaining walls can be used to stabilise stream banks or parts of stream banks susceptible to erosion or exposed to scouring flows.	Where the site is still subject to highly scouring urban flows. Where earth moving machinery can access the site. Where urban infrastructure is at risk from channel migration/erosion. This action should be used with caution because these techniques can accelerate bed and bank erosion downstream.	[3, 35]	[14, 36, 37] See summary in [19]
5e. Use engineering structures (e.g. cross-vanes, w-weirs or j-hooks)	Cross-vanes, w-weirs, j-hooks and other similar structures can stabilise stream banks by reducing near-bank shear stress, stream power and water velocity.	Where earth moving machinery can access the site, and can do so without causing undue damage to riparian vegetation. Care needs to be taken so that grade-control structures so not reduce connectivity, i.e fish passage.	[38]	[19, 38]
5f. Construct check dams	Check dams are small, sometimes temporary dams constructed across a waterway to counteract erosion by reducing water velocity.	In novel or severely-modified waterways where these dams are unlikely to limit the dispersal of native biota (e.g. fish).	[39]	See river restoration manuals
5g. Fence-off riparian land	Fencing riparian land restricts access to people and animals and prevents them from contributing to bank erosion.	In peri urban areas, particularly on agricultural land where cattle have access to the waterway.	[24]	

Strategy 6. Increase geomorphic complexity

Suitability of strategy: where the waterway is straight and has little to no geomorphic complexity (e.g. channelised drain, incised creekline with little habitat complexity), and where some attempt to repair scouring urban flows has been made – either via WSUD in the catchment or the presence of a flow-regulating structure upstream. If scouring flows have not been repaired, any instream improvements are unlikely to last for long.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
6a. Recreate channel sinuosity	Channel reconfiguration is often used to undo the damage caused by man-made channel straightening (channelisation)	Where earth moving machinery can access the site and where the riparian buffer is wide enough for sinuosity to be created.	[15, 40]	[15-18] See also RVR Meander tool
6b. Create pool-riffle sequence	Pool-riffle sequences are natural recurring geomorphic units in meandering gravel-bed streams.	Suitable in gravel-bed streams. Unsuitable for sand-bed streams, unless the sand is underlain by gravel. Where earthmoving machinery can access the site and where rapid restoration is required.	River restoration manuals	[41] and river restoration manuals
6c. Add logs (LWD) or boulder clusters	Logs alter the flow of water in the channel, creating patches of erosion (scour) and deposition which promote the formation of pools and bars.	Where the channel is narrow (< 10 m). Where earthmoving machinery can access the site. Where scouring urban flows have been repaired such that LWD inputs will not be lost. 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> [28]. The associated resource [29] describes the process and may also be useful.	[17, 19, 31, 33, 42-44]	[17, 19, 28, 29, 31, 32, 45, 46]
6d. Add gravel to the channel (sediment augmentation)	Many urban waterways are starved of coarse sediment. Adding gravel back to the channel can replace these missing sediments and support the construction of geomorphic units (i.e. riffles, banks, bars)	At high value locations where the channel is starved of course-grained sediment – evidence of this is where the channel has been actively eroding. In most locations respairing sources or coarse sediment (action 2d) and allowing the channel to naturally adjust will be more effective over the longer term.	[3, 10]	Gravel can be added in one location and flow can naturally redistribute it [12]
6e. Encourage the channel to naturally self-adjust See Strategy 3 all actions this factsheet	Many urban waterways are starved of the coarse sediment that builds riffles, bars and banks. Channel banks can be a good source of coarse sediment for the channel. If the channel is allowed to naturally self-adjust, then bank sediments can be transported downstream where they contribute to the construction of geomorphic units (riffles, banks, bars).	Where there is little construction in the upstream catchment, such that the urban waterway is in a state of sediment depletion. Where there is enough space in the riparian buffer for channel migration and/or widening. See Strategy 3 for the suitability of specific actions.	[3, 9]	See Strategy 3 this factsheet

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
6f. Remove fine sediment from the channel manually or by using a controlled flushing flow	Fine sediment associated with urban development can smother riffles and infill pools. These fine sediments can be manually removed or controlled flushing flows (e.g. environmental flows) can be used to transport the fine sediments onto the floodplain.	Where urban construction or agricultural development has occurred in the upstream catchment but has now largel y ceased (otherwise the benefits of this action will be short lived). Flushing flows will only be successful if they are able to mobilise fine sediments onto the floodplain. If flushing flows will exacerbate channel erosion then this action is not recommended. Manual removal of sediment should be done with caution as it may cause unintended damange to the stream bed and to riparian vegetation.	[47]	
6g. Promote/ protect trees and native vegetation along the bank	Tree roots stabilise the bank and encourage non-uniform erosion and promote the formation of different geomorphic units.	Most sites.	[40]	

Strategy 7. Restore connection to the floodplain

Suitability of strategy: most suitable where channel incision, levees or regulators have disconnected the river from its floodplain. This strategy is particularly important for stream health where the floodplain is well developed (i.e. lowland river sites) and supports diverse productive aquatic habitats (i.e. permanent and temporary wetlands/ponds). Suitable only where overbank flows do not pose a significant risk to people or urban infrastructure.

