Desk study

Resilient WASH systems in flood-prone areas

CARE Nederland

Techniques to improve the resilience of community WASH systems in flood-prone areas

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CARE Nederland

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This study has been commissioned by CARE Nederland, to explore the current body of knowledge with regards to resilient techniques in WASH for flood-prone areas, and to prepare the technical basis for the evaluation of WASH projects developed in areas that are exposed to flood risk

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Impact of floods on WASH systems

There are uncertainties with projected impacts of climate change, but reliability of projection depends on the area. For some regions projections of future precipitation change are more robust, while outside of these areas the predictions vary between models. Predictions also become less consistent between models as scale decreases.[1] One robust finding is that there will be changes in the seasonality of river flows in areas where much of the winter precipitation falls as snow.[2] Projections also indicate that not everywhere will be affected by reduced cumulative water availability – in fact, some areas will start to receive more annual rainfall, while other areas will receive less. Even so, the variability is likely to increase, with more intense rainfall over short periods of time or longer periods with little or no rainfall, with the increased likelihood of extreme water-related events such as floods or droughts.[3]

This document aims to look at methods of increasing resilience of WASH systems. Resilience is a concept used to describe how to make WASH systems more robust, thereby reducing the vulnerability of people that rely on them. Both resilience and vulnerability are concepts related to the capacity to anticipate / cope with / resist / recover from a hazard, and both are determined by physical, environmental, social, economic, political, cultural and institutional factors:[4]

- Vulnerability = potential to suffer harm or loss
- Resilience = potential to cope with harm or loss
- Increased resilience = reduced vulnerability

This table below shows an overview of the effects of floods on WASH systems in rural and urban settings.

	Effects of flood	Underlying causes of effects	Overall techniques to increase resilience of WASH system
Construction techniques			
Making concrete	• Floodwater can cause pressure on structures and erosion, which can affect badly made concrete structures (e.g. in tanks)	• Too much water used in the mix • Impure water used for mixing • Insufficient compaction / vibration • Not enough water used for curing	• Ensure adequate mixing, ratios, purity of ingredients • Minimize water content in mixture • Use vibration to produce compact concrete, especially for foundations • Ensure adequate curing
Floodplains management			
	• Flooding in downstream parts of the floodplain	• Increased amount of water reaching downstream areas (due to factors such as deforestation) • Inadequate governance and land-use planning (e.g. continued development in flood-prone areas)	• Structural measures to control water flow (e.g. storage reservoirs, modification of river, diversion of flood waters, improved infiltration) • Non-structural measures that do not control water flow but make potentially affected areas more prepared (e.g. early warning systems, flood avoidance such as regulation of new development, better flood preparedness, flood-resilient infrastructure)
Water supply, treatment & distribution			
Bottled water distribution	• Floodwater can cause usual water sources to become inaccessible, meaning there can be a lack of access to potable water	• Usual water sources are not flood-resilient	• Distribution of bottled water as part of a flood preparedness and response strategy, especially for dispersed populations
Saline water	• Salinity increases, meaning water is	• Seawater flooding open wells	• Diversify water sources for drinking in the short term until well water is

[1] Batchelor, C.; Schouten, T.; Smits, S.; Moriarty, P.; Butterworth, J. (2009) *14. Climate change and WASH services delivery – Is improved WASH governance the key to effective mitigation and adaptation?* Perspectives on water and climate change adaptation. IRC, The Hague, The Netherlands. p.2.
[2] Wilk, J.; Wittgren, H.B. (eds). (2009) *Adapting Water Management to Climate Change*. Swedish Water House Policy Brief Nr. 7. SIWI, 2009. p.5.
[3] UNEP / GRID, IPCC. Quoted in: USAID (2010) *Summary of the World Water Crisis and USG Investments in the Water Sector*, *May 15, 2010.* See also: Batchelor, C.; Schouten, T.; Smits, S.; Moriarty, P.; Butterworth, J. (2009) *14. Climate change and WASH services delivery – Is improved WASH governance the key to effective mitigation and adaptation?* Perspectives on water and climate change adaptation. IRC, The Hague, The Netherlands.
[4] Benson, C.; Twigg, J. (2007) *Tools for Mainstreaming Disaster Risk Reduction: Guidance Notes for Development Organisations*. Provention Consortium, Geneva, Switzerland. p.12.

	not potable, therefore alternative water sources have to be found for up to 2 years		potable • Avoid over-pumping well water • Household & communal level solar distillation • Managed Aquifer Recharge (MAR) can dilute saline groundwater • Protect open wells
Water storage tanks	• Damage to tanks from floodwater	• Unsuitable site for tank • Inadequate construction techniques	• Ensure good concreting techniques • Site tank to avoid natural drainage & flood detention areas (e.g. avoid flood area, or build mound)
Handpumps	• Handpumps damaged by floodwater • Floodwater enters well and contaminates water source	• Handpump location and height / construction of slab are not flood-resilient • Some types of handpump mechanism allow more floodwater to enter water source	• Avoid flooding by constructing a raised slab above floodwater level • Where flooding is inevitable, reduce risk by sealing manhole cover, fixing handpump securely to slab which has been properly cured, and choosing handpump with spout above maximum water level and / or closed rather than open system. • Train local people to repair & maintain handpumps as well as keep spare parts, to reduce dependence on external expertise & resources which will be limited
Traditional hand-dug wells	• Can become flooded	• Usual water sources are not flood-resilient • Poor siting	• Site correctly • Avoid erosion of aprons through deeper foundation edges • Construct raised headwall and / or slab above floodwater level • Construct watertight well shaft above water table • Where flooding is inevitable, consider alternative systems that have offset extraction of water (e.g. infiltration galleries or riverbed wells) or are more cost-effective (e.g. jetted wells)
Boreholes	• Can become flooded	• Usual water sources are not flood-resilient • Poor siting	• Site correctly • Avoid erosion of aprons through deeper foundation edges • Construct raised slab / mound above floodwater level • Construct watertight casing above water table
Urban water supply & distribution	• Damage to water distribution system and treatment works causes less water to be distributed to residents after the flood, causing some to look for alternative unsafe water sources	• Leaking water pipes & intermittent pumping • Damage to electrical and pumping equipment	• Keep distribution system functioning through sufficient water being treated at water treatment works, installing valves in network to allow repair, all pumps having standby capacity, having a roster of electro-mechanics on call, designing sufficiently large service reservoirs, introducing water rationing, keeping service reservoirs as full as possible prior to flood. • Creating alternative water supplies at strategic points, especially in high-density areas • Short-term water tankering • Making distribution pipes more resilient to flood damage
Urban water treatment	• Flooding of water treatment works with damage to equipment, resulting in reduction of water supplied to distribution system	• Water treatment works are not flood-resilient, or poorly sited • Certain components (e.g. dams) are not maintained or designed correctly • Water treatment works are not managed well	• Maintain continuous power supply to water treatment works (e.g. generators, reinforce electricity poles, agreement with electricity supplier) • Keep sufficient stocks of treatment chemicals on site • Keep treating sufficient water in order to supply urban residents (e.g. through all pumps having standby capacity, having a roster of electro-mechanics on call). • Make water treatment works more resilient to flood damage (e.g. design & maintenance of dams & intakes, embankments at treatment works, drainage pumps for sub-surface areas)

			• Consider household water treatment where existing treatment works cannot be made functional quickly. • Avoid dependency on large centralised water treatment works – spread the risk by having a few smaller works
Water treatment - other	• Water sources can become flooded resulting in contaminated water that might be used for drinking	• Water sources are not flood-resilient • Water sources are not protected • Poor siting of water sources	• Water treatment of water sources (e.g. one-off shock chlorination, ongoing treatment) using methods that can cope with high levels of turbidity • Water treatment of water at point of use (e.g. household treatment) together with initial and follow-up training • A flood response strategy can aid speed of treatment (e.g. stocks of equipment, or promotion of household treatment in non-flood times).
Hygiene promotion & WASH NFIs			
	• Contamination of household items through contaminated floodwater and silt • Loss of household NFIs resulting in more difficult situation with regard to water storage and use	• Being unprepared for flooding events • Living in floodable areas	• Including messages about contaminated items along with standard messages • Keep NFI stocks at strategic locations • Follow up NFI distribution promptly with hygiene promotion to promote proper use of items (flyers may help) • Coordinate NFI distributions with household water treatment provision • Coordinate between engineers and hygiene promoters to ensure necessary hardware is in place
Excreta disposal systems			
Urban sewerage systems (off-site excreta disposal)	• Lack of water for flushing results in blockages which can cause localized overflowing of sewers • Too much floodwater which enters the sewerage system can cause sewage to back up and mix with surface floodwater via access points or houses	• Flooding that causes the water supply, treatment or distribution system to malfunction, resulting in reduced water available for flushing • Not enough rodding points built into the system • Lack of flap valves on discharge pipes to prevent back flow of flood water • Lack of user awareness about what to flush into wastewater system • Damage to electrical and pumping equipment	• Keep sewerage system functioning through measures at the water supply, treatment and distribution side • Install back-flaps on sewerage discharge pipes • Have sufficient capacity for rodding pipes (e.g. rods, rodding eyes at suitable points) • Minimize blockages & pipe breakages through better design • Consider on-site excreta disposal as a short-term alternative option, prioritizing public areas
Urban wastewater treatment (off-site excreta disposal)	• Flooding of wastewater treatment works with damage to equipment, resulting in reduction of wastewater treated, as well as possible contamination from floodwater to downstream areas	• Wastewater treatment works are not flood-resilient, or sited in low-lying areas by necessity • Certain components are not maintained or designed correctly • Wastewater treatment works are not managed well	• Maintain continuous power supply to water treatment works (e.g. generators, reinforce electricity poles, agreement with electricity supplier) • Keep treating sufficient wastewater (e.g. through all pumps having standby capacity, having a roster of electro-mechanics on call) • Make wastewater treatment works more resilient to flood damage (e.g. embankments at treatment works)
On-site excreta disposal (rural and urban systems)	• On-site excreta disposal facilities can become flooded, thereby becoming unusable and causing a risk of	• Poor siting of facilities • Facilities are not flood-resilient	• Site facilities in safe / refuge areas • Use and rehabilitate existing unaffected facilities as a short-term measure • Design facilities so as to contain excreta above and below ground,

	contamination of floodwater		keeping mind longer-term issues (e.g. sustainability of emptying)
Cholera response			
Cholera Treatment Centres (CTCs)	• Floodwater (and high groundwater) can affect construction of pipes & tanks, and can affect wastewater disposal design • Flooding can cause contamination of surface water in surrounding areas if cholera-contaminated items (e.g. wastewater from tanks, bedpans, buckets etc) get flooded	• Poor or unavoidable siting of CTC in an area at risk from flooding	• Raise and compact entire CTC ground surface to above maximum floodwater level • Build adequately sized wastewater tank (and transfer tank if needed) to store all wastewater prior to collection • Construct watertight wastewater tanks, both above and below ground • Tanks built into the water table need to be designed to resist flotation • Any pumps should be corrosion-resistant, and should be powered by reliable generators that do not damage the pump • Superchlorinate all faeces and vomit to ensure total disinfection prior to wastewater being collected
Stormwater & wastewater drainage systems			
	• Floodwater may overflow existing drainage channels • Possible damage to vehicles, and injury to people, when drainage channels are not visible below food waters	• Drainage system does not follow natural drainage pattern in the area • Drainage channels are under-designed given the flow, and / or are not shaped correctly to optimize flow • Inadequate management of solid waste blocks drainage channels • Lack of maintenance of existing drainage system to cope with inevitable silt build-up • Increasing urbanization leading to more stress on older drainage system • Reduction in pervious surfaces due to development (less infiltration of runoff)	• Evaluate natural surface flow after rainfall • Favour open drains over closed drains • Design drainage channels to be able to cope with peak flows expected • Design drainage channels so as to maintain adequate self-cleansing velocities • Design robust drainage channels (lined where needed, weep holes) • Design screens and inlets of drainage channels with a view to ease of maintenance • Carry out regular maintenance / clearance of drainage channels, and design in access paths alongside channels • Manage solid waste properly so that less of it blocks drains • Consider Sustainable Urban Drainage Systems (SUDS) in urban areas which can reduce runoff volumes and peak flows (e.g. inlet control devices, vegetated surfaces, permeable paving, detention ponds, retention ponds, wetlands, soakaways & infiltration trenches, infiltration basins)
Solid waste management			
	• Floodwater can move solid waste into lower-lying areas where the water flows to (e.g. drainage channels) causing blockages • Ponding water provides ideal breeding sites for rodents and insects that can become disease vectors	• Inadequate solid waste management	• Create several waste disposal sites in different areas so that disposal can continue even when access is hampered due to floods • Site facilities on higher ground, with fuel reserves • Regular maintenance of drainage channels and involvement of community after flood event • Ensure a more robust solid waste management system is in place (collection, transport, disposal) • Encourage informal collectors • Encourage reuse & recycling • Communicate with communities on solid waste management issues • Discourage disposal of solid wastes in drainage channels and down manholes • Avoid infilling low-lying areas with solid waste which could otherwise act

			as temporary storage basins.

