Resilience to extreme weather

Sample of literature reviewed for chapter 3

Defensive options

THE ROYAL SOCIETY

Coastal flooding

KEY

- Ecosystem-based approaches
- Hybrid approaches
- Engineered approaches

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Maintenance of natural reefs (coral/oyster)	**Offshore buffer**	**Wave energy dissipation, likely to reduce coastal erosion**	Beck, M 2014 *Coral Reefs: the Seawall That Nature Built*. National Geographic. See http://newswatch.nationalgeographic.com/2014/05/13/coral-reefs-the-seawall-that-nature-built/, accessed 13.10.2014. Ferrario, F, Beck M W, Storlazzi, C D, Micheli, F, Shepard, C C & Airoldi L 2014 *The effectiveness of coral reefs for coastal hazard risk reduction and adaptation*. Nature Communications, **5**, 3794 (DOI:10.1038/ncomms4794). Grimsditch, G D & Salm, R V 2006 *Coral Reef Resilience and Resistance to Bleaching*. Switzerland: IUCN. Hoegh-Guldberg, O, Mumby, P J, Hooten, A J, Steneck, R S, Greenfield, P, Gomez, E, Harvell, C D, Sale, P F, Edwards, A J, Caldeira, K, Knowlton, N, Eakin, C M, Iglesias-Prieto, R, Muthiga, N, Bradbury, R H, Dubi, A & Hatziolos, M E 2007 *Coral reef under rapid climate change and ocean acidification*. Science **318**, 1737-1742 (DOI: 10.1126/science.1152509). McMullen, C P & Jabbour, J 2009 *Climate change science compendium*. Nairobi: UNEP. Parry, M L, Canziani, O F, Palutikof, J P, van der Linden, P J & Hanson, C E 2007 *Climate change 2007: Impacts, adaption and vulnerability. Contribution of the Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. See http://www.ipcc-wg2.gov/AR4/website/fi.pdf, accessed 13.10.2014. Sheppard, C R C 2003 *Predicted recurrences of mass coral mortality in the Indian Ocean*. Nature **425**, 294-297 (DOI:10.1038/nature01987).	• Coral reefs provide substantial protection against natural hazards, reducing wave energy by an average of 97%. • Reefs can reduce the size and therefore cost of coastal engineered defences required. • Reefs have the potential for self-repair as they are living structures which can lower maintenance costs but globally disturbances such as bleaching, fishing, pollution, waste disposal, coastal development, sedimentation, SCUBA diving, anchor damage, predator outbreaks, invasive species and epidemic diseases have all acted synergistically to degrade coral reef health and resilience • Potential additional benefits of reefs include fisheries and recreation. • There needs to be greater understanding of when reefs fail during high-energy events and their recovery time. • There needs to be a greater appreciation of the effectiveness and cost effectiveness of reefs as a coastal defence to motivate local and global actions to maintain and restore these ecosystems.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Maintenance of mangroves	Offshore buffer	Wave energy dissipation, likely to reduce coastal erosion	Alongi, D M 2008 *Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change*. Estuarine, Coastal and Shelf Science, **76**, 1–13. (DOI: 10.1016/j.ecss.2007.08.024). Alverson, K 2012 *Vulnerability, impacts, and adaptation to sea level rise: Taking an ecosystem based approach*. Oceanography, **25**(3), 231–235 (DOI: http://dx.doi.org/10.5670/oceanog.2012.101). Appelquist, L R 2013 Generic framework for meso-scale assessment of climate change hazards in coastal environments. Journal of Coastal Conservation, **17**(1), 59-74 (DOI : 10.1007/s11852-012-0218-z). Arburto-Oropeza, O, Ezcurra, E, Danemann, G, Valdez, V, Murray, J & Sala, E 2008 *Mangroves in the Gulf of California increase fishery yields*. PNAS, **105**(30), 10,456–10,459 (DOI: 10.1073/pnas.0804601105). Badola, R & Hussain, S A 2005 *Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India*. Foundation for environmental Conservation, **32**(1), 85-92 (DOI:10.1017/S0376892905001967). Das, S 2007 *Policy Brief: S Mangroves; A Natural Defence against Cyclones: An investigation from Orissa, India*. Kathmandu: The South Asian Network for Development and Environmental Economics (SANDEE). Das, S & Vincent, J 2009 *Mangrove protected villages and reduced death toll during Indian super cyclone*. PNAS, **106**(18), 7357- 7360 (DOI: 10.1073/pnas.0810440106). Kathiresan, K & Rajendran, N 2005 *Coastal mangrove forests mitigated tsunami*. Estuarine Coastal and Shelf Science, **65**(3), 601-606. Kumara, M P, Jayatissa, L P, Krauss, K W, Phillips, D H & Huxham, M 2010 *High mangrove density enhances surface accretion, surface elevation change, and tree survival in coastal areas susceptible to sea-level rise*. Oecologia, **164**, 545–553 (DOI: 10.1007/s00442-010-1705-2). **Continued on next page**	• Mangroves act as a natural barrier against severe storms and significantly reduce death, livestock loss and property damage. • Sediment-trapping can actively raise the forest floor in response to sea level rise as accumulation of sediment is enabled above the tidal range. • Mangrove forests are highly resilient and able to recover after extreme events with a high degree of ecological stability. • These protective functions have not been well researched, and there is a pressing need to better understand the roles that ecosystems can play in reducing wind and swell waves. • Additional benefits of mangrove forests include firewood, forest products for local communities and acting as nurseries for fish. • Adaptation measures must be part of an integrated approach to coastal area management which also considers human activities, putting in place risk-spreading strategies and testing innovative approaches.