Action	Explanation	Conditions where action is most likely to be suitable andeffective	Other references recommending action	Guidelines for implementation
7a. As per *Repairing lateral connectivity: what to do at the site and in the catchment* factsheet, Strategy 2 all actions	Enhanced river/ floodplain connectivity reduces the volume and velocity of streamflow in the main channel during flood periods. Reducing the power of these flood flows should help the recovery of geomorphic units, such as bars and benches, which would otherwise be washed downstream.	See associated factsheet.	[3]	See associated factsheet

Supporting documents

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Other useful tools

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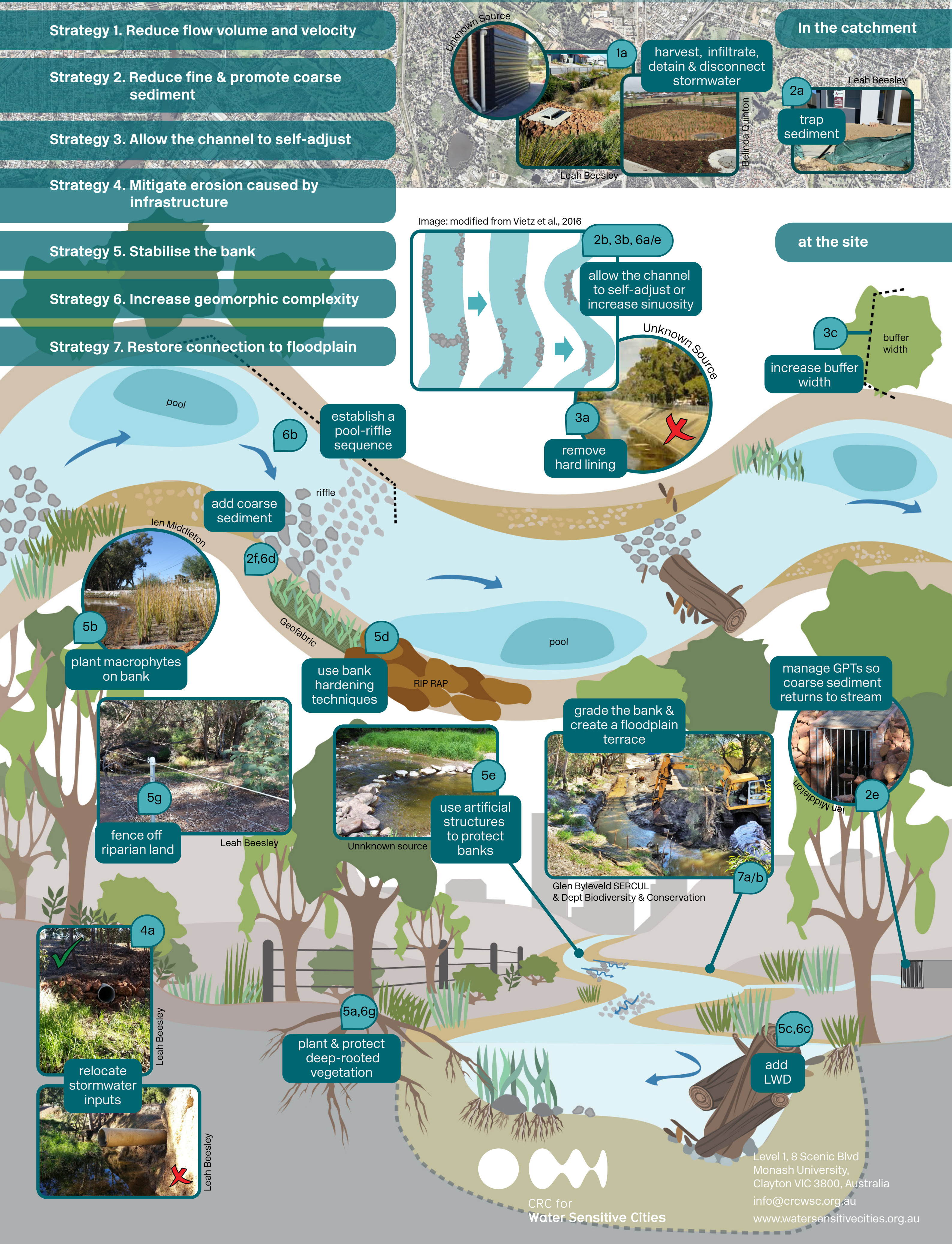
Repairing geomorphology: what to do at the site and in the catchment

- **Strategy 1. Reduce flow volume and velocity**
- **Strategy 2. Reduce fine & promote coarse sediment**
- **Strategy 3. Allow the channel to self-adjust**
- **Strategy 4. Mitigate erosion caused by infrastructure**
- **Strategy 5. Stabilise the bank**
- **Strategy 6. Increase geomorphic complexity**
- **Strategy 7. Restore connection to floodplain**



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