Definitions of floods

Floods can take many forms, which makes it not easy to pin down a precise definition for the term. In broad terms, a flood refers to an excess accumulation of water across a land surface – it is an event whereby water rises or flows over land that is not normally submerged.[5] While flooding is generally viewed in a negative context, it is important to point out that floods in fact may be beneficial – for example, floods can improve the fertility of soils in floodplains, and people choose to live near rivers despite the risks of floods because they perceive the advantages outweighing the disadvantages.

Understanding the type, source and probability of flooding, together with knowing what assets are exposed and their level of vulnerability, is needed in order to identify suitable flood risk management measures. Since floods vary a lot from place to place, it is important to understand that there is no flood management blueprint – rather suitability of measures depends on the context and local conditions.[6]

Floods can occur in unpopulated areas, but for the purposes of this document the definition of flooding is given in the context of populated areas and in relation to how they affect human infrastructure and activity. In populated areas, the effects of floods and the scale of disaster are not only the result of the flood itself (e.g. the type of flood, where one type might cause more damage than another), but are also magnified by a range of human vulnerabilities, inappropriate development planning and climate variability.[7] The following general types of floods have been identified according to the rapidity of onset:[8, 9]

- Rapid-onset floods – these include flash floods, tidal surges, floods provoked by cyclones or accompanied by strong winds, high runoff from heavy rainfall, dam bursts and overtopping, canals and rivers bursting their banks; typically water rises to dangerous levels within 48 hours. In urban areas that have developed on floodplains and where there are flood embankments to protect such areas, there is a high risk that these are breached, causing devastating urban flooding.
- Slow-onset floods – these are floods that occur due to prolonged rainfall that cause low-lying areas to gradually become flooded over a period of days or weeks. In urban areas, slums may be particularly vulnerable to this type of flooding because there are few drains and those that exist may be blocked by solid waste – in such areas the ground is also highly compacted, causing pathways and alleys to become streams after heavy downpours.

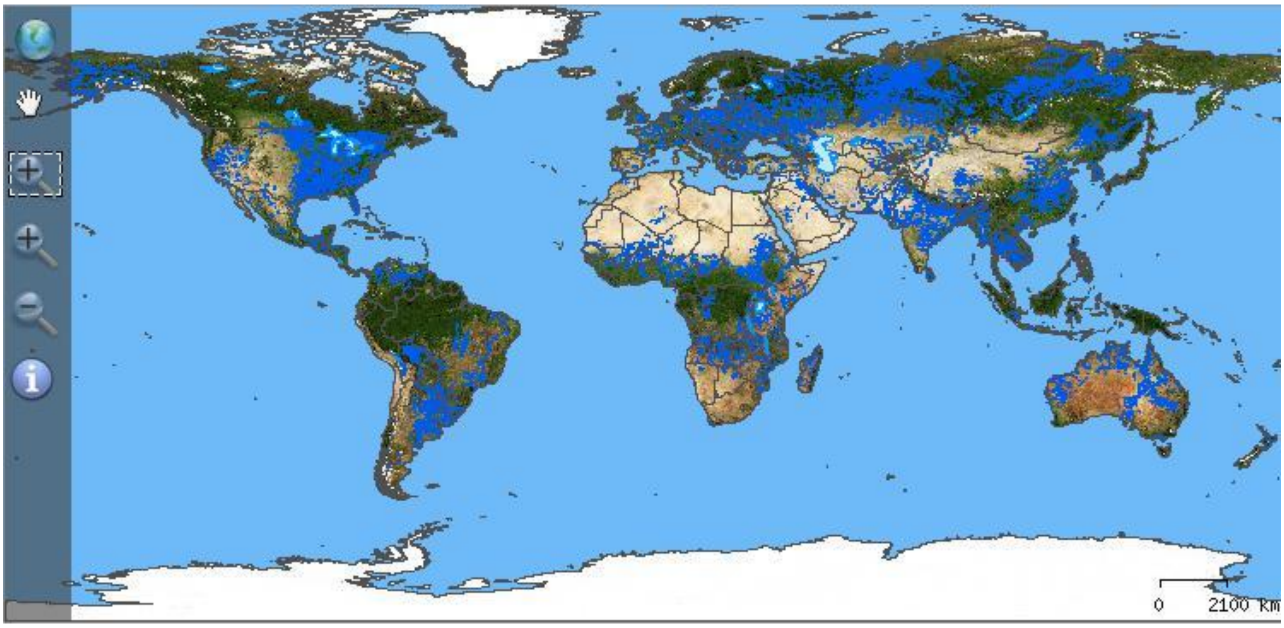

Figure 1: Regions with floods between 1979 and 2010
Source: Global Risk Data Platform: http://preview.grid.unep.ch/index3.php?preview=map

Within the categories of rapid and slow-onset floods, these floods can also have unique characteristics that may affect the type of WASH intervention which is most appropriate:

- Annual seasonal flooding – many communities are flooded every year, whereas some floods are one-off events.
- Rapid or slow-draining floods – areas may drain quickly, or could be under water for some considerable time.

[5] Few, R.; Ahern, M.; Matthies, F.; Kovats, S. (2004) *Floods, health and climate change: a strategic review*. Working Paper 63. Tyndall Centre for Climate Change Research, Norwich, UK. p.7
[6] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.46
[7] Alam, K. (2008) *Flood disasters - Learning from previous relief and recovery operations*. ALNAP/Provention Consortium. p.2
[8] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3.
[9] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.104

- Flooding exacerbated by human activity – infrastructure which fails after a flood event (e.g. flood embankments) can increase the damage and rapidity of the flood; also some low-lying areas which are naturally flood-prone, including reclaimed land, may be built on or cultivated due to population pressure, which can result in flood impacts.
- Seawater or freshwater flooding –storm surges[10] and tsunamis are typically responsible for seawater flooding, which will affect land and water sources in a different way compared to freshwater flooding.
- Urban or rural floods – much of the surface (such as roads and buildings) in an urban area is impervious, leading to a higher risk of flash floods in urban areas compared to a rural areas with the same amount of rainfall.[11] While rural floods might affect larger areas of land and poorer people, urban floods tend to be more costly and difficult to manage due to the concentration of people and assets in an urban setting. This was illustrated after floods in Yemen in 2008, where the estimated costs of loss and damage to the water and sanitation sector showed that damage to urban water and wastewater systems comprised 83% of the total (rural damage totaled $5.63 million, compared to $20.86 million for urban water and $7.07 million for urban wastewater).[12] Given the fact that half the world's population currently lives in cities, increasing by 2050 to about 70%, urban flooding will become more important over time as more people are likely to be affected, especially as urban development continues to expand onto floodplains and flood-prone areas.[13]

Regarding the spatial distribution of previous flood events, data can be obtained from the Global Risk Data Platform. Figure 1 shows the regions with floods recorded between 1979 and 2010.

Although floods do not have a standardized rating system like hurricanes or earthquakes do, the Dartmouth Flood Observatory divides floods into three classes:[14]

- Class 1:
  - Large flood events, with significant damage to structures / agriculture, together with fatalities; and / or
  - 1-2 decades-long reported interval since the last similar event
- Class 1.5:
  - Very large flood events, with a greater than 2 decades but less than 100 year estimated recurrence interval; and / or
  - A local recurrence interval of at 1-2 decades and affecting a large geographic region (> 5000 sq. km)
- Class 2:
  - Extreme events, with an estimated recurrence interval greater than 100 years.

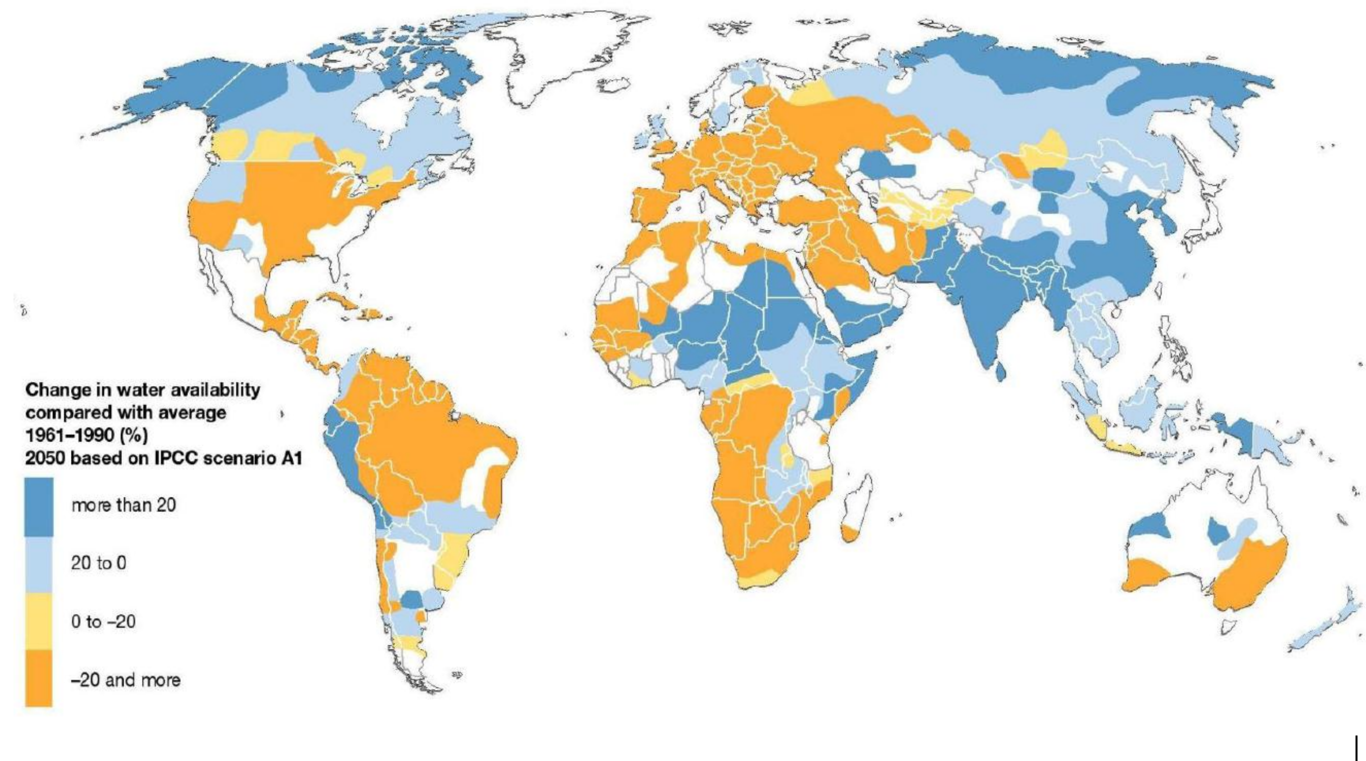

Figure 2: Projected change in water availability by 2050
Source: UNEP / GRID, IPCC. Quoted in: USAID (2010) *Summary of the World Water Crisis and USG Investments in the Water Sector, May 15, 2010.*