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
			Continued from previous page McIvor, A L, Möller, I, Spencer, T & Spalding, M 2012 *Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40*. Cambridge: Nature Conservancy and Wetlands International. See http://www.wetlands.org/Portals/0/publications/Report/reduction-of-wind-and-swell-waves-by-mangroves.pdf, Accessed 02.10.14. Schmitt, K, Albers, T, Pham, T T & Dinh, S C 2013 *Site-specific and integrated adaptation to climate change in the coastal mangrove zone of Soc Trang Province, Viet Nam*. Journal of Coastal Conservation, **17**(3), 545-558 (DOI 10.1007/s11852-013-0253-4). See 'mangrove planting & re-establishment' and 'maintenance of saltmarsh, wetlands and inter-tidal ecosystems' references.	
Mangrove planting & re-establishment	**Offshore buffer**	**Wave energy dissipation, likely to reduce coastal erosion**	de Lacerda, L D 2002 *Mangrove Ecosystems: Function and Management*. Berlin: Springer. Gilman, E L, Ellison, J, Duke, N C & Field, C 2008 *Threats to mangroves from climate change and adaptation options: A review*. Aquatic Botany, **89**(2), 237-250 (DOI: 10.1016/j.aquabot.2007.12.009). Lewis, R R III 2005 *Ecological engineering for successful management and restoration of mangrove forests*. Ecological Engineering, **24**, 403–418. Kamali, B & Hashim, R 2011 *Mangrove restoration without planting*. Ecological Engineering, **37**(2), 387–391. Linham, M, Nicholls, R & Zhu, X (eds.) 2010 *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. Roskilde: UNEP. See http://orbit.dtu.dk/fedora/objects/orbit:86544/datastreams/file_5699563/content, accessed 13.10.2014. **Continued on next page**	See the 'mangrove maintenance' summary. • Mangrove restoration can be carried out via direct planting or via natural recruitment. • In Vietnam, for example, planting 12,000 hectares of mangroves cost $1.1 million but saved an estimated $7.3 million per year in dike maintenance.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Reid, H & Huq, S 2005 *Climate change: Biodiversity and livelihood impacts. In Tropical Forests and Adaptation to Climate Change: In Search of Synergies*. (ed. Robledo, C, Kanninen, M & Pedroni, L). Borgor Barat: Center for International Forestry Research. See 'maintenance of mangroves' and 'maintenance of saltmarsh, wetlands and inter-tidal ecosystems' references.	
Maintenance of saltmarsh, wetlands, inter-tidal ecosystems	**Onshore buffer**	**Wave energy dissipation, erosion reduction, floodplain provision**	Barbier, E B 2008 *In the wake of tsunami: Lessons learned from the household decision to replant mangroves in Thailand.* Resource and Energy Economics, **30**(2), 229-249. Brampton, A H 2002 *ICE Design and Practice Guide: Coastal Defence*. London: Thomas Telford. Costanza, R, Perez-Maqueo, O, Luisa Martinez, M, Sutton, P, Anderson, S J & Mulder, K 2008 *The Value of Coastal Wetlands for Hurricane Protection*. Ambio, **37**(4), 241-248 (DOI: http://dx.doi.org/10.1579/0044-7447(2008)37[241:TVOCWF]2.0.VO;2). Friess, D A, Krauss, K W, Horstman, E M, Balke, T, Bouma, T J, Galli, D & Webb, E L 2012 *Are all intertidal wetlands naturally created equal? Bottlenecks, thresholds and knowledge gaps to mangrove and saltmarsh ecosystems*. Biological Reviews. **87**, 346–366 (DOI: 10.1111/j.1469-185X.2011.00198.x). Maris, T, Cox, T, Temmerman, S, de Vleeschauwer, P, van Damme, S, de Mulder, T, van den Bergh, E and Meire P 2007 *Tuning the tide: creating ecological conditions for tidal marsh development in a flood control area*. Hydrobiologia **588**, 31–43 (DOI 10.1007/s10750-007-0650-5). Möller, I, Kudella, M, Rupprecht, F, Spencer, T, Paul, M, van Wesenbeeck, B K, Wolters, G, Jensen, K, Bouma, T J, Miranda-Lange, M & Schimmels S 2014 *Wave attenuation over coastal salt marshes under storm surge conditions*. Nature Geoscience **7**, 727–731 (DOI:10.1038/ngeo2251). **Continued on next page**	• Wetland habitats induce wave and tidal energy dissipation by increasing the roughness of the surface over which incoming waves and tides travel, this reduces the erosive power and waves and diminishes the height of storm surges. • They act as a sediment trap for materials, thus helping to build land seawards and the dense root mats of wetland plants also helps to stabilise shore sediments, reducing erosion. • Additional benefits can include providing new habitats and environmental benefits including carbon sequestration, water quality improvements (suppresses the growth of toxic algae and stimulates phytoplankton growth, which is essential for the food web), nature conservation, fisheries production and the creation of recreational space. • Wetlands, saltmarshes and mangroves may also cause a reduction in installation and maintenance costs of sea defences behind them. • Management of some wetland habitats require greater expertise than others, many wetland restoration and maintenance projects are implemented by communities at a local scale. • Governmental adoption of proactive coastal management plans to protect, enhance, restore and create marine habitats is necessary as without such a framework, action to restore wetlands is likely to be fragmented and uncoordinated. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page National Research Council 1994 *Restoring and protecting marine habitat: the role of engineering and technology*. Washington, DC: National Academy Press. Nicholls, R J & Klein, R J T 2005 *Climate change and coastal management on Europe's coast. From: Managing European Coasts Past, Present and Future*. Berlin: Springer-Verlag. Platong, J 1998 *Status of mangrove forests in southern Thailand. Wetlands International- Thailand Programme*. Hat Yai, Thailand, Publication 5. Saenger, P & Siddiqi, N A 1993 *Land from the sea: The mangrove Afforestation program of Bangladesh*. Ocean and Coastal Management, **20**(1), 23-39. Shepard, C C, Crain, C M & Beck, M W 2011 *The protective role of coastal marshes: a systematic review and meta-analysis*: PLoS ONE (DOI: 10.1371/journal.pone.0027374). Temmerman, S, Meire, P, Bouma, T J, Herman, P M J, Ysebaert, T & de Vriend, H J 2013 *Ecosystem-based coastal defence in the face of global change*. Nature, **504**(7478), 79-83 (DOI: 10.1038/nature12859). White, P C L, Godbold, J A, Solan, M, Wiegand, J, & Holt, A R 2010 *Ecosystem services and policy: A review of coastal wetland ecosystem services and an efficiency based framework for implementing the ecosystem approach. In Ecosystem Services* (ed. Harrison, R M & Hester R E). Cambridge: The Royal Society of Chemistry. Wolters, M, Garbutt, A & Bakker, J P 2005 *Salt-marsh restoration: evaluating the success of de-embankments in north-west Europe*. Biological Conservation. **123**, 249–268 (DOI:10.1016/j.biocon.2004.11.013). See 'maintenance of mangroves', 'mangrove planting & re-establishment' and 'maintenance of other coastal vegetation, forest and ecosystems' references.	**Continued from previous page** • Barriers to the protection and reestablishment of wetlands include a lack of public awareness of the flood and erosion protection benefits offered by these ecosystems and in some tropical and subtropical areas a fear that wetlands may facilitate mosquito breeding and disease transmission.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Maintenance of other coastal vegetation, forest & ecosystems	**Onshore buffer**	**Wave energy dissipation, erosion reduction**	Renaud, F G, Sudmeier-Rieux, K & Estrella, M 2013 *The Role of Ecosystems in Disaster Risk Reduction*. New York: United Nations University Press. See 'maintenance of saltmarsh, wetlands, inter-tidal ecosystems' references.	• Coastal vegetation acts as a partial barrier on the coastline and can dissipate incoming wave energy and thus erosion. Energy dissipation is dependent on the density of vegetation and its porosity. • Primary species such as creepers and grasses on sand dunes (behind the frontal dune crest) make the sand more stable, and are effectively wind breakers. Further back, large trees perform a similar function. • Vegetation will restrict wave propagation up to a specific water level, beyond which overtopping will take place. Once the threshold is exceeded the vegetation itself will erode rapidly and be destroyed even at moderate water depth. • Removing and degrading coastal vegetation can increase the risk of flooding. • One of the largest barriers to the maintenance of coastal vegetation is the loss of land to development.
Coastal re-vegetation / afforestation (above inter-tidal zone)	**Onshore buffer**	**Wave energy dissipation, erosion reduction**	See 'maintenance of other coastal vegetation, forest & ecosystems' and 'maintenance of saltmarsh, wetlands, inter-tidal ecosystems' references.	See 'maintenance of other coastal vegetation, forest and ecosystems' summary.
Beach and dune nourishment	**Onshore buffer**	**Wave energy dissipation, erosion reduction**	Dean, R G 2002 *Beach Nourishment Theory and practice*. Singapore: World Scientific Publishing. Linham, M, Nicholls, R & Zhu X (ed.) 2010 *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. Roskilde: UNEP. See http://orbit.dtu.dk/fedora/objects/orbit:86544/datastreams/file_5699563/content, accessed 13.10.2014. Lubke, R A, 1985 *Erosion of the beach at St Francis Bay, Eastern Cape, South Africa*. Biological Conservation **32**, 99-127. Nicholls, R J, Cooper, N & Townend, I H 2007 *The management of coastal flooding and erosion*. In Future Flood and Coastal Eorison Risks (ed. Thome, C R & Evans, E P). London: Thomas Telford. Reeve, D, Chadwick, A & Fleming, C 2004 *Coastal Engineering Processes, Theory and Design Practice*. Abingdon: Spon Press.	• Beach and dune nourishment is the artificial addition of sediment to beach areas with sediment deficits, this technique is generally applied to sandy beaches. • Beach nourishment is a flexible coastal management solution as it is reversible. • Beach and dune nourishment allows wave energy dissipation, by creating 'dissipative' (wide and shallow) beach profiles and gradients. • Beach nourishment does not stop erosion, but provides sediment from external sources upon which erosional forces continue to act. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
				Continued from previous page • Due to longshore drift causing sediment redistribution, beach nourishment often positively impacts adjacent areas which were not directly undernourished, perhaps reducing erosion for the entire coastal cell. • Beach widening can also promote tourism and recreational activities. Ecological benefits include enhanced nesting sites for sea turtles when designed with these requirements in mind. • Disadvantages include the high maintenance costs for period re-nourishment, increasing a false sense of security for coastal development and high (maintenance) costs due to transport distance for beach material. Costs may be higher in the developing world as the coastal engineering industry is less developed.
Artificial reefs (and/or substrates for reef replenishment)	**Offshore buffer zone creation**	**Wave energy dissipation, likely to reduce coastal erosion**	Adger, W N, Hughes, T P, Folke, C, Carpenter, S R & Rockström, J 2005 *Social-Ecological Resilience to Coastal Disasters*. Science, **309**(5737), 1036-1039 (DOI: 10.1126/science.1112122). Perkol-Finkel, S, Shashar, N & Benayahu, Y 2006 *Can artificial reefs mimic natural reef communities? The roles of structural features and age*. Marine Environmental Research, **61**(2), 121–135 (DOI: 10.1016/j.marenvres.2005.08.001). See 'maintenance of natural reefs' references.	• The application of engineering approaches to the rebuilding of coral reefs. • These artificial reefs have been found to contain similar structural features to natural reefs but they have not been shown to work at meaningful scales. • They do not address the root causes of regional-scale degradation of reefs and therefore do not provide realistic solutions to the increased global threats to coral reefs. • The role of reefs as coastal defences and how to restore these benefits needs to be addressed in greater detail. See 'maintenance of natural reefs' summary.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Dyke, levee	**Physical barrier**	**Wave energy dissipation, erosion reduction**	Brampton, A H 2002 *ICE Design and Practice Guide: Coastal Defence*. London: Thomas Telford. French, P W 2001 *Coastal defences: Processes, Problems and Solutions*. London: Routledge. Hillen, M M, Jonkman, S N, Kanning, W, Kok, M, Geldenhuys, M A & Stive, M J F 2010 *Coastal defence cost estimates. Case study of the Netherlands, New Orleans and Vietnam*. The Netherlands: TU Delft. Linham, M, Nicholls, R & Zhu, X (ed.) 2010 *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. Roskilde: UNEP. See http://orbit.dtu.dk/fedora/objects/orbit:86544/datastreams/file_5699563/content, accessed 13.10.2014. Mai, C V, van Gelder, P H A J M, Vrijiling, J K & Mai, T C 2008 *Risk Analysis of Coastal Flood Defences- A Vietnam case*. The 4th international symposium on flood defence; managing flood risk, reliability and vulnerability. Toronto: Institute for catastrophic loss reduction.	• Dykes provide a high degree of protection to low-lying coastal areas and are the cheapest hard defence when the value of coastal land is low. • A large area of land is required which can be problematic as coastal areas often have high associated land values. • Permanently fixing the position of the coastline can have negative effects on a dynamic coastline as natural processes such as responses to sea level changes, beach/dune interactions and sediment input from coastal erosion are prevented. • Dykes can, however, be implemented in conjunction with other methods, which can address the negative impacts. • Dykes require ongoing maintenance to ensure the structure continues to provide design levels of protection, this can incur substantial costs. • Dykes can create a false sense of security on the landward side of the defences.
Coastal barrage	**Physical barrier**	**Wave energy dissipation, erosion reduction**	Kazi, A 2014 *A review of the assessment and mitigation of floods in Sindh, Pakistan*. Natural Hazards, **70**(1), 839-864 (DOI: 10.1007/s11069-013-0850-4). Linham, M, Nicholls, R & Zhu, X (ed.) 2010 *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding*. Roskilde: UNEP. See http://orbit.dtu.dk/fedora/objects/orbit:86544/datastreams/file_5699563/content, accessed 13.10.2014. Nicholls, R J 2006 *Storm Surges in Coastal Areas. In Natural Disaster Hotspots. Case Studies* (ed. Arnold, M, Chen, R S, Deichmann, U, Dilley, M, Lerner-Lam, A L, Pullen, R E & Trohanis, Z). Washington, DC: The World Bank. Townend, I & Burgess, K 2004 *Methodology for assessing the impact of climate change upon coastal defence structures. In Proceedings of the 29th International Conference on Coastal Engineering 2004* (ed. McKee Smith, J). London: World Scientific. Xia, J, Falconer, R A, Lin, B & Tan, G 2011 *Estimation of future coastal flood risk in the Severn Estuary due to a barrage*. Journal of Flood Risk Management, **4**(3), 247-259 (DOI: 10.1111/j.1753-318X.2011.01106.x).	• Coastal barrages are engineered structures designed to prevent storm surges entering low-lying estuarine areas. • Barrages have high capital and maintenance costs, but can reduce construction and maintenance costs for defences on their landward side. • Construction and maintenance costs are likely to increase into the future in response to sea level rise. • Barrages can offer potential additional benefits including improvement of coastal water quality, and can provide additional services eg recreation, power production and water supply. • Barrier projects can also act as a catalyst for development of newly protected areas eg Thames Barrier spurred the regeneration of London derelict docklands with new transport links, homes, businesses and the important financial district around Canary Wharf.