[10] For example, in the Maldives storm surges caused by unusually large sea swells have affected distances of up to 600m inland from the coast. See: http://reliefweb.int/node/233884
[11] Bryant, E. 2005. *Natural Hazards* (Second edition). Cambridge University Press, Woolongong, Australia.
[12] Government of Yemen (2009) *Damage, Losses and Needs Assessment: October 2008 Tropical Storm and Floods, Hadramout and Al-Mahara, Republic of Yeme*n. Government of Yemen. p.64.
[13] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.21-23
[14] http://www.dartmouth.edu/~floods/Archives/ArchiveNotes.html

Resilient techniques to improve WASH in flood-prone areas

Observed and projected patterns of climate change can have a significant effect on flood risk. It is clear from projections that not everywhere will be affected due to changing weather patterns. Some areas will start to receive more annual rainfall, while other areas will receive less (see Figure 2). Even so, the variability is likely to increase, with more intense rainfall over short periods of time or longer periods with little or no rainfall, with the increased likelihood of extreme water-related events such as floods or droughts.[15] The IPCC estimate that the most widespread direct risk to human settlements from climate change is from flooding and landslides, which would be driven by projected increases in rainfall intensity and, in coastal areas, sea-level rise. Areas likely to be at risk more than others include riverine and coastal settlements, although urban flooding could occur anywhere where the capacities of storm drains, water supply and waste management systems are inadequate.[16]

However, there are uncertainties with climate change projections, and when coupled with the sources of uncertainty that exist when trying to forecast flood frequencies and associated flood risk, it is clear that flood risk forecasts are likely to be inaccurate. In this case, it would seem that any flood risk management activities should be able to cope with a larger range of uncertainty. This could be achieved through:[17]

- Having more flexible and incremental approaches to flood risk management
- Incorporating greater flexibility into the design of engineered measures
- Accepting over-specification for inflexible measures

Having said that, at present it is probably non-climatic risks which have a higher impact on flood risk, rather than long-term climate change. For example, rapid urbanization in flood-prone areas can itself cause greater flood risk resulting from a normal variability in climate, independent of climate change – in Jakarta, land subsidence resulting from groundwater extraction and compaction has a tenfold greater effect on relative ground and seawater levels than the projected level in sea level rise predicted from climate change.[18]

For this research, the definition of "flood-prone areas" therefore includes populated areas with the following characteristics:

- ✓ Those areas that have experienced flooding in the past – both one-off floods and seasonal floods
- ✓ In an overall geographical sense, areas where water availability is predicted to increase due to climate change
- ✓ Lower-lying areas, such as river valleys or coastal areas
- ✓ Urban areas in particular, where population and assets are concentrated in one place and unplanned development occurs on marginal land

[15] UNEP / GRID, IPCC. Quoted in: USAID (2010) *Summary of the World Water Crisis and USG Investments in the Water Sector*, *May 15, 2010.* See also: Batchelor, C.; Schouten, T.; Smits, S.; Moriarty, P.; Butterworth, J. (2009) *14. Climate change and WASH services delivery – Is improved WASH governance the key to effective mitigation and adaptation?* Perspectives on water and climate change adaptation. IRC, The Hague, The Netherlands. See also: WHO (2009) *Vision 2030: The resilience of water supply and sanitation in the face of climate change*. WHO, Geneva, Switzerland.

[16] IPCC (2001) *Summary for policymakers - Climate Change 2001: impacts, adaptation, and vulnerability. A Report of Working Group II of the Intergovernmental Panel on Climate Change.* IPCC, Geneva, Switzerland. p.13

[17] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.27-30

[18] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.24

Flood scenarios & links to other disasters

Flooding has a potential effect to cause other disasters – this can be identified as short-term impacts, which are usually more obvious and easier to address, as well as longer-term impacts, which are harder to identify and quantify (e.g. disease, reduced nutrition and education etc). The latter may be more important in the long run compared to short-term impacts – for example it has been estimated that the total mortality directly attributable to the Mozambique floods of 2000 (short-term impact) was less than the expected increase in child mortality alone resulting from the reduction of GDP caused by the floods (the longer-term impact).[19] Some specific short and longer-term effects are summarized below:[20]

- Floods can cause displacement, and therefore can be linked to any secondary disaster that might result from this (e.g. WASH-related disease outbreak), as well as to all the various problems that such settings bring (e.g. protection issues).
- Floods cause direct economic monetary losses as a result of damage to tangible assets such as infrastructure or crops.
- Floodwater can damage to infrastructure and buildings. In a slow-onset flood, the level of damage is influenced by flood depth, flood duration, contaminants in the floodwater, and land deformation and soil saturation. In general, flood depths over 600mm tend to result in structural damage to buildings. In rapid-onset floods, damage is influenced by greater lateral pressures caused by waves and currents, with faster velocities resulting in more damage.[21]
- While floods can be beneficial in rural areas due to the introduction of nutrient-rich sediments, floods can also cause increased poverty and food insecurity, especially in urban areas. Urban populations, especially those in informal settlements, are highly vulnerable to floods due to the effects of high population density, poor shelter, and inadequate access to resources.[22]
- Where flood events often occur with such frequency that people have no time to recover before another flood hits, their usual coping strategies for normal cyclical flooding become inadequate. This can result in increasing poverty and chronic food insecurity.
- Flooding negatively impacts wellbeing of women and girls, sometimes so than men. For example, women often find it difficult to find privacy and security for defecation and cleaning/drying of sanitary pads.[23] Larger scale impacts are also possible, for example in some societies it is the agricultural sector that provides the main source of income for women, yet this is a sector that is often affected by flooding – so in such a case, women become overrepresented among the unemployed.
- Flooding causes saturated soils, which can lead to landslides.
- Flooding can result in land and property-related disputes, especially in areas where there is a high demand for housing such as urban areas. At times, land markers are washed away which can cause these disputes.[24]
- Similar to other natural disasters, floods can cause a breakdown in law and order.
- Flooding can negatively affect human health:
  - A review of health consequences of flood disasters found that faecal-oral disease (e.g. nonspecific diarrhoea, cholera, typhoid) is the primary health impact – this will be due to consumption of contaminated water and crowded conditions in displacement camps. Incidence of mosquito-borne disease such as malaria is known to increase after flooding due to an increase in the number of breeding sites for vectors, and leptospirosis is known to have spread after flooding through mud and water that carried infected urine of rodents.[25]
  - Sleeping on wet, cold floors can increase respiratory infections.
  - Floods can also cause physical injury and drowning.
  - As with other natural disasters, flooding can impact on mental health and wellbeing. An increase in aggressive behaviour in children after flooding in Bangladesh was observed to increase from zero to almost 10%.[26]
  - In addition, health facilities may be affected (equipment damaged, electricity cuts affecting cold chain) which will also have a knock-on impact.
- Floods can cause chemical contamination if they inundate industrial plants, waste storage facilities, or contaminated land. Although probably most chemicals get diluted and pose little risk, there is the probability that risk of exposure might increase after the flood when chemicals have been deposited on the land and are ingested through inhalation and ingestion of food.[27]
- Floods can result in crops, livestock and food stocks being lost, as well as seeds and tools – this leads to decreased access to food, reduced exports and increased prices of basic food and commodities.
- Floods can alter the course of rivers, and in doing so affect agriculture, transport and infrastructure over a wide area.
- Floods can affect access and communication, due to the floodwater itself which may not recede quickly or any damaged infrastructure and debris that the flood might leave behind – this can have a knock-on effect on food availability by reducing access to markets and medical services.

[19] Morgan, O.; Ahern, M.; Cairncross, S. (2005) Revisiting the tsunami: health consequences of flooding. *PLoS Med* 2(6): e184. p.492.
[20] Unless otherwise stated, information comes from: ACAPS (2012) *Disaster Summary Sheets (Draft)*. Assessment Capacities Project, Geneva, Switzerland.
[21] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.147-148
[22] IPCC (2001) *Summary for policymakers - Climate Change 2001: impacts, adaptation, and vulnerability. A Report of Working Group II of the Intergovernmental Panel on Climate Change.* IPCC, Geneva, Switzerland.
[23] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.26
[24] Ferris, E. (2010) *Earthquakes and Floods: comparing Haiti and Pakistan*. The Brookings Institution, Washington DC, USA.
[25] Morgan, O.; Ahern, M.; Cairncross, S. (2005) Revisiting the tsunami: health consequences of flooding. *PLoS Med* 2(6): e184. p.491.
[26] Durkin, M.S.; Khan, N.; Davidson, L.L.; Zaman, S.S.; & Stein, Z.A. (1993). The effects of a natural disaster on child behaviour: Evidence for posttraumatic stress. *American Journal of Public Health*, **83**, p.1549.
[27] Experience from Honduras. See: Balluz, L.; Moll, D.; Diaz Martinez, M.G.; Merida Colindres, J.E.; & Malilay, J. (2001) Environmental pesticide exposure in Honduras following hurricane Mitch. *Bull World Health Organ*, 79, p.292.

- Flood-related debris (e.g. silt and organic matter) can block drainage channels and its presence can also affect the use of houses and other infrastructure.
- Electricity is often affected during floods, which can have knock-on effects on things that rely on it such as industrial production.
- Flooding can dislodge landmines or other unexploded ordinances that have been buried under the ground surface.
- Flooding may increase exposure to dangers from animals (e.g. venomous snakes) that share small areas of higher ground with humans.

Certain conditions exacerbate or increase the effects of flooding:[28]

- Time of year – in winter the effects on human health will be greater with additional illnesses occurring due to the cold and damp.
- Strong winds can exacerbate the effects of flooding as they can cause structures already weakened by flooding to collapse.
- Construction in flood-prone areas.
- Obstruction of drainage channels by solid waste.
- Geography: valleys have a greater chance of flooding compared to open areas, as do low-lying areas such as riverine areas downstream of dams and coastal areas.
- Rapidity of onset – flash floods (with higher velocity water flow) have more fatalities and injuries than slow-onset floods.
- The ability of the ground to resist erosion and landslides.
- Arid and semi-arid areas can have severe flooding due to more runoff occurring faster as a result of less vegetation to intercept it.
- Deforestation results in more water going to runoff since it removes the surface area that would otherwise catch and evaporate raindrops directly to the air, and also removes what made the soil drier through the action of roots.
- Areas where floods are uncommon are usually less prepared than areas which are used to floods, and this can exacerbate a flood's impact.
- Previous heavy storms can already have saturated the soil, exacerbating the effect of a following rainstorm.
- High groundwater levels mean little ground is available for infiltration, which can affect speed and volume of flooding.
- Inadequately designed dams, or those that are not maintained, can exacerbate flooding downstream.
- Urban areas have a higher risk of flash flooding than rural areas.
- Sewage treatment plants, waste dumps and dangerous industries that are located in flood-prone areas can result in contamination of floodwater which can lead to secondary hazards.
- Areas with low-level housing can suffer more from the effects of flooding compared to areas where there are houses raised on stilts/piles or where there are multi-storey houses.
- Type of building material can exacerbate the effect of a flood, for example mud-built houses.
- Lack of infrastructure such as health centres can exacerbate the effects of flooding due to the inability to treat injuries and diseases that might result from a flood.
- Lack of a flood early warning system (or an inability to get the early warning information to people who will be affected) can exacerbate a flood's impact since people will be unprepared.

[28] Unless otherwise stated, information comes from: ACAPS (2012) *Disaster Summary Sheets (Draft)*. Assessment Capacities Project, Geneva, Switzerland.

Overview of flood-resilient WASH techniques

Introduction

Techniques are covered under the term 'flood-resilient'

There are two main ways to understand what is meant by flood-resilient WASH techniques – these are:

1. WASH technologies that are intended for floods (e.g. spate irrigation or groundwater dams) – these intentionally use floodwater for WASH activities (e.g. spate irrigation intentionally diverts river water for improving water to crops). As such, there will be ways to make these intentional flood techniques more resilient. These techniques will not covered in this document, but have been covered in the sister document to this one on resilient WASH for drought-prone areas.[29]
2. WASH technologies that are not intended for floods (e.g. hand dug wells or latrines) – these do not intentionally use floodwater as part of the WASH activity (e.g. a hand dug well might have been dug to improve water quantity and quality, but unlike spate irrigation it may not have been constructed with floods in mind as a means to recharge the water quantity). In this case, we would look at ways to make the structures more resilient against floods. These techniques are the ones that will be largely covered in this document.

Good WASH practice versus flood-specific advice

Promoting good practice in WASH is a part of effective Disaster Risk Reduction activities – implementing well thought-out and constructed facilities can make them more resilient in the face of disasters and climate change. However this document is not meant to be a regurgitation of good WASH practice, which is available in many good books and articles. Rather it attempts to focus on specific actions related to flooding (including some good practice actions), and takes into account as much experience from past flood events as possible, which help to inform the recommendations. As such, it aims to be more of a 'nuts and bolts' kind of document to summarize in a 'how to' way what actions can be taken to both prepare for and respond to floods, rather than give out generalized recommendations.

Hardware and software

Techniques in the following sections will focus on most aspects of WASH in both rural and urban areas, including both technical and non-technical components, both of which are necessary when discussing how to make WASH facilities more resilient. On the one hand, software is only as good as the technology it promotes – technological innovation and improvement of techniques are necessary to improve resilience.[30] On the other hand, it is known that about 80% of projects become unsustainable not because of technical issues but because of non-technical issues such as management, social relationships and community dynamics.[31] The various measures for making WASH more flood-resilient must therefore cover hardware and software components, therefore relevant sections in this document will also attempt to cover both.

Factors affecting choice of intervention or technology

Note that there is no standard intervention or choice of technology to fit all situations – what will make WASH facilities more resilient to flooding in different areas will vary according to different factors. These can include:

- Flood type and the nature of floodwater (e.g. depth, velocity, debris, rapidity of onset, duration – see 'Definitions of floods' section)
- Regularity of flood event – how often do floods occur
- The site characteristics (e.g. soil type, location)
- Type of displacement caused by the floods – interventions to serve people who are displaced into centralized areas, may be different from those interventions that are appropriate for people in a dispersed setting (e.g. with host families, or those who stayed at home).

[29] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands.
[30] Godfrey, S.; Gonzalez, L. (2010) Crossfire: the key focus on challenging environments should be technological, paying special attention to physical design and construction. *Waterlines*, Vol.29 no.3, pp.181-185.
[31] ACF-IN (2008) '*How to Make WASH Projects Sustainable and Successfully Disengage in Vulnerable Contexts: a practical manual of recommendations and good practices based on a case study of five ACF-IN water, sanitation & hygiene projects*. p.166.

- The phase of the emergency – different techniques will be valid depending on whether it is an emergency response phase (e.g. flying toilets or an emergency latrine option in a camp) or a prevention/mitigation phase (e.g. making latrine infrastructure at home more flood proof)
- The cause of the emergency
- Available capacity
- Political and social / cultural context
- Financial and economic factors (e.g. capital and ongoing costs)

<u>Contribution of flood-resilient WASH facilities to reducing vulnerability</u>

Making WASH facilities more resilient to flooding can contribute towards reducing vulnerability, yet we must be realistic as to how far this can be achieved in reality. This is because there are many other aspects that can make a community vulnerable, so unless these are also addressed then the impact of WASH projects at reducing overall vulnerability will remain limited. Also, adaptation options against flooding cover a much wider reach than individual WASH projects and includes longer-term decisions related to things like planning of settlements and their infrastructure, or the placement of industrial facilities.[32] Making WASH facilities more resilient and communities less vulnerable therefore is inherently tied into decisions and planning taken on a larger scale and longer timeframe, probably by governmental institutions, yet the scale and timeframe of the average WASH project is small and short-lived.

<u>Compromise versus a perfect solution</u>

In flood events, it is important to understand that the choice of intervention will usually be a compromise rather than a perfect solution. On the one hand, there is a need to rapidly reduce disease risk, but in doing so it might mean accepting certain sub-optimal conditions in terms of things like technology effectiveness, longer-term sustainability or water quality.

[32] IPCC (2001) *Summary for policymakers - Climate Change 2001: impacts, adaptation, and vulnerability. A Report of Working Group II of the Intergovernmental Panel on Climate Change.* IPCC, Geneva, Switzerland. p.13

Techniques to increase resilience and reduce vulnerability

Overall issues to consider (cross-cutting issues)

The following are potential cross-cutting issues related to increasing resilience of WASH projects in flood-prone areas:

Technical, logistical & resource issues

- In flood emergencies, rapid installation / set-up of WASH facilities is often needed. Experience shows that this is often missing,[33] with delays of up to 2 weeks between a flood event and the first WASH assistance arriving.[34] Speed can be aided by better forward planning, stocks and coordination (see below).
- Certain WASH interventions are only suitable during a particular phase of a flood emergency – therefore phasing of WASH interventions should be an integral part of any response (e.g. where bottled water during the first few days is replaced by tankered water, which again is replaced by longer-term solutions).[35] Phase 1 (0-2 months) is typified by instability and a rapidly changing situation requiring immediate WASH actions, Phase 2 (2-6 months) is typified by stabilization where short to medium-term WASH actions are appropriate, and Phase 3 (6-12 months) is typified by the resettlement of communities where longer term WASH actions are suitable which may include prevention strategies.[36]
- The technical choice of intervention will also depend on the type of flooding and level of displacement that it causes. Where people are displaced in large numbers to non-flooded areas outside of their area, then the interventions will often more reflect standard WASH interventions for camp settings. However, when people are not displaced (e.g. when they stay near the home, such as where flooding is seasonal) then different WASH interventions will be required that are adapted to flood events.[37]
- Preparation of safe / refuge areas can be a good preparation strategy – these are areas above flood level that allow people to congregate immediately after a flood before temporary shelters are arranged or until they can return home, and as such they can include facilities such as meeting places, schools and WASH facilities.[38] Since these facilities will not likely be used at other times, maintenance can become an issue.[39]
- An ability to access the population immediately after a flood is required – therefore different transport options need to be considered and planned for (e.g. helicopter, boat, jetski).[40]
- Facilities in shelter sites may be more heavily used during the evening than during the day, due to the fact that men usually return to the house during daytime. This has implications on the supply, operation and maintenance of agency-run facilities.[41]
- An adequate level of technical expertise and staff availability (including surge capacity) in relief agencies is needed, yet is often lacking in some flood situations[42] and this can compromise the effectiveness of an intervention. For example in Ecuador, some water treatment units that were set up and adjusted by experienced technicians operated well, compared to those that remained in their boxes due to lack of technical capacity to set them up.[43] Expertise is essential for certain design and construction phases and we should not assume that indigenous knowledge will contain everything to solve local problems – rather it is a balance between the two.[44] Also the short-term hiring of technical consultants is not enough to guarantee quality work and success.[45]
- Each system needs to be designed and constructed so as to be site-specific. A successful technology at one site should be transferred to another area with different physical and/or social settings only after great care and some modification.[46] This is to say that a certain amount of experimentation and failure may be needed in this process. It is therefore recommended to start small, learn as you go and expand as needed.[47]

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[33] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7
[34] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[35] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.15
[36] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.1
[37] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.15
[38] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.217
[39] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.16
[40] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[41] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.14
[42] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7
[43] Reiff, F. (1982) *Floods and water supplies: lessons learned in Ecuador*. PAHO/WHO Virtual Disaster Library.
[44] Falkenmark, M.; Fox, P.; Persson, G.; Rockström, J. (2001) *Water harvesting for upgrading of rainfed agriculture. Problem analysis and research needs*. Stockholm International Water Institute.
[45] Hedlund, K. (2007) *Slow-onset disasters: drought and food and livelihoods insecurity. Learning from previous relief and recovery responses*. ALNAP / Provention Consortium. p.8
[46] Falkenmark, M.; Fox, P.; Persson, G.; Rockström, J. (2001) *Water harvesting for upgrading of rainfed agriculture. Problem analysis and research needs*. Stockholm International Water Institute.

Health issues

- There is a need for active and improved water quality and disease (water-borne) surveillance in flood emergencies.[48] For disease surveillance, this includes maintaining and strengthening surveillance systems for infectious diseases in general (e.g. leptospirosis – a disease known to spread after flooding – is difficult to diagnose and is often mis-diagnosed as dengue, and there are few specialist laboratories which can make the diagnosis). Improved disease surveillance also includes enhancing surveillance following flood events specifically in order to determine mortality, morbidity (where possible, the infectious agent should be confirmed by laboratory test) and the associated risk factors.[49]

Institutional issues

- There is a need for better coordination between agencies, authorities and the private sector. This is not only to ensure a coordinated response and to aid sharing of information and resources, but it should be seen as a vital part of capacity building of local authorities. Experience from Mozambique showed that many district administrations emerged from the floods with little or no knowledge of how to face the next disaster since they were not involved in budgetary and planning processes – agencies' agendas had been output-driven (wells, schools etc) rather than geared towards building longer-term capacity in government institutions.[50] This coordination should happen not only during and after the emergency, but also during the planning phase since those agencies involved in planning for the emergency may be different from those carrying out the response.[51,52,53] However, for true coordination to happen, there is a need for decision-making power to be decentralized from head offices to the field level. Experience from Haiti showed that 'coordination' meetings often ended up only as information sharing forums rather than effective modes to coordinate and improve services – this was due to lengthy internal decision-making processes within agencies where field staff did not have the authorization to make decisions which had to be referred to headquarter level, which made any planning and implementation very inefficient.[54]
- An integrated WASH response to floods is essential, where both hardware and software considerations are taken into account, and where there is as much focus on things like sanitation and hygiene as there is on water supply. Key things to understand when delivering an integrated response in flood situations are:
    - Humanitarian responses to flood situations in the past have probably focused more on water than sanitation, yet both are important. This is not just in order to target WASH-related diseases from different angles, but also because the areas are interlinked so that an improvement in one area will impact another area. For example, hygiene promotion is much more than the dissemination of messages about handwashing – rather it encompasses the optimal use, care and maintenance of water and sanitation facilities, and can be a mechanism to involve affected populations in the design and delivery of an effective and appropriate response through dialogue, participation and feedback.[55,56]
    - As such, a water supply project without hygiene promotion is likely to be a lot less effective. Yet the reverse can also be true, where doing hygiene promotion without hardware will not be effective – experience from Haiti showed that in some areas there were very few agencies that could deliver hardware compared to those that were only doing hygiene promotion.
    - With the nature of disaster situations changing (increased scale of affected areas and numbers of people), it is more likely that WASH agencies might be the only ones working in one area, compared to previously common situations where many agencies might be concentrated in one area such as a refugee camp. It is important then that these agencies have a variety of competencies to cover all aspects of WASH including water, sanitation and hygiene promotion, rather than becoming more specialized.[57]
    - Kick-starting some services might rely on others being carried out. The reality of some flood situations is that interest from the community in sanitation projects may be dependent on them getting a clean water supply first, which might be closer to their own priorities.[58]
- A pre-prepared flood response plan is needed, which includes pre-positioning of WASH materials in official designated shelters.[59] Experience from India shows that those agencies that had stocks fared better in the response.[60]

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[47] NWP; Aquaforall; Agromisa; Partners voor Water. (2007) *Smart Water Harvesting Solutions*. Netherlands Water Partnership.
[48] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7
[49] Few, R.; Ahern, M.; Matthies, F.; Kovats, S. (2004) *Floods, health and climate change: a strategic review*. Working Paper 63. Tyndall Centre for Climate Change Research, Norwich, UK. p.47
[50] Wiles, P.; Selvester, K.; Fidalgo, L. (2005) *Learning lessons from disaster recovery: the case of Mozambique*. Working Paper Series No.12. World Bank, Washington, USA. p.25
[51] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. pp.4,6
[52] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[53] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7
[54] Koestler, A.G.; Koestler, L. (2011) Hygiene promotion without water – water supply without hygiene promotion: new emergencies after disasters. *35th WEDC International Conference, Loughborough, UK.*
[55] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.6
[56] Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland.
[57] Koestler, A.G.; Koestler, L. (2011) Hygiene promotion without water – water supply without hygiene promotion: new emergencies after disasters. *35th WEDC International Conference, Loughborough, UK.*
[58] Djonoputro, E.; Blackett, I.; Rosenboom, J.-W.; Weitz, A. (2010). Understanding sanitation options in challenging environments. *Waterlines* Vol.29 No.3 July 2010. p.190
[59] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009