River flooding

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Re-establishment of floodplains, 'green rivers'	**Reduced magnitude of flooding events in target areas**	**Controlled flooding of designated areas to reduce discharge in main river channel downstream**	De Boer, C & Bressers, H 2011 *Analysing the Renaturalization of the Dutch Regge River: Complex and Dynamic Implementation processes*. The Netherlands: University of Twente. See http://doc.utwente.nl/77862/4/Complex_and_Dynamic_Implementation_Processes_-_Regge_River_(2).pdf, accessed 13.10.2014. De Laney, T A 1995 *Benefits to downstream flood attenuation and water quality as a result of constructed wetlands in agricultural landscapes*. Journal of Soil and Water Conservation, **50** (6), 620-626. Doswald, N & Osti, M 2011 *Ecosystem-based approaches to adaptation and mitigation- good practice examples and lessons learned in Europe*. Bonn: Federal Agency for Nature Conservation. See http://www.bfn.de/fileadmin/MDB/documents/service/Skript_306.pdf, accessed 13.10.2014. Harvey, J W, Conklin, M H & Koelsch, R S 2003 *Predicting changes in hydrologic retention in an evolving semi-arid alluvial stream*. Advances in Water Resources, **26**, 939–950. (DOI: 10.1016/S0309-1708(03)00085-X). van der Hurk, M, Mastenbroek, W & Meijerink, S 2014 *Water safety and spatial development: An institutional comparison between the United Kingdom and the Netherlands*. Land Use Policy, **36**, 416-426 (DOI: 10.1016/j.landusepol.2013.09.017). Lane, S N & Milledge, D G 2013 *Impacts of upland open drains upon runoff generation: a numerical assessment of catchment-scale impacts*. Hydrological Processes, **27**(12), 1701-1726 (DOI: 10.1002/hyp.9285). Nepf, H, Ghisalberti, M, White, B & Murphy, E 2007 Retention time and dispersion associated with submerged aquatic canopies. Water Resources Research, **43**(4) (DOI:10.1029/2006WR005362). See 'natural flood management' references.	• River and flood plain renaturation is the main ecosystem based approach used in Europe to mitigate current flooding risk. This term can include riverbed alterations, dyke relocation, habitat restoration, creation and protection and the removal of invasive species. • Renaturation restores rivers and canals to more natural meandering rivers and restores the surrounding landscape, this reduces rate of water flow and therefore decreases the likelihood of downstream flooding. • Increased submerged vegetation leads to an increase in flow resistance and a subsequent reduction in conveyance capacity. • Upland drains, grips, have higher flow velocities than overland flow, thus potentially delivering flow more rapidly to the drainage network, reducing upland drainage can reduce the risk of flooding downstream. • Flood plain restoration has potentially serious socio-economic costs, threatening existing agricultural land and settlements which may cause local opposition. • Early communication with local communities can forestall common challenges and enable better land use zoning and ensuring the derivation of maximum benefits to the communities by understanding what is wanted or needed. • There are often additional benefits with respect to biodiversity (these projects are often combined with nature conservation projects) as well as opportunities for tourism and recreation. See 'natural flood management' summary.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Catchment afforestation, increased vegetation cover	Reduced stream discharge; water capture; reduced risk of flash flooding	Increased interception and infiltration by trees/roots	Anderson, H W, Hoover, M D & Reinhart, K G 1976 *Forests and water: Effects of forest management on floods, sedimentation and water supply. General Technical Report PSW-018*. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. Archer, N A L, Bonell, M, Coles, N, MacDonald, A M, Auton, C A & Stevenson, R 2013 *Soil characteristics and landcover relationships on soil hydraulic conductivity at hillslope scale: A view towards local flood management*. Journal of Hydrology, **497**, 208-222 (DOI: 10.1016/j.jhydrol.2013.05.043). Bulygina, N, McIntyre, N & Wheater, H 2011 *A comparison of rainfall-runoff modelling approaches for estimating impacts of rural land management on flood flows*. Hydrological Research, **44**(3), 467-483 (DOI:10.2166/nh.2013.034). Calder, I,R & Aylward, B 2006 *Forest and floods: Moving to an Evidence-based approach to watershed and integrated flood management*. Water International, **31**(1), 1-13 (DOI:10.1080/02508060608691918). Carroll, Z L, Bird, S B, Emmett, B A, Reynolds, B & Sinclair, F L 2004 *Can tree shelterbelts on agricultural land reduce flood risk?* Soil Use and Management, **20**(3), 357-359. van Dijk, A I J M & Keenan, R J 2007 Planted forests and water in perspective. Forest Ecology and Management, **251**(1-2), 1-9 (DOI: 10.1016/j.foreco.2007.06.010). Jackson, B M, Wheater, H S, Mcintyre, N R, Chell, J, Francis O J, Frogbrook, Z, Marshall, M, Reynolds, B & Solloway, I 2008 *The impact of upland land management on flooding: insights from a multiscale experimental and modelling programme*. Journal of Flood Risk Management, **1**(2) 71-80 (DOI: 10.1111/j.1753-318X.2008.00009.x). Lull, H W & Reinhart, K G 1972 *Forests and floods in the eastern United States. Res. Pap. NE-226*. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, North-eastern Forest Experiment Station. **Continued on next page**	• Catchment afforestation and increased vegetation cover play a role in flood risk reduction but not prevention. • Trees contribute to greater hydraulic roughness of floodplains (which slows water flow) and increase soil permeability to water. • Natural management of the upper catchment has potential to reduce the risk of flash flooding, but is unlikely to have a serious effect on major downstream flooding events under extreme rainfall. • Natural obstacles in-stream can slow flow rates but there is limited data on how effectively this reduces flood risk. • The role of afforestation in flood risk reduction is dependent on local conditions, the placement and management of interventions and is relative to the scale of the hazard. • Interception and infiltration (and so flood risk reduction) may be greater in natural forests than plantation forests. Research at the Scottish Borders also found that the soil permeability of aged broadleaf forest was 5-8x greater than neighbouring grassland, giving greater capacity to infiltrate high intensity rainfall. • There are potential benefits to biodiversity but this is dependent on target species/habitats. See 'planting of riparian 'buffers'' and 'changes to catchment agricultural land management' summaries.