- A demand-responsive approach and participation should be promoted[61] which can allow ownership of technology and structures when planning and implementing flood-resilient WASH systems. This should be non-negotiable in prevention / rehabilitation phases but even after an emergency it should be possible to a degree. It is not something that must take lots of time, rather it is a mindset that should be adopted with the aim to involve beneficiaries and take their concerns seriously (e.g. where possible, site selection needs to take into account community preferences with respect to convenience).[62] Part of this process involves consultation with both men and women, which alone can improve interventions, but going further than only consulting affected people and involving them in deciding on technology / service levels and management arrangements is likely to further improve a project's success, since it can allow people to be better able to cope with problems in times of stress.[63, 64] Women in particular should be actively involved as they have a vested interest to make the system work (due to lower water collection times for example). Part of involving people in the design stage requires understanding that flexibility in the design should be encouraged depending on beneficiary feedback. During technical design, the true participatory process allows continual learning and adjustment to go both ways – in this view, participation is not a concession by powerful outsiders but an essential process for project success.[65]
- Management arrangements of WASH facilities should be such that the need for outside assistance is reduced. During flood emergencies, it is common for outside assistance to take time to arrive, yet it is the first weeks that are sometimes the most critical in terms of WASH needs. It therefore makes sense as part of a prevention strategy to build capacity into local communities as much as possible in order that they can maintain and operate facilities during a flood, and possibly replicate technologies when floodwater has receded. This was shown to work well after a project that made flood-resilient latrines and handpumps in a flood-prone area of India – here community volunteers were trained in chlorination and filtration techniques, and masons were trained in construction of raised latrines and water points.[66]
- Flood risk reduction and response are more likely to be effective when they include and build on coping mechanisms in the assessment and programme design – often people know what they need to do and have some resources while lacking other resources.[67] Any existing traditional flood-proofing practices may be products of trial and error that evolved over time, and as such they should be valued and taken into consideration by engineers and planners.[68] In regions where access is particularly difficult, it is effective for agencies to build on this and support communities to build their own solutions.[69]
- At unofficial refuge sites, landowners may not have given their agreement for the people to remain there. Therefore any only temporary types of structures should not be built unless agreement has been secured from the landowner.[70]

<u>Vulnerable groups</u>

- Women who are displaced may be extremely vulnerable, and often need privacy particularly when visiting latrines, as well as protection against sexual harassment, violence or exploitation (e.g. through having separate facilities or adequate lighting). Agency staff need to be aware of these needs, and provide adequate assistance and protection.[71]
- The elderly and less mobile are also vulnerable in flood situations, as they may be less able to reach uncontaminated water sources – there have been cases where the elderly ended up drinking floodwater because of this.[72]

<u>Financial & economic issues</u>

- Access to funding should be made available not only for relief agencies, but also for municipal water & wastewater departments.

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[60] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7

[61] Research shows that services are better sustained with demand-responsive approaches and is the reason why it was one of the guiding Dublin Principles in 1992. Also see: Wijk-Sijbesma, C, van (2001): The best of two worlds. Methodology for participatory assessment of community water services. Delft: *IRC International Water and Sanitation Center Technical Paper Series 38*. p156, p.220.

[62] Danert, K.; Armstrong, T.; Adekile, D.; Duffau, B.; Ouedraogo, I.; Kwei, C. (2010) *Code of Practice for Cost Effective Boreholes*. RWSN, St. Gallen, Switzerland. p.7. Available at http://www.rwsn.ch/documentation/skatdocumentation.2010-08-23.4523209156/file

[63] See: www.fao.org/docrep/W7314E/w7314e0q.htm - experience in India showed that water conservation projects that involve people in all stages from planning through to execution had higher success rates, while those that did not involve them tended to fail.

[64] Alam, K. (2008) *Flood disasters - Learning from previous relief and recovery operations*. ALNAP/Provention Consortium. p.5

[65] Cullis, A.; Pacey, A. (1992) *A development dialogue: rainwater harvesting in Turkana*. IT Publications, London, UK. pp.116.

[66] Shekhar, A.; Dwivedi, S.; Bhagwat, I. (2010). Ensuring safe water and sanitation during floods in rural communities of Bihar State, India. *Waterlines* Vol.29 No.3 July 2010. p.206

[67] Alam, K. (2008) *Flood disasters - Learning from previous relief and recovery operations*. ALNAP/Provention Consortium. pp.3,5

[68] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.171

[69] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7

[70] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.14

[71] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.15

[72] Roger Young and Associates (2000) *Bangladesh 1998 Flood Appeal: an independent evaluation.* Final Report. Disasters Emergency Committee. p.30

Resilient techniques to improve WASH in flood-prone areas

- Where free or maintenance-cost-only water sources (usually the choice of the poor) are unavailable due to flooding, access can be given to paid-for sources. This is useful in urban areas where there are such sources available. However, experience shows that it is difficult to target the poor and requires blanket access.[73]

[73] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.16

Concrete techniques

Overview:
Poor construction techniques are to blame for many failures in water and sanitation structures, which in turn makes these structures more vulnerable to the effects of flooding. Key construction issues such as the making of concrete, correct construction of stone masonry, as well as the issue of pipes passing through water-bearing structures. This section focuses on concrete making. Proper techniques are often bypassed or shortened, which increases the risk of failure and reduces the life of the structures.

Key techniques for construction & implementation: [74]

- All dry ingredients should be mixed first before adding water.
- Use the correct ratios for different applications – refer to relevant tables.[75] A field method to check if contractors have used the correct ratio is to take some of the wet mix, put it into a transparent bottle and shake up with some water – the cement fraction should settle out on top when it is left to stand, giving an indication of the cement fraction.[76]
- Add only the very minimum amount of water for workability – this is one of the most important aspects to making strong concrete. The amount of water needed for the hydration process when mixing concrete is a lot less than what is normally added to mixtures in the field, where additional water is needed to increase workability of the concrete. The point is that the less water used, the better, since if too much water is used, the concrete will become weaker. This is because any excess water not used in hydration will remain in the pores – when this water evaporates, the pores remain – the more water added, the bigger the pores and the weaker the final product. Admixtures can be added to the concrete mix in order to reduce the amount of water needed. Research has shown that superplasticizers work best by reducing the amount of water that needs to be added when mixing concrete, which results in 35% less shrinkage. The resulting end material is stronger and can reduce the amount of micro cracks in mortar by half compared to normal mortar while resulting in 76% fewer leaks. In general, the amount of plasticizer to be added should not be greater than 2% of the dry material weight.[77] A plasticizer that can be used that is possibly available is household washing up liquid. In hot climates though, more research is needed in the field application of plasticizers, since the reduction of water used (and increased strength of product) may not be that great due to more water needed to prevent drying out between mixing and application.[78]
- Type of water used should be as pure as possible.
- Don't use weathered rock for concrete aggregate. For the best concrete it is best to use a fresh rock aggregate such as crushed granite of gneiss or well-washed river gravel. With the latter the river has removed the weak pieces.[79]
- Use clean gravel – impurities will weaken the concrete.
- Use aggregate (gravel) of 5-20mm for non-porous concrete[80] and 5-10mm for porous concrete.[81] Aggregate can be graded using 2 locally-made sieves of 5mm and 20mm – discard any aggregate that remains on the 20mm sieve or that falls through the 5mm sieve. The reasons for having a maximum size is to do with workability, but also that the maximum size is not greater than the "cover" of concrete over a reinforcing bar – if a stone would span the distance from outer edge to reinforcement, this can become a zone of weathering where water can get in to corrode the reinforcement.[82]
- Reinforce lower side of flat slabs as concrete is weak in tension. Reinforcement can be avoided if making dome shape structures (e.g. cover to rainwater tank, or domed latrine slab).
- Spacing of reinforcement bars depends on the slab span, thickness and type of reinforcement used – refer to relevant tables.[83]

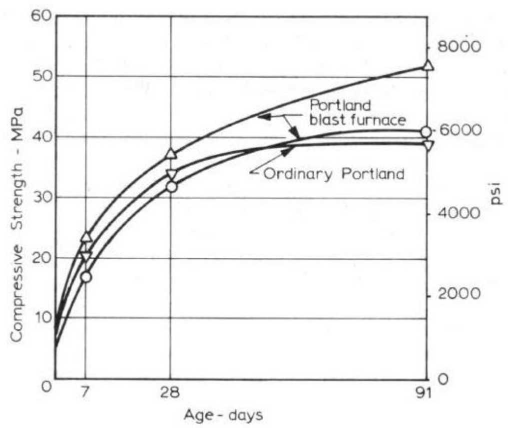

Figure 3: Concrete strength with curing
Neville, A.M. (1981) *Properties of Concrete*. Pitman.

[74] Unless otherwise stated, taken from: Constantine, T. (2001) *Cracking in Waterproof Mortars*. DTU, Warwick University, UK.
[75] For example see: Davis, J.; Lambert, R. (1995). *Engineering in Emergencies*. IT, London, UK. p.571
[76] Author's experience of a technique used by engineers in Somaliland.
[77] http://en.wikipedia.org/wiki/Plasticizer
[78] Personal communication with Dr Terry Thomas, Warwick University, UK.
[79] Personal communication with Bob Elson, WEDC, Loughborough University, UK.
[80] Davis, J.; Lambert, R. (1995). *Engineering in Emergencies*. IT, London, UK. p.570
[81] Watt, S.B.; Wood, W.E. (1979). *Hand Dug Wells and their Construction*. IT, London. p.158
[82] Personal communication with Bob Elson, WEDC, Loughborough University, UK.
[83] For example see: Harvey, P.; Baghri, S.; Reed, B. (2002) *Emergency Sanitation: Assessment and Programme Design*. WEDC, Loughborough, UK. p.91. See also: Davis, J.; Lambert, R. (1995). *Engineering in Emergencies*. IT, London, UK. pp.573-576.

- Place reinforcement bars with a 30mm “cover” from the nearest edge.
- If possible use a poker vibrator to eliminate air bubbles, especially when casting foundations. This should be placed vertically to the full depth of the concrete for 15 seconds, then withdrawn slowly and repeated at intervals of 150-250mm across the surface.[84]
- Ensure adequate curing - this is one of the most important aspects to making strong concrete, but is often bypassed in the field due to lack of water, knowledge or organization. Adequate curing is necessary to keep the process of hydration going as long as possible – the longer the time, the stronger the concrete. This hydration process will stop once the concrete has dried out, resulting a strength of concrete according to the time of curing. Although curing can continue even for years, 7 and 28 days are normally quoted (see Figure 3) – curing should last at least 7 days, if not longer especially in cold weather. Curing involves sprinkling water on the concrete every day as well as covering it, preferably in a shady area. Covering can be done with material like plastic or sacking, but covering in wet sand also works well, as does putting the concrete entirely in water.