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
			Continued from previous page Marshall, M R, Francis, O J, Frogbrook, Z L, Jackson, B M, McIntyre, N, Reynolds, B, Solloway, I, Wheater, H S & Chell, J 2009 *The impact of upland land management on flooding: results from an improved pasture hillslope*. Hydrological Processes, **23**(3), 464-475 (DOI: 10.1002/hyp.7157). McIntyre, N and Marshall, M 2010 *Identification of rural land management signals in runoff response*. Hydrological Processes, **24**(24) 3521-3534 (DOI: 10.1002/hyp.7774). See 'planting of riparian 'buffers'' references.	
Maintenance of existing vegetation	**Water capture etc**	**Water interception and infiltration**	See 'catchment afforestation, increased vegetation cover', 'planting of riparian 'buffers'' and 'changes to catchment agricultural land management' references.	See 'catchment afforestation, increased vegetation cover', 'planting of riparian 'buffers'' and 'changes to catchment agricultural land management' summaries.
Planting of riparian 'buffers'	**Intercept base- and flood-flow inputs from catchment**	**Groundwater and/or surface flow pass through buffer soils prior to entering stream**	Bren, L J 1993 *Riparian Zone, stream and floodplain issues: A review*. Journal of Hydrology, **150**(2-4), 277-299. (DOI: 10.1016/0022-1694(93)90113-N). Nisbet, T 2004 *Interactions between floodplain woodland and the freshwater environment*. UK: Forest Research. See http://www.forestry.gov.uk/website/pdf.nsf/pdf/FR_report_2004-5_floodplain.pdf/$FILE/FR_report_2004-5_floodplain.pdf, accessed 13.10.2014. Nisbet, T, Silgram, M, Shah, N, Morrow, K & Broadmeadow, S 2011 *Woodland for water: Woodland measures for meeting Water Framework Directive objectives*. UK: Forest Research. See http://www.forestry.gov.uk/pdf/FRMG004_Woodland4Water.pdf/$file/FRMG004_Woodland4Water.pdf, accessed 13.10.2014. Rolls, S & Sunderland, T 2014 *Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2). Natural England Research Reports, Number 057*. Bristol: Natural England. See 'catchment afforestation, increased vegetation cover', 'changes to catchment agricultural land management' and 'natural flood management' references.	• Forests can contribute to reductions in water runoff and velocity. However this is heavily dependent on the individual catchment context eg slope, vegetation type, soil condition and broader catchment hydrology. • Additional benefits can include increased biodiversity and water quality. See 'catchment afforestation, increased vegetation cover', 'changes to catchment agricultural land management' and 'natural flood management' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Changes to catchment agricultural land management	**Reduced run-off rate; increased water capture**	**Reduced soil compaction (machinery, livestock); reduced upland drainage; reduced vegetation removal**	Burek, P, Mubareka, S, Rojas, R, de Roo, A, Bianchi, A, Baranzelli, C, Lavalle, C & Vandecasteele, I 2012 *Evaluation of the effectiveness of natural water retention measures*. Italy: Joint Research Centre of the European Commission. Lane, S N, Brookes, C J, Hardy, R J, Holden, J, James, T D, Kirkby, M J, McDonald, A T, Tayefi, V & Yu, D 2003 *Land management, flooding and environmental risk: New approaches to a very old question*. Proceedings of the CIWEM National Conference. Robinson, M 1990 *Impact of improved land drainage on river flows*. Wallingford, UK: Institute of Hydrology. See http://core.kmi.open.ac.uk/download/pdf/60661.pdf, accessed 13.10.2014. Wilson, L, Wilson, J, Holden, J, Johnstone, I, Armstrong, A & Morris, M 2011 *The impact of drain blocking on an upland blanket bog during storm and drought events, and the importance of sampling-scale*. Journal of Hydrology, **404**(3-4), 198-208 (DOI: 10.1016/j.jhydrol.2011.04.030). See ‘catchment afforestation, increased vegetation cover’, ‘planting of riparian ‘buffers’’ and ‘natural flood management’ references.	• Run-off from farms can be reduced by installing grass buffers, temporary ponds, grassed waterways in headwater valley bottoms, changing crop cultivation practices on arable land, appropriate ditching and decanalisation. • Re-blocking drainage has been shown to lower peak flow rates during storms. • The contribution of agricultural drainage to flash flooding is dependent both on the location of the drainage and local conditions such as soil type. • There is little evidence that less intensive farming will always reduce flood risk however these types of farms have less of the factors supporting rapid runoff and have healthier soil. See ‘catchment afforestation, increased vegetation cover’, ‘planting of riparian ‘buffers’’ and ‘natural flood management’ summaries.
‘Natural’ flood management	**Reduced flow velocity; water storage**	**Natural instream obstructions (eg ‘woody debris dams’) slow water flow, facilitate local flooding to reduce discharge rate**	Frontier Economics, Irbaris & Ecofys 2013 *Economics of climate resilience natural environment theme: Natural flood management CA0401* London: Frontier Economics Ltd. See http://randd.defra.gov.uk/Default, accessed 13.10.2014. Government Office for Science 2004 *Future Flooding*. London: Government Office for Science. See https://www.gov.uk/government/publications/future-flooding, accessed 13.10.2014. **Continued on next page**	• Natural flood management is a term which described the natural management of waterways allowing instream obstructions such as woody debris to slow water flow. • Research has shown that natural flood management at the local scale can deliver benefits, it is most effective in reducing the frequency of flooding for high probability fluvial events. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Howgate, O R & Kenyon, W 2009 *Community cooperation with natural flood management: a case study in the Scottish Borders*. Area, **41**(3), 329-340 (DOI: 10.1111/j.1475-4762.2008.00869.x). Nisbet, T R & Thomas, H 2008 *Project SLD2316: Restoring floodplain woodland for flood alleviation*. London: DEFRA. See http://www.forestry.gov.uk/pdf/defra_floodplain_report_15june2008.pdf/$FILE/defra_floodplain_report_15june2008.pdf, accessed 13.10.2014. Nisbet, T R, Marrington, S, Thomas, H, Broadmeadow, S & Valatin, G 2011 *Project RMP5455: Slowing the flow at Pickering*. London: DEFRA. See http://www.forestry.gov.uk/fr/INFD-7ZUCQY#final1, accessed 13.10.2014. See 'catchment afforestation', 'increased vegetation cover', 'planting of riparian 'buffers'' and 'changes to catchment agricultural land management' references.	**Continued from previous page** • Natural flood management can be used alone or as part of a package of other soft/hard engineering measures. For example in combination with detention basins water storage in rural areas can reduce peak flow by 8 – 60%. • Most reported natural flood management programs have been carried out at a small scale. The complexity of systems makes scaled-up approaches less certain. • Possible additional benefits include improving water quality, carbon sequestration and habitat restoration. • Implementation of these projects may resisted by land-owners who are often reluctant to adopt the measures proposed because of a lack of private return from changing land-use from agricultural production. The long lag periods between implementation and benefits being realised, together with the number of parties also acts to delay or prevent implementation. • Successful projects have relied upon good communication and engagement with the community to over-ride hostility and ensure successful project implementation. • More research is needed into the effectiveness of these measures, especially at larger scales. See 'catchment afforestation', 'increased vegetation cover', 'planting of riparian 'buffers'' and 'changes to catchment agricultural land management' summaries.
Stream habitat 'restoration'	**Improve bank stability, reduce peak flows**	**Increased sinuosity in channel, construction of bars and grading of banks**	Bechtol, V, Laurian, L 2005 *Restoring straightened rivers for sustainable flood mitigation*. Disaster Prevention and Management, **14**(1), 6-19. Buijse, A D, Klijn, F, Leuven, R S E W, Middelkoop, H, Schiemer, F, Thorp, J H & Wolfert, H P 2005 *Rehabilitation of large rivers: references, achievements and integration in river management*. Large Rivers **15**(1-4), 715-738. **Continued on next page**	• Reconnection of the river and floodplain increases area available for plant communities and improves water regimes. This increases hydraulic storage and conveyance capacity to dampen low-level water level fluctuations and reducing the peak flow of major floods. • Full rehabilitation of many streams is utopian due to the manifold functions they perform, therefore current attempts have only recovered stretches or certain features. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
			Continued from previous page Nienhuis, P H & Leuven, R S E W 2001 *River restoration and flood protection: controversy or synergism?* Hydrobiologica, **444**, 85-99 (DOI 10.1023/A:1017509410951). Palmer, M A, Hondula, K L & Koch, B J 2014 *Ecological restoration of streams and rivers: Shifting strategies and shifting goals*. Annual Review of Ecology, Evolution and Systematics, **45** (DOI: 10.1146/annurev-ecolsys-120213-091935). Smits, A J M, Nienhais, P H & Leuven, R S E W (ed.) 2000 *New approaches to river management*. Leiden: Backhuys. Sparks, R, Ahn, C, Demissie, M, Isserman, A, Johnston, D, Lian, Y, Ndeovic-Budic, Z & White, D 2005 *Linking hydrodynamics, conservation biology and economics in choosing naturalisation alternatives for the Illinois River, USA*. Large Rivers **15**(1-4), 521-538. de Waal, L C, Large, A R G, Gippel, C J & Wade, P M 1996 *River and floodplain rehabilitation in Western Europe: opportunities and constraints*. Large Rivers **9**, 679–693.	**Continued from previous page** • Although river rehabilitation is often more expensive than anticipated the significant benefits it brings make this type of flood management cost-effective. • An increase in ecotourism and recreation may in some cases compensate for the loss of agricultural jobs and productivity.
Dam	**Physical barrier; water storage**	**Retains water in reservoir to reduce downstream discharge rate and flood risk**	Hayashi, S, Murakami, S, Xu, K-Q & Watanabe, M 2008 *Effect of the Three Gorges Dam Project on flood control in the Dongting Lake area, China, in a 1998-type flood*. Journal of Hydro-Environment Research, **2**(3), 148-163. International Commission on Irrigation and Drainage (ICID) 2000 *ICID Position Paper: Role of Dams for Irrigation, Drainage and Flood Control*. New Delhi: ICID. See http://www.icid.org/dam_pdf.pdf, accessed 13.10.2014. Kingsford, R T 2000 *Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia*. Austral Ecology, **25**(2), 109-127 (DOI: 10.1046/j.1442-9993.2000.01036.x). **Continued on next page**	• Dams enable water to be retained in a reservoir which can reduce the downstream discharge rate and therefore the flood risk. • The construction of dams is costly and often faces opposition from local groups and environmental and social grounds. • Dams can have positive economic impacts by reducing peak flows and floods that cause agricultural and non-agricultural losses. Intensive economic development has been realised on numerous rivers such as the Mississippi, Nile, Tennessee, and Damodar rivers because of flood protection provided by dams. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