[84] Davis, J.; Lambert, R. (1995). *Engineering in Emergencies*. IT, London, UK. p.572

Floodplains management

Overview:
Although perhaps most interventions that humanitarian agencies will be involved in will be localized (at community or neighbourhood level) and smaller in scale, the fact remains that part of making WASH facilities more resilient to flooding will occur through other activities at a larger scale (e.g. city or catchment level), which can reduce flood risk by reducing the volume of water before it reaches flood-prone areas (e.g. reduce water quantity and reducing flow intensity). Integrated floodplain management is a way to look at flood risk at a catchment scale, and includes both structural and non-structural measures. Historically, there has been a tendency to concentrate on structural measures (that control water flow) as these have been seen to prevent flooding – yet what is now accepted is that regardless of whatever structural measure is taken, a residual flood risk still remains. Floodplains management therefore needs to also focus on non-structural measures (that don't control water flow) that can help reduce the effects of floods. Therefore there will be a need to move away from an over-reliance on engineered structural measures (which have high up-front costs, often only transfer flood risk to another area, and can result in greater impact when they fail) towards more adaptable non-structural measures (which have lower up-front costs, but which require good forecasting systems).[85]

Key techniques for construction & implementation:

- Structural measures that control the flow of water can provide protection against many types of flooding. However, as stand-alone measures, often they do not provide a robust, long-term solution for addressing flood risk. Experience shows that such efforts at flood control in both urban and rural contexts have produced limited results when applied in isolation from overall policy in the floodplains, and sometimes have even exacerbated flooding problems (e.g. by lulling people into a false sense of security through unimpeded development in areas where flooding will occur at some point). Structural measures however can be effective if they are integrated in the overall development policy, and are used in conjunction with other non-structural measures, while being planned and implemented with the participation of local people (who have an understanding of possible negative consequences).[86] [87] Structural measures include:
    - Construction of sea walls against storm surge.[88]
    - Common flood control structures and actions can be classified as those that (see Figure 4):[89]
        - Reduce flood peak by providing storage – these can be on-line (e.g. dams upstream) or off-line (e.g. storage basins / reservoirs not in the main river channel – see 'Stormwater & wastewater drainage systems' section for details). This may also improve infiltration (see below).
        - Modify the river:
            - Confine the flow within a predetermined area (e.g. levees)
            - Increase the flow velocity to reduce peak stage (e.g. dredging)
        - Divert flood waters to another area (e.g. irrigation canals, and conveyance and storage)
        - Improve infiltration and reduce runoff (e.g. contouring, terracing and reforestation)
        - Improve discharge through external means such as pumping
    - Some of these structures and techniques simultaneously improve water availability, and as such have been covered in other research (dams, terracing & contouring, reducing runoff), notably the sister document to this one on resilient

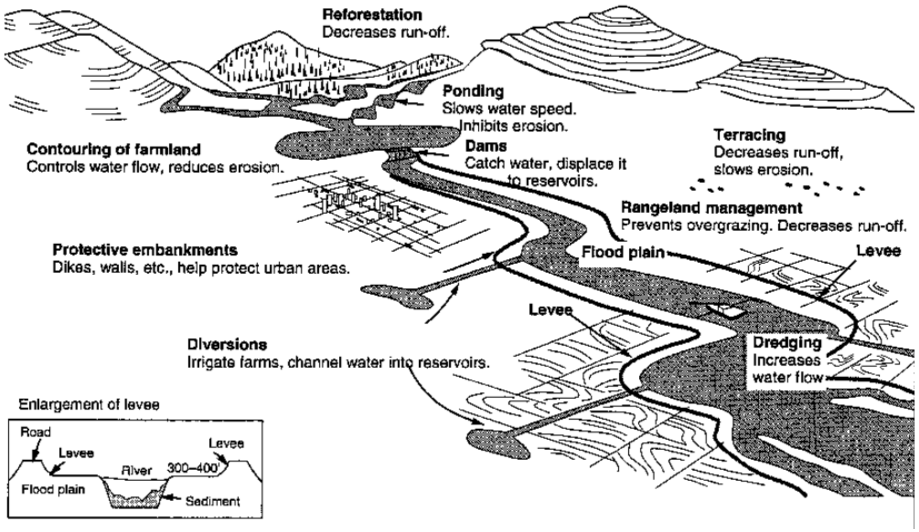

Figure 4: Flood control structures and actions
Reed, S.B. (1997) Introduction to hazards. 3rd Edition. UNDP. p.90

[85] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.32-33
[86] Alam, K. (2008) *Flood disasters - Learning from previous relief and recovery operations*. ALNAP/Provention Consortium. p.3
[87] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.25
[88] This was recommended after storm surges hit the Maldives. See: http://reliefweb.int/node/233884
[89] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.120

WASH for drought-prone areas.[90] They therefore will not be covered here in more detail. For larger-scale techniques such as levees, large-scale irrigation and reforestation, these are beyond the scope of this study. However, a detailed and helpful review of these techniques and their individual advantages and disadvantages for urban environments has been published in 2012.[91]

- Non-structural measures are those that do not control the flow of water itself, but rather make potentially affected areas more prepared for a flood. However they may still involve 'structural' work (e.g. raising a well head and handpump). Non-structural measures include:[92]
    - Emergency planning & management, such as early warning systems.
    - Flood avoidance through good land use planning and regulation of new development, in order to prevent future flood risk, since building on floodplains may obstruct natural drainage and lead to damage to property and injury or death. However, the reality of preventing new development in inappropriate areas may seem unlikely, given the pressure on land resources as well as other political and economic considerations. Planning and regulation though also includes other aspects, such as groundwater management to reduce subsidence.
    - Increased preparedness for a flood – various preparedness techniques are covered in this document, but preparedness also includes addressing other factors that contribute to vulnerability such as poverty.
    - Construction of flood-resilient infrastructure – this is easier to do at lower cost and with less disruption when new structures are built, rather than later as a retrofit solution. Yet improving resilience of facilities is also possible in the recovery phase after a flood, through better design and construction of older infrastructure. Both aspects are covered as techniques in this document.

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[90] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands.

[91] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.196-277

[92] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.33-36

Water supply, treatment & distribution

Bottled water distribution

Overview:

- Although a bottled water distribution will probably not reach everyone, this has been an preferred intervention in some flood emergencies due to speed of implementation, the fact that costs are sometimes borne by the bottle companies and because less technical skill is required compared to other supply and treatment options.[93]

Key techniques for siting:

- Keep this as an option for the acute stages of an emergency (i.e. a one-off distribution in the first 72 hours).[94]
- If there is not enough bottled water for the population, it might be an idea to give priority to dispersed populations which are more difficult to reach with safe water in the acute phase, while covering using other methods (e.g. centralized bulk treatment) to address water needs for other areas where people live in groups (e.g. camps).

Key techniques for construction & implementation:

- The bottled water should be distributed immediately. The constraint here is that there is often a lag between when the disaster occurs and when agencies are operational on site.
- Distribution can be done by most means, including helicopter.
- Efforts must be taken to ensure that distribution is well coordinated, and that bottled water reaches those who are most vulnerable. There is a risk that the healthiest and strongest members of a community will be most able to collect bottled water, while the young, the old, sick and disabled will not have access to distribution.
- Although empty bottles can create a waste problem, some clever planning should be able to make use of them:
    - Empty bottles can allow the introduction of SODIS as a household water treatment technology in the weeks and months following such a distribution. However, uptake of household water treatment in the acute phase of an emergency is known to be low (see 'Water treatment – other' section), so this may not be valid as an immediate strategy where an interim option is available (e.g. tankered water). For some dispersed populations it could be considered where no other options exist.
    - Empty bottles also can be promoted as water storage containers, their advantage being that recontamination is reduced due to their narrow openings and lids.
- Water can also be distributed as chlorinated water in sealed plastic bags where half volume is air to allow it to float.[95]
- As part of a flood preparedness strategy, bottled water vendors can be mapped allowing agreements to be made with certain vendors to supply water in an emergency.

[93] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. pp.8, 22
[94] This was the conclusion of a learning workshop in Haiti. See: Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[95] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.16

Saline water quality

Overview:
Brackish water is defined as starting at having a Total Dissolved Solids content of 1,000 mg/l, and saline water as having 10,000 mg/l.[96] Saline water is a problem in many areas of the world, but typical environments for saline groundwater are coastal areas and shallow aquifers in arid/semi-arid regions.[97] Salinity is derived from natural sources, but the biggest threat to groundwater is said to come largely from anthropogenic factors, where it is derived from saline intrusion in coastal regions, the percolation of irrigation water and wastewater returns to aquifers.[98] This section however looks at techniques for dealing with saline water as a result of occasional natural seawater flooding events.

Key techniques for siting:
- In coastal areas avoid digging or drilling through the freshwater aquifer.

Key techniques for construction & implementation:
- In areas where water sources have been flooded by seawater and have become saline, the following techniques could help regenerate the water source:
    - When cleaning up wells and boreholes, avoid pumping out the well repeatedly in order to reduce salinity – this is to avoid too much disturbance of the lenses of freshwater and seawater that need time to invert.[99] Excess salinity and contamination can be removed through some initial pumping, but a guide is to pump only the volume of water in the well itself.[100]
    - It may take up to 2 years for the freshwater and seawater layers to fully invert, so after initial cleaning the well water will probably be unpalatable for a time. How long depends on the local tolerance to the water taste, but can be used when people feel they are able to drink it. In the meantime, the water can be used for other domestic purposes while water for drinking should come from alternative sources.[101]
    - After pumping, wells can be shock-chlorinated (see 'Water treatment – other' section).
    - In areas of shallow saline groundwater, Managed Aquifer Recharge (MAR) techniques[102] have been used to dilute this groundwater which can then be re-extracted – the same principle could be applied to water sources contaminated by seawater. Examples of where this has been applied in a non-seawater flooded area are "Tajamar" infiltration ponds in Paraguay and roof water recharge systems in Mozambique. These techniques will not be detailed in this document, but have been covered in the sister document to this one on resilient WASH for drought-prone areas.[103] See also the 'Stormwater & wastewater drainage systems' section.
- Use of "skimming wells" has been investigated as a way to skim water from a thin freshwater aquifer, and may have applicability in areas suffering from saline water problems.[104] Ranney collectors act in a similar way.[105] These function in a similar way to infiltration galleries, but where radial horizontal collector pipes are connected to a well or borehole shaft to collect water from an upper freshwater layer – the well or borehole shaft is watertight below the freshwater layer but exists as a collection chamber from where the water is pumped.
- As part of a flood preparedness strategy, open wells can be protected in order to reduce the amount of debris and seawater contamination that might enter from a flood event – this may include increasing the height of the well wall above ground level, as well as providing access and / or a sealable cover to the well.
- Although it will probably be easier to locate alternative water supplies, household water treatment for salinity could still be an option to consider. Household solar stills (Figure 5) have not been widely promoted, yet can provide 2.5 – 3 litres per m^2 surface area per day.[106] However there is scope to increase yields – more efficient and expensive stills (Aqua Solaris) have

[96] Multiply by 0.7 to get to EC in µS/cm – see: Weert, F. van; Gun, J. van der; Reckman, J. (2009) *Global Overview of Saline Groundwater Occurrence and Genesis*. International Groundwater Resources Assessment Centre (IGRAC), Utrecht, The Netherlands.
[97] See global map of groundwater salinity at www.igrac.net. See also: Weert, F. van; Gun, J. van der; Reckman, J. (2009) *Global Overview of Saline Groundwater Occurrence and Genesis*. International Groundwater Resources Assessment Centre (IGRAC), Utrecht, The Netherlands. p.7
[98] Gale, I. (Ed) (2005) *Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas.* IAH-MAR and UNESCO-IHP. p.5.
[99] Vilholth, K. (2011) *Cleaning wells after seawater flooding*. Technical notes on drinking water, sanitation and hygiene in emergencies no.15. WHO, Geneva, Switzerland.
[100] Author's experience of email recommendations from WEDC given in Sri Lanka after the tsunami of 2004.
[101] Vilholth, K. (2011) *Cleaning wells after seawater flooding*. Technical notes on drinking water, sanitation and hygiene in emergencies no.15. WHO, Geneva, Switzerland.
[102] See section on 'Stormwater and wastewater drainage systems'.
[103] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands. pp.40-57
[104] Saeed, M.M.; Ashraf, M.; Asghari, M.N.; Bruen, M.; Shafique, M.S. (2001) *Root Zone Salinity Management Using Fractional Skimming Wells With Pressurized Irrigation – Farmers' skimming wells technologies: practices, problems, perceptions and prospects.* Working Paper 40. IWMI, Lahore, Pakistan. Available online: http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR40.pdf
[105] http://en.wikipedia.org/wiki/Ranney_collector
[106] Author's experience in Kenya. See also: Practical Action. *Solar distillation technical brief.*

been tried that can increase volume to 40 litres per m^2 per day.[107] Regarding the standard version that has been field tested, they require water temperature to be high, while the condensing surface to be as cool as possible – for this reason stills are most efficient in the early evening when water is still warm but temperature of the glass is a lot lower,[108] and stills continue to produce water during the night. The Watercone is a mass-produced innovation that can produce 1.5 litres maximum per cone per day, but tends to be expensive.[109] Solar stills can be constructed using local materials which are cheaper. There are key points to get right:

- Keep water temperature in the solar still as high as possible:
  - Use a condensing surface with a low absorption capacity. Glass is most commonly used as it is "wettable" (i.e. water condensing in a film rather than forming droplets which reflect radiation) but should ideally be sufficiently thick to withstand rain, wind and some knocks – 1/8" or 3.2mm is adequate. Plastic should not be used due to the high temperatures.[110]
  - Keep the glass and walls clean. The warm humid environment may encourage the growth of biological films inside the still.
  - Keep water level in the still to between 0.5 – 2.5 cm deep only = less water to heat up = increased efficiency, but not too little that it will dry up.[111]
  - Insulate the base and walls of the still = retains the heat rather than losing it out the sides and base of the structure. Expanded polystyrene sheets 1" thick is widely available and is good for this purpose. The lining on top of this insulation will retain more heat if it is black.
  - Make the solar still waterproof – the easiest way to do this is to use a liner. EPDM or butyl rubber is a good choice as they will not break up or give unpleasant taste/odour to the water.[112]
  - Lining the walls inside the solar still with a reflective material (e.g. aluminium foil) may increase reflection of heat energy but has not been tried.
- Avoid vapour leaks. Silicone applied using an application gun works well to seal the glass to the frame. Seals may need to be renewed at intervals because of the warm humid environment.
- Width of glass is normally limited to between 0.65 – 0.9 metres.[113]
- Add 3 times the daily clean water amount each morning to flush the still – water will flow out through the overflow. Failure to do this will result in salts deposited in the still.
- The slope of the glass should be minimal. Water will run off glass even set at 1 degree tilt. As a guide, set the angle so that the distance from water level to glass is in the range of 5 – 7 cm in order to minimize air volume in the still, and to increase efficiency.[114]
- Never allow the still to go dry otherwise it can melt the lining and insulation in the still.

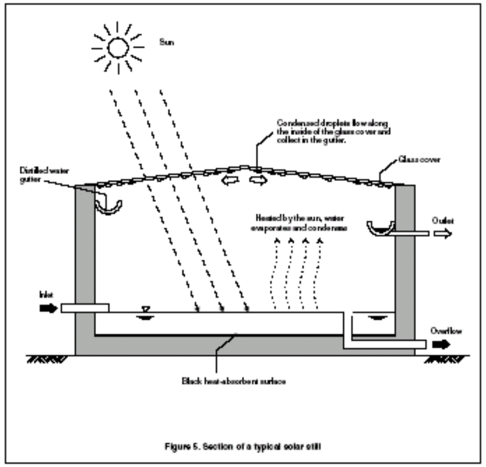

Figure 5: Typical single basin solar still
Shaw, R. (ed) (1999).*Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London.

- Communal solar stills have been constructed in some locations.[115] Like any other larger communal installations, there have been problems with maintenance. They may work however if they could be owned and managed by people who have a vested interest in the technology (e.g. water vendors).
- For volumes of water over $1m^3$ per day, reverse osmosis (RO) or electrodialysis can be considered.[116] The type of technology will depend on the salt concentration of the water to be treated however – distillation for salt concentrations between 20,000 and 100,000 mg/L, RO can be used for salt concentrations of between 50 and 50,000 mg/L, and electrodialysis is suitable for 200 to 10,000 mg/L.[117] Therefore if the problem of salinity is from seawater (which has about 21,000 mg/L salt content), distillation or RO may be more appropriate. However, for rural areas and most small towns, it will be wise to avoid more complex systems unless you can guarantee technical competence in the design, construction and maintenance of the

[107] Koninga, J. de; Thiesen, S. (2005) Aqua solaris – an optimized small scale desalination system with 40 litres output per square meter based upon solar-thermal distillation. *Desalination.*
[108] Practical Action. *Solar distillation technical brief.*
[109] CARE Yemen (2004). *East of Aden Watercones Pilot Project Report.*
[110] http://www.appropedia.org/Understanding_Solar_Stills
[111] http://www.appropedia.org/Understanding_Solar_Stills
[112] http://www.appropedia.org/Understanding_Solar_Stills
[113] http://www.appropedia.org/Understanding_Solar_Stills
[114] http://www.appropedia.org/Understanding_Solar_Stills
[115] See: Alward, R. (1970) *Installation of a solar distillation plant on Ile de la Gonave, Haiti. Internal report No. I.67.* Brace Research Institute, McGill University, Canada. See also: Aadan, A.I. (1982) *Final report on solar water distillation project. Warbixin iyo gunaanud ee mashruuca kudha sannadka1981ka.* Jamhuuriyadda Dimoqraadiga Soomaaliya.
[116] Practical Action. *Solar distillation technical brief.*
[117] Personal communication with Mike Smith, WEDC, based on information from Lenntech.

systems, as well a supply of spare parts and chemicals. If considering this route, it is particularly important is to get a full water analysis done prior to system design, and to have design carried out by RO specialists.[118]

[118] Author's own experience.

Water storage tanks

Overview:
Storage tanks are used in many situations where water is supplied. In flood zones, such tanks need to be resistant to the effects of flooding. This section covers different considerations when choosing a type of tank, as well as siting and construction tips.

Key techniques for siting:

- Siting tanks in floodable areas can follow similar guidelines to buildings:[119]
  - Avoid natural drainage paths, water courses and water detention areas
  - Site the structure with any short side along the contours
  - Construct the tank on the best bearing soil on ground higher than the probable maximum flood level
  - When siting on high ground is not possible, construct the tank on individual high mounds with thoroughly compacted soil and surrounded by trees to maintain stability
- Do not site near big trees whose roots might crack the tank foundations and walls.
- Do not site tanks where heavy vehicles will pass close to tank foundations, which might affect the walls.

Key techniques for construction & implementation:

- The reason for constructing a tank is to retain the water. Therefore one of the most important aspects is that seepage and cracks must be avoided in tanks. Therefore good quality construction work with adequate supervision is vital to create a sound structure – this is especially important in areas with swelling soils that can affect the integrity of the lining – something that may occur more frequently in flood-prone areas. Some generally applicable issues are detailed below to prevent cracking/seepage:
  - Take care when building in clayey areas – montmorillonite, calcium-containing clays (in marls/gypsum sediments) and black cotton soils are all prone to swelling and can crack sub-surface tank walls that are not built robustly enough.[120]
  - For above-ground tanks, the foundation is a very important component to prevent cracks in the walls. Therefore it is important to construct an adequately robust foundation from reinforced concrete – when doing so, concrete needs to be laid with vibration in order to be sure it is leak-proof.[121] Reinforced concrete tanks have been observed to fare better to flooding than masonry tanks.[122]
  - Admixtures can be added to the concrete mix in order to reduce the amount of water needed. Research has shown that superplasticizers work best by reducing the amount of water that needs to be added when mixing concrete, which results in 35% less shrinkage. The resulting end material is stronger and can reduce the amount of micro cracks in mortar by half compared to normal mortar while resulting in 76% fewer leaks. In general, the amount of plasticizer to be added should not be greater than 2% of the dry material weight.[123] A plasticizer that can be used that is possibly available is household washing up liquid. In hot climates though, more research is needed in the field application of plasticizers, since the reduction of water used (and increased strength of product) may not be that great due to more water needed to prevent drying out between mixing and application.[124]
- Those tanks that are built into the water table or in areas prone to flooding, need to be able to resist flotation and the excavation will need to be de-watered (see 'Cholera response' section).
- Create a fence around the tank to prevent large vehicles from driving too close and damaging the lining.
- A round tank will resist floodwater better than a square tank, and a round tank is usually better structurally than a square or rectangular tank..
- In emergency response, bladder tanks should be put on sturdy structures – experience from the past shows that tanks were often placed on weak structures.[125]
- Ensure that the taps or outlet is above floodwater level.

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[119] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.158
[120] Personal communication, Dick Bouman, Aquaforall. See also: Worm, J.; Hattum, T. van (2006) *Rainwater harvesting for domestic use*. Agrodok 43. Agromisa Foundation and CTA, Wageningen, The Netherlands. p.43.
[121] Experience of CARITAS berked programme, Somaliland, 2008.
[122] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[123] http://en.wikipedia.org/wiki/Plasticizer
[124] Personal communication with Dr Terry Thomas, Warwick University, UK.
[125] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009

Handpumps

Overview:
Handpumps are frequently installed on hand-dug wells and boreholes in rural areas, including many flood-prone areas. They facilitate a contamination-free method to extract water, but historically handpump functionality has been negatively affected by numerous issues related to user operation & maintenance, which in turn has resulted in a large percentage of handpumps that do not work. However, while this is an important issue, this section only looks at techniques to improve resilience of structures and water quality to flood events.

Key techniques for siting:
- When choosing well or borehole site, choose non-floodable zone, and a location that is not on a major drainage route (see relevant section).

Key techniques for construction & implementation:
- Ensure that an apron has been constructed – experience shows that without an apron, floodwater can more easily contaminate the groundwater.[126] Ensure that aprons have deeper foundations at the edge to resist floodwater erosion (see 'Traditional hand-dug wells' section).
- Ensure that there is a good seal between the handpump and apron, to prevent surface water leaking through the apron around the handpump.
- When building in floodable areas is unavoidable, construct in such a way that the water source does not become contaminated directly with surface water. The exact construction will depend on the flood level in the area:
    - Construct a raised slab, the top of which is higher than the maximum flood level:
        - Where water extraction is with handpumps, for hand-dug wells or boreholes it is possible to construct a raised headwall / structure and slab, but in this case additional steps will be required to allow access to the slab (see 'Traditional hand-dug wells' and 'Boreholes' sections for details).
- If for whatever reason it is not possible to raise the slab high enough to avoid some floodwater, you should accept that inundation is sometimes going to take place. Although this might not be ideal, keep in mind that a flooded but protected water source will still most likely have better quality water than other unprotected water sources that have not been flooded (which might be considered better options during a flood).[127] In this case, always cover the well with a slab and:
    - Choose a handpump that has its spout above the highest water level
    - Ensure that pump base is fixed to slab properly and that the slab has been properly cured (to avoid any cracks that could occur later with heavy use)
    - If it is likely that the spout will be inundated, choose a lower risk pump (e.g. in India Mark or Canzee pumps, any floodwater that enters the spout would then fill the rising main, but this would only enter the aquifer slowly due to valves in the pumping mechanism) over more open pumps (e.g. in rope pumps, any floodwater that enters the rising main goes directly to the water source without any hindrance).
- In areas where there are many handpumps that are prone to flooding and may need repair after a flood event, a prevention strategy should include training local people to repair and maintain pumps, as well as to keep stockpiles of spare parts. Experience from Bangladesh has shown that where widespread damage to handpumps occurred after a flood, the limiting factor to getting the work done was the availability of external expertise and manpower.[128]

[126] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.5
[127] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.15
[128] Hoque, B.A.; Sack, R.B.; Siddiqi, M.; Jahangir, A.M.; Hazera, N.; & Nahid, A. (1993) Environmental-Health and the 1991 Bangladesh Cyclone. *Disasters*, 17, 143-152.