			Continued from previous page Kingsford, R T & Thomas, R F 2001 *Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee River in arid Australia*. Hurstville, Australia: New South Wales National Parks and Wildlife Service. Sims, H 2001 *Moved, left no address: dam construction, displacement and issue salience*. Public Administration and Development, **21**(3), 187-200 (DOI: 10.1002/pad.165). Walker, K F & Thoms, M C 1993 *Environmental effects of flow regulation on the Lower River Murray, Australia*. Regulated Rivers: Research & Management, **8**(1-2), 103-119. Williams, G P & Wolman, M G 1984 *Downstream effects of dams on alluvial rivers. U.S.* Washington: United States Government Printing Office. See http://relicensing.pcwa.net/documents/Library/PCWA-L-307.pdf, accessed 13.10.2014.	**Continued from previous page** • Dams can have a significant ecological impact, reduced water flow can damage floodplain wetlands; dam releases can cause scouring and armouring of the riverbed, removing a complex set of habitats; and the retention of sediment and debris can have significant implications for ecosystems downstream. • Potential additional benefits include hydroelectricity, irrigation support and assisting navigation. However if storage is used for the generation of hydropower then seasonal flow may be enhanced, ameliorating difficulties downstream.
Drain, dyke, levee, sluice, pump	**Flood management, drainage**	**Water regulation through drainage channels, physical barriers, and active pumps**	Gergel, S E, Dixon, M D & Turner, M G 2002 *Consequences of human-altered floods: levees, floodplains and foodplain forests along the Wisconsin River*. Ecological Applications, **12**(6), 1755-1770. Heine, R A & Pinter, N 2012 *Levee effects upon flood levels: an empirical assessment*. Hydrological Processes, **26**(21), 3225-3240 (DOI: 10.1002/hyp.8261). Lane, S N & Milledge, D G 2013 *Impacts of upland open drains upon runoff generation: a numerical assessment of catchment-scale impacts*. Hydrological Processes, **27**(12), 1701-1726 (DOI: 10.1002/hyp.9285). Nunnally, N R, Shields, F D Jr. & Hynson, J 1987 *Environmental considerations for levees and floodwalls*. Environmental Management **11**(2),183–191 (DOI: 10.1007/BF01867197). Smith, S D, Wellington, A B, Nachlinger, J L & Fox, C A 1991 *Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada*. Ecological Applications **1**(1), 89–97. **Continued on next page**	• Water flow is redirected to decrease flooding or to harvest water to off-river storages. This can protect towns, crops and homesteads. • Drains can improve the productivity of agricultural land but can in some cases impact on flooding downstream. • Levees are effective flood control measures and are relatively cheap to implement and build. While well established in some cases there is little evidence as to the effectiveness of these options. • Levee construction reduces the area of the floodplain open to storage of flood waters and reduces the width of the floodplain open to conveyance of flood flow. This increases the flood height and velocity, increasing the risk if the levee fails. Levees may also impact the hydrological regime up and downstream and exacerbate flooding in these locations. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
			Continued from previous page Tobin, G A 1995 *The Levee Love Affair: A stormy relationship?* Journal of the American Water Resources Association, **31**(3), 359-367 (DOI: 10.1111/j.1752-1688.1995.tb04025.x).	**Continued from previous page** • Mainline levees (adjacent to the channel) are more risky than setback levees which are a compromise by maintaining the abundance of tree species in unleveed areas whilst also allowing flood control. • Levees can have significant environmental impact both on the river and the surrounding flood plain.
Dredging	**Flood management, increased stream discharge**	**Increased capacity of water channels allowing increased discharge of water load**	Chartered Institution of Water and Environmental Management (CIWEM) 2014 *Floods and Dredging – a reality check*. London: CIWEM. Environment Agency 2011 *Dredging Pilot Studies Report*. Bristol: Environment Agency. See http://webarchive.nationalarchives.gov.uk/20140328084648/http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0411btqg-e-e.pdf, accessed 13.10.2014. Kok, G. 2006 *Macro and micro dredging as a tool for mitigating floods and droughts in the Red River Delta, Vietnam*. Terra et Aqua, **103**, 3-13. See https://www.iadc-dredging.com/ul/cms/terraetaqua/document/1/5/4/154/154/1/terra-et-aqua-nr103-01.pdf, accessed 13.10.2014.	• Dredging is defined as the systematic removal of accumulated material from river or other watercourse channels. In its most extreme form, dredging may be used to realign river channels creating linear, canalised watercourses. • By increasing the channel gradient the channel the efficiency of water movement is increased, leading to a reduction in water levels and in fluvial flood frequency. However for large and less frequent floods, dredging is not practical to the extent that would be required to confine such events as the storage and conveyance capacity of the channel is a small fraction of the wider flood plain, so cannot prevent flooding in these cases. • When flow rate is impeded by channel constriction eg a bridge or high downstream water levels eg tide locking, and in-channel structures, dredging may provide no benefits during extreme events. • Negative consequences of dredging include increasing flood risk for communities downstream by speeding up the movement of flood water through the river and drainage network, destabilising river banks, causing erosion and risking damage to infrastructure, loss of wildlife and habitats both within the river and across the wider floodplain and reduction in water quality. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	**Summary**
				Continued from previous page • Dredging is rarely a one-off activity therefore there are continuous maintenance costs as material will re-accumulate over time and the river will re-adjust to a more natural form with unintended consequences including bank failure and erosion. • Additional benefits of dredging include biodiversity measures; ditches in artificial environments such as drained fenlands have adapted to exploit niches created by river management- pioneer species rely on a certain level of disturbance.
Canalization of urban streams	**Conveyance of flood flows**	**Focuses on shunting water quickly to downstream systems**	Marsalek, J, Jiménez-Cisneros, B, Karamouz, M, Malmquist, P-A, Goldenfum, J & Chocat, B 2007 *Urban water cycle processes and interactions*. Paris: UNESCO & Leiden: Taylor and Francis. Tucci, C M E 2007 *Urban Flood Management*. Geneva: World Meteorological Organization.	• Canalization of urban streams rapidly moves water away from the urban area. • Canalization may increase the land available for development. • Disadvantages include an increased risk of downstream flooding and a loss of biodiversity.
Sustainable urban drainage systems (SUDS)	**Water capture, storage and filtration; reduced risk of flash flooding in urban areas**	**Use of 'natural' processes/ habitats to decrease surface flow in urban areas through water capture and storage.**	Duffy, A, Jefferies, C, Waddell, G, Shanks, G, Blackwood, D & Watkins, A 2008 *A cost comparison of traditional drainage and SUDS in Scotland*. Water Science and Technology, **57**(9), 1451–1459 (DOI:10.2166/wst.2008.262). Forest Research 2010 *Benefits of Green Infrastructure*. Farnham, UK: Forestry Research. See http://www.forestry.gov.uk/pdf/urgp_benefits_of_green_infrastructure.pdf/$FILE/urgp_benefits_of_green_infrastructure.pdf, accessed 13.10.2014. Gill, S E, Handley, J F, Ennos, A R & Pauleit, S 2007 *Adapting cities for climate change: the role of the green infrastructure*. Built Environment **33**(1), 115–133. Graham, A, Day, J, Bray, B & Mackenzie, S 2012 *Sustainable drainage systems: Maximising the potential for people and wildlife*. Slimbridge, UK: Wildfowl and Wetlands Trust and Lodon: RSPB. See www.rspb.org.uk/Images/SuDS_report_final_tcm9-338064.pdf, accessed 13.10.2014. **Continued on next page**	• Sustainable urban drainage systems reduce the flow and volume of storm-water entering drainage systems in 3 ways: i) delaying the downstream passage of flood flows, ii) reducing the volume of runoff through interception, and iii) promoting rainfall infiltration into the soil. • A mixture of approaches are used which filter or retain water near where it falls, offering flood protection and biodiversity benefits eg swales, filter strips). • Urban green infrastructure plays an important role in 'climate proofing' cities and towns and supports carbon capture whilst larger woodlands can support timber products and by-products from street tree management can provide renewable energy, mulches and composts. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Mentens, J, Raes, D & Hermy, M 2006 *Green roofs as a tool for solving the rainwater runoff problems in the urbanized 21st century?* Landscape and Urban Planning **77**(3), 217–226 (DOI: 10.1016/j.landurbplan.2005.02.010). Rolls, S. & Sunderland, T 2014 *Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2).* Bristol: Natural England Research Reports. See http://publications.naturalengland.org.uk/publication/6692039286587392, accessed 13.10.2014. Xiao, Q, McPherson, E G, Simpson, J, R & Ustin, S L 1998 *Rainfall interception by Sacramento's urban forest*. Journal of Arboriculture, **24**(4), 235-244.	**Continued from previous page** • Sustainable urban drainage systems have been found to be cost-effective flood control mechanisms. Capital costs of traditional drainage are over double the capital costs of SUDS, annual; maintenance costs are 20-25% cheaper for SUDS and SUDS are half the costs over a 60 year life span. • They are most effective for smaller storms. Canopies become saturated during larger storms so effectiveness is limited. Effectiveness varies according to climate, tree species and time of year. • Additional benefits include better air and water quality and the provision of buffers for habitats and species. Sustainable urban drainage systems can have health and well-being benefits

Drought

Intervention	Aim	Process / Mechanism	Evidence: References	Evidence: Summary
Removal of 'thirsty' invasive plant species	**Decrease competition for water**	**Removal of invasive plants with high uptake of groundwater**	Boy, G 2013 *Invasive alien plants and their management in Africa*. Nairobi: UNEP/GEF. de Wit, M P, Crookes, D J, & van Wilgen, B W 2001 *Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion*. Biological Invasions, **3**(2), 167-178 (DOI 10.1023/A:1014563702261). Parish, G, Anhalt, G & Sellar J S 2006 Thirsty Plants, dry soil: Changes in soil moisture content after removal of invasive species. CW Journal, **4**(2), 11-17. Parish G & Sellar J 2007 *Thirsty Plants — Hydrological changes accompanying removal of invasive plants at Midewin national tallgrass prairie*. In *World environmental and water resources congress 2007: Restoring our natural habitat* (ed. Kabbes, K C). Reston, Virginia: American Society of Civil Engineers. Turpie, J K, O'Connor, T, Mills, A & Robertson, H 2007 *The ecological and economic consequences of changing land use in the southern Drakensberg grasslands of South Africa*. SAJEMS, **10**(4), 423-441. Zavaleta, E 2000 *The economic value of controlling an invasive shrub*. AMBIO: A Journal of the Human Environment, **29**(8), 462-467 (DOI: 10.1579/0044-7447-29.8.462).	• There is strong evidence that the clearing of 'thirsty' invasive species increases water yields and reduces the cost per unit of water. • Research in the USA has shown increases in soil moisture and water table following the manual removal of invasive woody species. • Barriers to the removal of invasive species include cost, low local awareness and reluctance to lose profitable crop plants. • The removal of invasive species is often carried out for biodiversity conservation rather than drought management.
Reforestation	**Decrease water loss through evaporation; improve water capture; reduce erosion**	**Increase forest vegetation cover to increase shade, lower local temperatures, reduce water loss through evaporation, capture rainwater**	Birch, J C, Newton, A C, Alvarez Aquino, C, Cantarello, E, Echeverría, C, Kitzberger, T, Schiappacasse, I & Tejedor Garavito, N 2010 *Cost-effectiveness of dryland forest restoration evaluated by spatial analysis of ecosystem services*. PNAS, **107**(50), 21925-21930 (DOI: 10.1073/pnas.1003369107). Hamilton, L S & Cassells, D 2003 *Hydrology overview. In Running Pure: The Importance of Forest Protected Areas to Drinking Water* (ed. Dudley, N & Stolton, S). Gland: World Bank/WWF Alliance for Forest Conservation and Sustainable Use. **Continued on next page**	• Research has shown that forests aid water capture and that there is a positive link between afforestation and groundwater recharge through soil water infiltration. • Some tree species have a negative effect on soil moisture (see 'Removal of 'thirsty' invasive plant species' section), care should therefore be taken to ensure that suitable tree species are chosen. • Research into the cost-benefit analysis of dryland reforestation suggests that passive restoration is cost-effective but that the costs of active reforestation generally outweighed the benefits. **Continued on next page**

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Ilstedt, U, Malmer, A, Verbeeten, E & Murdiyarso, D 2007 *The effect of afforestation on water infiltration in the tropics: A systematic review and meta-analysis*. Forest Ecology and Management, **251**(1-2), 45-51 (DOI: 10.1016/j.foreco.2007.06.014). Postel, S L & Thompson, B H Jr 2005 *Watershed protection: Capturing the benefits of nature's water supply services*. Natural Resources Forum, **29**(2), 98-108 (DOI: 10.1111/j.1477-8947.2005.00119.x). Smith, J 2002 *Afforestation and reforestation in the clean development mechanism of the Kyoto Protocol: Implications for forests and forest people*. International Journal of Global Environmental Issues, **2**(3/4), 322-343. See 'forest conservation' and 'agroforestry' references.	**Continued from previous page** • Additional benefits include reduced wind erosion, desertification, protection against flash flooding (see riverine flooding), improved water quality, climate change mitigation and income for the local population if managed sustainably. See 'forest conservation' and 'agroforestry' summaries.
Forest conservation	**Prevent loss of drought protection functions provided by existing forests**	**Conserve existing forest vegetation cover so that it continues to increase shade, lower local temperatures, reduce water loss through evaporation, capture rainwater**	Ffolliott, P F, Brooks, K N, Gregersen, H M & Lundgren, A L 1995 *Dryland forestry: Planning and management*. New York: John Wiley and Sons, Inc. Worku, A, Pretzsch, J, Kassa, H & Auch, E 2014 *The significance of dry forest income for livelihood resilience The case of the pastoralists and agro-pastoralists in the drylands of southeastern Ethiopia*. Forest Policy and Economics, **41**, 51-59. See 'reforestation' and 'agroforestry' references.	• In times of drought, trees are usually survive better than grasses so can provide forage. See 'reforestation' and 'agroforestry' summaries.
Agroforestry	**Control erosion, improve water infiltration, shade soil to conserve moisture, provide windbreaks**	**Increasing use of productive trees (timber, fruit, fodder) in dryland agriculture to increase shade, lower local temperatures and reduce water loss through evaporation.**	Lin, B B 2007 *Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture*. Agricultural and Forest Meteorology, **144**, 85-94 (DOI: 10.1016/j.agrformet.2006.12.009). Lin, B B 2010 *The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agrosystems*. Agricultural and Forest Meteorology. **150**, 510-518 (DOI: 10.1016/j.agrformet.2009.11.010). **Continued on next page**	• Increased canopy cover can reduce ground temperatures, reducing evaporation and evapotranspiration from some crops. • In order to receive local uptake, agroforestry must be compatible with local agricultural needs and constraints. • Some agroforestry studies have shown a positive effect of agroforestry on droughts but there have been few studies. More research is therefore required to better understand the effect of agroforestry on drought. See 'reforestation' and 'forest conservation' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Nguyen, Q, Hoang, M H, Oborn, I, van Noordwijk, M 2012 *Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptation in Vietnam*. Climatic Change, **117**(1-2), 241-257 (DOI: 10.1007/s10584-012-0550-1). Vandenbelt, R J 1990 *Agroforestry in the semiarid tropics*. In Agroforestry: Classification and Management (ed. MacDicken, K G & Vergara, N T), New York: John Wiley. See 'reforestation' and 'forest conservation' references.	
Breeding drought resilient crops and livestock	**Decrease drought loss to crops and livestock; increase capacity of agropastoral systems to function at higher temperatures**	**Research into and development and distribution of crop and livestock varieties that tolerate drought**	Consultative Group on International Agricultural Research (CGIAR) 2011 *Findings on the impacts of CGIAR research 1971–2011*. Washington, DC: CGIAR fund. Kassie, G T, Erenstein, O, Mwangi, W, Setimela, P, Langyintuo, A & Kaonga, K K 2012 *Drought tolerant maize in Malawi: Lessons learned and the way forward*. Texcoco: CIMMYT International Maize and Wheat Improvement Center. Lybbert, T J & Bell A 2010 *Stochastic benefit streams, learning and technology diffusion: Why drought tolerance is not the new Bt*. AgBioForum, **13**(1), 13-24.	• It has been reported that the use of drought tolerant crops in southern Africa give an average yield advantage of 20 – 50%. • Ensuring uptake (socio-economic intervention) just as important as successful breeding a program.
Sustainable agroecosystem management practices	**Soil cover to conserve moisture; crop and livestock diversity to spread risk of climate shocks; reduce erosion**	**Increase uptake of range of context-specific practices including intercropping, crop-livestock integration, minimum tillage**	Giller, K E, Witter, E, Corbeels, M & Tittonell, P 2009 *Conservation agriculture and smallholder farming in Africa: The heretics' view*. Field Crops Research, **114**, 23-34 (DOI: 10.1016/j.fcr.2009.06.017). ICIPE 2013 *Climate-smart push-pull: Resilient, adaptable conservation agriculture for the future*. Nairobi: ICIPE. Mrabet, R, El-Brahli, A, Anibat, I & Bessam, F 2004 *No-tillage technology: Research review of impacts on soil quality and wheat production in semiarid Morocco. In Mediterranean rainfed agriculture: strategies for sustainability* (ed. Cantero-Martínez, C & Gabiña, D). Zaragoza: CIHEAM. **Continued on next page**	• Techniques such as agroforestry, low tillage agriculture, the use of traditional planting pits, contour bunds and half-moon structures to capture rain water can all help increase soil moisture. • Additional benefits can include diversified income, an increase in social cohesion/capability and benefits to biodiversity. • Empirical evidence is not clear on the effect on yields, labour requirements, soil fertility and erosion. Research is required to identify where these methods can provide benefits. See 'agroforestry' and 'soil moisture conservation' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
			Continued from previous page Mrabet, R, Moussadek, R, Fadlaoui, A & van Ranst, E 2012 *Conservation agriculture in dry areas of Morocco*. Field Crops Research, **132**(14), 84–94 (DOI: 10.1016/j.fcr.2011.11.017). Pretty, J, Toulmin, C & Williams, S 2011 *Sustainable intensification in African agriculture*. International Journal of Agricultural Sustainability, **9**(1), 5-24. Shames, S, Wollenberg, E, Buck, L E, Kristjanson, P, Masiga, M and Biryahwaho, B 2012 *Institutional innovations in African smallholder carbon projects. CCAFS report no. 8*. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). See www.ccafs.cgiar.org, accessed 29.10.2014. See 'agroforestry' and 'soil moisture conservation' references.	
Soil and water conservation	**Conserve soil moisture; make efficient use of rainfall; prevent erosion**	**Low-tech structures – bunds, contours, planting pits – conserve soil and water at the micro level. Traditional and modern techniques.**	FAO 2002 *Crops and drops: Making the best use of water for agriculture*. Rome: FAO. Pretty, J, Toulmin, C & Williams, S 2011 *Sustainable intensification in African agriculture*. International Journal of Agricultural Sustainability, **9**(1), 5-24. Reij, C, Scoones I & Toulmin, C (ed.) 1996 *Sustaining the soil: Indigenous soil and water conservation in Africa*. New York: Earthscan. Reij, C, Tappan, G & Smale, M 2010 Re-Greening the Sahel: Farmer-led innovation in Burkina Faso and Niger. In Millions fed (ed. Spielman, D J & Pandya-Lorch, R) Washington, DC: International food policy research institute. See http://www.ifpri.org/sites/default/files/publications/oc64ch07.pdf, accessed 16.10.2014. See 'sustainable agro-ecosystem management practices' and 'agroforestry' references.	• The construction of low tech structures such as bunds and planting pits with the aimed at increasing agricultural productivity. • These techniques have been shown in some areas to have positive impacts on livelihoods, social networks and agricultural productivity. • Hard to get quantitative evidence of impact on drought as often implemented with other measures but is some evidence of a positive impact on water levels from planting pits. • Local engagement is essential for project success. The most successful methods are those which show an improvement within the first few years. See 'sustainable agro-ecosystem management practices' and 'agroforestry' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Reservoirs, ponds & other water storage	Improved water storage	Provision of water storage facilities, reduced evaporation, ability to monitor water use	Boelee, E, Yohannes, M, Poda, J-N, McCartney, M, Cecchi, P, Kibret, S, Hagos, F & Laamrani, H 2013 *Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa*. Regional Environmental Change, **13**(3), 509-519. Eguavoen, I, Derib, S D, Deneke, T T, McCartney, M, Otto, B A & Billa, S S 2012 *Digging, damming or diverting? Small-scale irrigation in the Blue Nile Basin, Ethiopia*. Water Alternatives, **5**(3), 678-699. FAO 2002 *Crops and drops: Making the best use of water for agriculture*. Rome: FAO. International Water Management Institute (IWMI) 2013 *IWMI recommendations for priority action in the dry zone of Myanmar*. Colombo: IWMI.	• Reservoirs significantly reduce the risk of crop failure during drought by providing a large store of water. • Potential draw backing include costly construction and maintenance, damage to existing systems (if on a large scale) and potential increase in water borne diseases.
Wells	Access to groundwater supply	Allows additional non-surface water to be accessed; lower evaporation rate from groundwater	Calow, R 2009 *What will climate change mean for groundwater supply in Africa?* London: Overseas Development Institute. Lovell, C 2009 *Productive water points in dryland areas: Guidelines on integrated planning for rural water supply*. London: ITDG Publishing. Mishra, S, Ravindra, A & Hesse, C 2013 *Rainfed agriculture for an inclusive, sustainable and food secure India*. London: International Institute for Environment and Development (IIED). See http://pubs.iied.org/10041IIED.html, accessed 29.10.2014. See 'sustainable agro-ecosystem management practices' and 'soil and water conservation' references.	• Ground water is generally more reliable than surface water and tends to be good quality. • Wells can be built near population centres. • The amount of water that can be sustainably withdrawn from aquifers is limited by the recharge rate. • Aquifer recharge rate is expected to change with climate change. • Land management techniques (see sustainable agro-ecosystem management practices and soil and water conservation) can aid aquifer recharge. See 'sustainable agro-ecosystem management practices' and 'soil and water conservation' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Irrigation	Maintenance of water supply, prevention of crop-failure due to drought	Redistribution of water supply to maintain crops during low-rainfall periods	Foster, S & Shah, T 2012 *Groundwater resources and irrigated agriculture: making a beneficial relation more sustainable*. Stockholm: Global Water Partnership. International Water Management Institute (IWMI) 2013 *IWMI recommendations for priority action in the dry zone of Myanmar*. Colombo: IWMI.	• Irrigation often involves some of the interventions described above above (eg water storage and transfer, and management of vegetation). • Irrigation can greatly increase crop yields and can enable small farmers in drought prone areas to produce 'cash crops' such as vegetables. • Uncontrolled irrigation can cause major aquifer depletion. Aquifers are prone to the 'tragedy of the commons'. • The effect of irrigation on biodiversity depends on whether water is taken from or directed to natural ecosystems.
Interbasin water transfer	Redistribution of water between basins	Use of engineering (channels, tunnels, dams, aqueducts etc) to redirect water from one basin to another	Sharma, B R 2013 *Impact of climate change on water resources and potential adaptations for Indian agriculture*. Annals of Agricultural Research, **34**(1), 1-14. World Wide Fund for Nature (WWF) *Pipedreams? Interbasin water transfers and water shortages.* Gland, Switzerland: WWF.	• Interbasin water transfer is the transfer of water from areas considered to have a water surplus to those with a water shortage. • Interbasin water transfer can provide large quantities of water to areas suffering from drought. • Draw backs include a very high cost and potentially significant damage to biodiversity and livelihoods in the donor basin. • Consequences vary considerably between basins but there is evidence that interbasin water transfer disturbs the water balance in both river basins.
Waste water recycling	Re-use of waste water	Water treatment to allow waste water to be recycled	Bixio, D, Thoeye, C, De Koning, J, Joksimovic, D, Savic, D, Wintgens, T & Melin, T 2005 *Wastewater reuse in Europe*. Desalination, **187**, 89-101 (DOI:10.1016/j.desal.2005.04.070). Mateo-Sagasta, J, Medlicott, K, Qadir, M, Raschid-Sally, L, Drechsel, P & Liebe, J 2013 *Safe Use of Wastewater in Agriculture* (ed. Liebe, J & Ardakanian, R). Bonn: United Nations Water-Decade Program on Capacity Development.	• Reuse of waste water can significantly reduce the water requirements of a population. • In many countries the use of waste water in unregulated which can lead to health issues. • There is little economic evidence on costs and benefits of waste water reuse.

Heatwaves

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Afforestation	**Lower local temperatures**	**Creation of shade, increase in evapo-transpirative cooling, altered wind flow patterns**	Brown, R D & Gillespie, T J 1995 *Microclimate landscape design: creating thermal comfort and energy efficiency*, New York: John Wiley and Sons. Chen, D, Wang, X, Thatcher, M, Barnett, G, Kachenko, A & Prince, R 2014 *Urban vegetation for reducing heat related mortality*. Environmental Pollution, **192**, 275-284 (DOI:10.1016/j.envpol.2014.05.002). Kotzen, B 2003 *An investigation of shade under six different tree species of the Negev desert towards their potential use for enhancing micro-climatic conditions in landscape architectural development*. Journal of Arid Environments, **55**(2), 231-74 (DOI: 10.1016/S0140-1963(03)00030-2). Oke, T R 1988 *The urban energy balance*. Progress in Physical Geography, **12**(4), 471-508 (DOI:10.1177/030913338801200401). Oke, T R, Crowther, J M, McNaughton, K G, Monteith, J L & Gardiner, B 1989 *The Micrometeorology of the Urban Forest* [and Discussion]. Philosophical Transactions of the Royal Society of London B: Biological Sciences **324**(1223), 335-49 (DOI: 10.1098/rstb.1989.0051). Oke, T R 2009 *The need to establish protocols in urban heat island work*. Phoenix, Arizona: Eighth Symposium on Urban Environments. See http://ams.confex.com/ams/89annual/techprogram/paper_150552.htm, accessed 24.10.2014. Shashua-Bar, L, Pearlmutter, D & Erell, E 2011 *The influence of trees and grass on outdoor thermal comfort in a hot-arid environment*. International Journal of Climatology, **31**(10), 1498-506 (DOI: 10.1002/joc.2177). Also see 'Urban planning' references.	• It has been shown that tree-shading can reduce heat stress locally. • The effectiveness is dependent on the tree placement, canopy height, and leaf size and structure. • Urban parks have been shown to be between 1 and 3 °C cooler than surrounding urban areas. • There is currently little evidence as to the effectiveness at a city-scale and little data is available on non-urban projects. • In areas with extremely high temperatures and water shortages urban tree mortality becomes an issue although using a diverse range of species may help limit this. • Little data available on the cost-benefits of this approach. • Additional benefits may include improved biodiversity.
Maintenance of existing vegetation & trees	**Lower local temperatures**	**Maintenance of shade, evap-otranspirative cooling etc.**	See 'afforestation' and 'urban planning' references.	See 'afforestation' and 'urban planning' summaries.

Intervention	Aim	Process / Mechanism	Evidence	
			References	Summary
Green roofs (veg cover), vertical greening systems	Lower local temperatures	Increased shade, increased evapotranspi-rative cooling, reduction in 'ur-ban heat island' effect	Alexandri, E & Jones, P 2006 *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates*. Building and Environment, **43**(4), 480-493 (DOI: 10.1016/j.buildenv.2006.10.055). Davies, M, Steadman, P & Oreszczyn, T 2008 *Strategies for the modification of the urban climate and the consequent impact on building energy use*. Energy Policy, **36**(12), 4548-4551 (DOI: 10.1016/j.enpol.2008.09.013). Gill, S E, Handley, J F, Ennos, A R & Pauleit, S 2007 *Adapting cities for climate change: The role of the green infrastructure. Built Environment*, **33**(1), 115-133. Niachou, A, Papakonstantinou, K, Santamouris, M, Tsangrassoulis, A & Mihalakakou, G 2001 *Analysis of the green roof thermal properties and investigation of its energy performance*. Energy and Buildings, **33**, 719-729. Rosenzweig, C, Solecki, W, Parshall, L, Gaffin, S, Lynn, B, Goldberg, R, Cox, J & Hodges, S 2006 *Mitigating New York city's heat island with urban forestry, living roofs and light surfaces*. New York: NASA See http://www.giss.nasa.gov/research/news/20060130/103341.pdf, accessed 24.10.2014. Speak, A F, Rothwell, J J, Lindley, S J & Smith C L 2013 *Reduction of the urban cooling effects of an intensive green roof due to vegetation damage*. Urban Climate, **3**, 40-55 (DOI: 10.1016/j.uclim.2013.01.001). See 'white roofs' references.	• Green roofs and vertical greening systems act to reduce the `urban heat island` effect and cool buildings through increased shade and evapotranspirative cooling. • Green roof have been shown to have a significant cooling effect both with the building and the street canyon. • In order to remain effective regular maintenance of green roofs and vertical greening systems must be carried out. • Additional benefits may include improved air quality and in some cases recreational space. • The implementation of green roofs and vertical greening may be restricted by: the ability of older buildings to cope with additional weight, water requirements (especially in countries where drought is often an issue) and competition for roof space, for example with solar panels.
White roofs	Lower local temperatures	Increased reflection, reduction in 'urban heat island' effect	Akbari, H & Matthews, H D 2012 *Global Cooling updates: reflective roofs and pavements*. Energy and Buildings, **55**, 2-6, (DOI:10.1016/j.enbuild.2012.02.055). Krayenhoff, E S & Voogt, J A 2010 *Impacts of urban albedo increase on local air temperature at daily–annual time scales: Model results and synthesis of previous work*. Journal of Applied Meteorology and Climatology, **49**, 1634-1648 (DOI: 10.1175/2010JAMC2356.1). **Continued on next page**	• White roofs increase the albedo of urban areas, reducing the energy absorbed by buildings and therefore reducing temperatures. • Relative to other measures white roofs are low cost and require little maintenance. • Existing buildings may be modified to increase their albedo. **Continued on next page**

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<tr><th rowspan="2">Intervention</th><th rowspan="2">Aim</th><th rowspan="2">Process / Mechanism</th><th colspan="2">Evidence</th></tr>
<tr><th>References</th><th>Summary</th></tr>
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Levinson, R & Akbari, H 2009 Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency, 3(1), 53-109 (DOI: 10.1007/s12053-008-9038-2).

Schubert, S & Grossman-Clarke, S 2013 The influence of green areas and roof albedos on air temperatures during extreme heat events in Berlin, Germany. Meteorologische Zeitschrift, 22(2), 131–143 (DOI 10.1127/0941-2948/2013/0393).

Sproul, J, Wan M P, Mandel B H & Rosenfeld A H 2014 Economic comparison of white, green, and black flat roofs in the United States. Energy and Buildings, 71, 20-27 (DOI: 10.1016/j.enbuild.2013.11.058).

See ‘urban planning’, ‘green roofs (veg cover), vertical greening systems’ references.</td><td>Continued from previous page

• White roofs may increase the need for heating in cool climates and may face competition for roof space, for example from solar panels.
• Additional benefits may include reduced global warming caused by the increase in albedo.</td></tr>
<tr><td>Urban planning, grid design etc.</td><td>Lower local temperatures</td><td>Use of building materials and spatial planning to increase albedo, improve air-flow and lower temperatures</td><td>Frumkin, H 2002 Urban sprawl and public health. Public Health Reports, 117, 201-217.

Harlan, S L, Brazel, A J, Prashad, L, Stefanov, W L & Laren, L 2006 Neighborhood microclimates and vulnerability to heat stress. Social Science and Medicine, 63, 2847-2863 (DOI: 10.1016/j.socscimed.2006.07.030).

Kleerkoper, L, van Esch, M & Salcedo, T B 2012 How to make a city climate-proof, addressing the urban heat island effect. Resources, Conservation and Recycling, 64, 30-38 (DOI: 10.1016/j.resconrec.2011.06.004).

Koppe, C, Kovats, S, Jendritzky, G & Menne, B 2004 Heat-waves: Risks and responses. Copenhagen: World Health Organisation. See http://www.urbanclimate.net/matzarakis/papers/WHO_2.pdf, accessed 29.10.2014.

Valladares-Rendón, L G & Lo, S-L 2014 Passive shading strategies to reduce outdoor insolation and indoor cooling loads by using overhang devices on a building. Building Simulation, 7(6), 671-681 (DOI: 10.1007/s12273-014-0182-7).

See ‘white roofs’ and ‘afforestation’ references.</td><td>• Urban areas are significantly warmer than surrounding rural areas – `the urban heat island effect`.
• Causes include: low albedo surfaces, a high surface area, atmospheric pollution, reduced air movement, reduced evaporation, increased heat storage and anthropogenic heat emission.
• Changes in urban design can act to limit the urban heat island effect. Options used include: increased vegetation and areas of water (eg ponds, fountains etc.), wider streets to increase turbulence and avoid heat trapping, shading buildings (eg with green walls), street orientation to enable air movement, shading outdoor areas, improving air quality and increasing surface albedo.
• Major redesign of most cities is prohibitively expensive but incorporation of these features when areas or building are redeveloped will reduce people’s exposure to heat waves.

See ‘white roofs’ and ‘afforestation’ summaries.</td></tr>
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<tr><td>Air conditioning</td><td>Lower local temperatures</td><td>Reduction of air temperature and humidity</td><td>de Munck, C, Pigeon, G, Masson, V, Meunier, F, Bousquet, P, Tréméac, B, Merchat, M, Poeuf, P & Marchadier, C 2013 How much can air conditioning increase air temperatures for a city like Paris, France? International Journal of Climatology, 33, 210-227 (DOI: 10.1002/joc.3415).

National Collaborating Centre for Environmental Health 2008 Current evidence on the effectiveness of interventions during heat episodes. Vancouver: National Collaborating Centre for Environmental Health. See http://www.ncceh.ca/sites/default/files/Heat_Interventions_Sept_2008.pdf, accessed 29.10.2014.

O'Neill, M, Zanobetti, A & Schwartz, J 2005 Disparities by race in heat-related mortality in four US cities: The role of air conditioning prevalence. Journal of Urban Health, 82(2), 191-197 (DOI: 10.1093/jurban/jti043).

Salamanca, F, Georgescu, M, Mahalov, A, Moustaoui, M & Wang, A 2014 Anthropogenic heating of the urban environment due to air conditioning. Journal of Geophysical Research: Atmospheres, 119, 5949–5965, (DOI:10.1002/2013JD021225).</td><td>• Air conditioning is one of the most effective protective factors against the effects of heat.
• The cost and energy demand of air conditioning means that many of the people most at risk during heatwaves cannot afford it.
• In heat waves community cooling centres can be effective in helping vulnerable members of society.
• Air-conditioning can raise night time temperatures further disadvantaging those without access to air conditioning.
• Air conditioning has a high energy demand so if fossil fuel is used in power generation it can be a cause of increased greenhouse gas emissions and decreased air quality.</td></tr>
<tr><td>Insulation</td><td>Retain lower temperature inside buildings</td><td>Prevent transfer of heat from outside to inside buildings</td><td>Porritt, S, Goodier, C I & Shao, L 2009 Briefing: Heat-wave-coping measures for housing. Proceeding of the ICE – Energy, 162(3), 101-103.

Porritt, S M, Cropper, P C, Shao, L & Goodier, C I 2012 Ranking of interventions to reduce dwelling overheating during heat waves. Energy and Buildings, 55, 16-27 (DOI: 10.1016/j.enbuild.2012.01.043).

Public Health England 2014 Heatwave plan for England 2014: Protecting health and reducing harm from severe heat and heatwaves. London: Public Health England.</td><td>• Insulation acts to prevent heat transfer into buildings, maintaining lower inside temperatures during heat waves.
• The effectiveness of insulation in maintaining low inside temperatures is dependent on the form of insulation and where it is applied.
• An additional benefit of insulation is the reduction winter heating requirements so reducing energy requirements and therefore greenhouse gas emission.</td></tr>
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