Traditional hand-dug wells

Overview:
This category describes shallow wells which draw water from a natural aquifer or man-made aquifer (e.g. near sand dam or around ponds) but which are not located inside a riverbed. It can include wells that are far from a river, or wells that receive water from shallow aquifers hydraulically connected to the river. Sometimes the holes dug are very large, allowing people and sometimes animals are able to walk into the well to where the water is. A variation is the infiltration well, suitable for low-yielding aquifers where the amount of materials used for construction is less.[129]

Key techniques for siting:

- When choosing well site, try to choose non-floodable zone, and away from natural drainage channels. Normally wells should be sited at a sufficient distance away from sources of contamination, and this includes ponding surface water. For microbiological contamination, the distance from the source of contamination (e.g. latrine) to the water intake (screen) needs to be sufficient so as to pose a "low" to "very low" risk – this translates into a minimum of 25 days of potential travel of pathogens in the ground. Travel time is influenced by porosity, hydraulic conductivity (permeability) and hydraulic gradient. For medium size sand with an average porosity, the distance equivalent to 25 days is around 30 metres, but this can increase to over 100 metres for coarser sediments. However, the distance from contamination to water intake can reduce significantly where the screen intake is at a sufficient depth – this is due to greater variation of aquifer properties in vertical directions than lateral, meaning that a borehole with handpump could be placed very close to a latrine with low risk. However, screen depth must increase with increased extraction rate.[130]
- Hand-dug wells can be an option for water supply in safe / refuge areas as part of a prevention strategy.[131]

Key techniques for construction & implementation:

- Ensure that an apron has been constructed. Ensure that aprons have deeper foundations at the edge to resist floodwater erosion caused by running water that can undermine a concrete slab (see Figures 6 and 7).
- When building in floodable areas is unavoidable, construct in such a way that the water source does not become contaminated directly with surface water. The exact construction will depend on the flood level in the area:
    - Construct a raised headwall and/or slab, the top of which is higher than the maximum flood level:
        - Where water extraction is with buckets and the maximum flood level is not very high (i.e. flood level is less than the distance to the average person's mid torso when they stand on the apron), a raised headwall can be built with a height that exceeds the maximum floodwater level. This can prevent future floodwater from contaminating the water source.
        - Where water extraction is with handpumps or the maximum flood level is high (i.e. higher than the distance to the average person's mid torso when they stand on the apron), the headwall and slab can be raised further but in this case additional steps will be required to allow access to the slab (see 'Boreholes' section for details).
        - If the extended headwall is done as part of a well rehabilitation (as in the case where the original well headwall was overtopped by floodwater) and

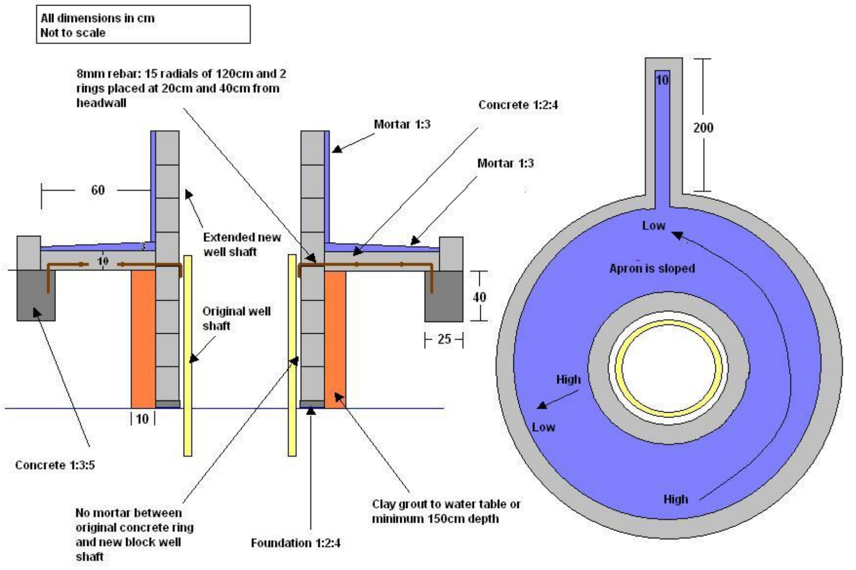

Figure 6: Flood-proofed well, Madagascar - raised headwall built to the exterior of the original well shaft and clay grout
Eric Fewster, Medair

[129] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands. p.93
[130] Lawrence, A.R.; McDonald, D.M.J.; Howard, A.G.; Barrett, M.H.; Pedley, S.; Ahmed, K.M.; Nalubega, M. (2001). *Guidelines for assessing the risk to groundwater from on-site sanitation*. British Geological Society, Keyworth, UK.
[131] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.16

where it is not possible to build directly onto the original lining structure for whatever reason (e.g. original structure is partly broken, or where it would be difficult to add additional concrete rings) then a separate well shaft lining can be built next to the exterior of the original lining (see Figure 8). This new lining would form the new headwall and would support any slab, and as such it should continue below ground level to a minimum depth of 1.5 metres (or to water table) in order to give support and also help prevent any short-circuiting of infiltrated floodwater. The two linings should be able to move independently (i.e. do not add concrete between the two) so that the well can be deepened in future – in such a case, the original well shaft would move while the new exterior lining would act as the permanent lining.

- In addition to a raised structure, ensure that construction of the well shaft above the water table is watertight – this is in order to avoid any possible short-circuiting of floodwater that infiltrates into the ground around the well shaft:
  - Where the well lining is porous, has cracks or un-mortared joints, a grout can be added to the outside of well shaft to a minimum depth of 1.5 metres, or to the water table (see Figure 9).
  - If using concrete rings, ensure that they are properly mortared together, and if possible bolted together. An in-situ permanent lining is possibly an easier way to ensure the shaft is watertight – this is where one-skin moulds are used to hold concrete against the dug wall of the hole, with the result that the concrete well shaft is cast in one piece from top to bottom (see Figure 10).[132] The in-situ lining method also has other advantages:
    - The telescopic lining that goes together with a permanent in-situ lining is independent, which allows the well to be deepened at a later date without affecting the permanent lining and slab (e.g. in case the well was not sunk deep enough the first time)
    - The well shaft has less chance to go out of vertical alignment during caissoning (where a shaft is sunk by digging).
    - Heavy lifting equipment for pre-cast rings is obsolete while procedures are inherently safer. In contrast, a telescopic shaft can be made from curved blocks built onto a foundation cutting ring – the blocks can be extended as and when necessary.[133]

- If for whatever reason it is not possible to raise the slab high enough to avoid some floodwater, you should accept that inundation is sometimes going to take place. Although this might not be ideal, keep in mind that a flooded but protected water source will still most likely have better quality water than other unprotected water sources that have not been flooded (which might be considered better options during a flood).[134] In this case, always cover the well with a slab and:
  - Ensure that manhole cover is sealed – use a mortar of 1:3 to seal the edge of the hatch to the slab (this can always be opened for maintenance by tapping with a hammer later)
  - If installing handpumps, contamination risk can be minimized by choosing a handpump that has its spout above the highest water level and / or choosing a lower risk pump, as well as ensuring that the pump base is fixed to slab properly and that the slab has been properly cured (see 'Handpumps' section for details).

Figure 7: Deeper edges to apron to prevent erosion and undercutting, Madagascar
Eric Fewster, Medair

Figure 8: Flood-proofed well, Madagascar – exterior raised headwall under construction
Eric Fewster, Medair

[132] Watt, S.B.; Wood, W.E. (1979) *Hand Dug Wells and their Construction*. IT, London, UK. pp. 83-92
[133] For an excellent construction manual, see: Watt, S.B.; Wood, W.E. (1979) *Hand Dug Wells and their Construction*. IT, London, UK. In addition, Medair (Madagascar) in 2004 created some more efficient designs of cutting ring and block moulds.
[134] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.15

- Consider alternative extraction methods that are offset and above flood level (e.g. infiltration galleries or riverbed wells (see relevant sections)).
- Consider a more cost-effective way of reducing flood contamination risk than raising hand-dug wells headwalls and slabs (e.g. jetted wells with handpumps – see 'Riverbed jetted & driven wells' section).

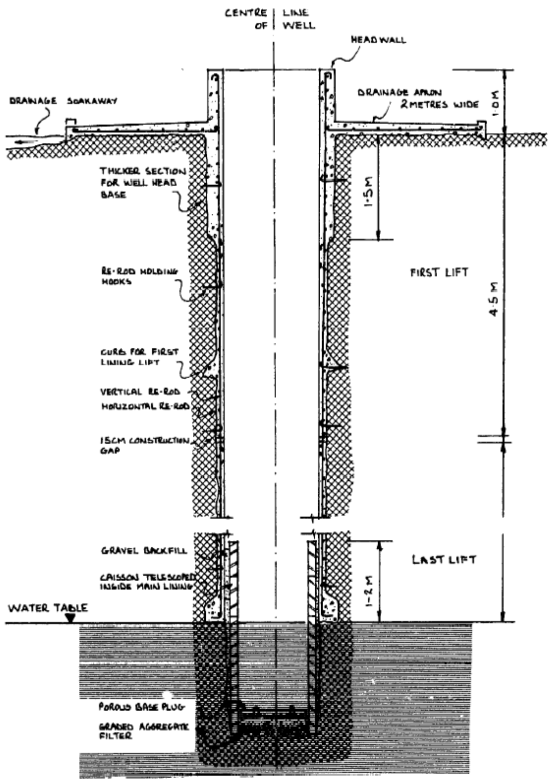

Figure 10: Hand-dug well with telescopic lining
Watt, S.B.; Wood, W.E. (1979) *Hand Dug Wells and their Construction*. IT, London, UK.

Figure 9: Flood-proofed well, Madagascar – clay grout being added
Eric Fewster, Medair

Riverbed hand-dug wells

Overview:
This category describes shallow wells which draw water from a natural or man-made aquifer specifically within a riverbed. The simplest version of these is a shallow hole dug every season in a riverbed which gets flooded with every flood event. Other versions allow the water to be accessed all year round through offset handpumps located above the flood level, making them ideal for abstracting water in areas where conventional hand-dug wells would get flooded (see Figure 11). A possible disadvantage with such a system is the possibility of contamination of water due to limited filtration depth between surface water in the river and the well intake.

Key techniques for siting:
- Wells need to be sited in riverbeds that are dry for part of the year, allowing construction to take place.
- There should be water remaining in the riverbed throughout the dry season.
- Where wells are dug with the intention to abstract water using manual or motorized suction pumps, due to pumping requirements it is best to site these wells:[135]
    - Within 30 metres of the pump location.
    - In areas where there are no high banks and where maximum floodwater height is lower than these banks – this is so that suction pumps can still operate (effectively will abstract water between 6 – 7 metres height).

Key techniques for construction & implementation:
- Simplify construction methods while getting a more robust end product in a safer fashion. Pre-cast concrete rings can be used, but is more easily done with a cutting foundation ring and curved concrete blocks, some of which are made from porous concrete (see ‘Traditional hand-dug wells’ for details).
- For where the well is made within or partially within a riverbed where it will be flooded or have floodwater beside or close to it:
    - The well shaft can be made so that it is buried within the sand, and is uncovered after each flood event for access to the water. A slab is made to cover the top ring and a manhole access cover is created for dry season access but which can be closed during a flood event. In such a case:
        - The top of the ring should be ideally 1.5 metres minimum from the riverbed surface. This is so that:
            - There is at least a minimum of infiltration that occurs from surface water during the wet season when the river is flooded
            - That there is less chance that the well shaft and pipework will be washed away in a flood event. Sand becomes mobile to a certain depth which differs for different rivers but has been recorded to be normally between 0.66 and 2 metres in seasonal riverbeds.[136]
    - The well shaft can also be made so that it protrudes from the riverbed sand level. A slab is made to cover the top ring and a manhole access cover is installed for dry season access. In such a case:
        - The well shaft needs to be protected – a hydrodynamic well head should be constructed to minimize damage from floodwater and the debris it contains. This well head has a shape of an upturned boat which deflects water and debris in the floodwater. The manhole cover opens in the upstream direction so that it closes when the floods arrive.[137]
        - Such a construction is probably best suited to riverbeds of low porosity and permeability where sediments have some stability and little is transported in floodwater, otherwise damage to the well could easily take place.[138]

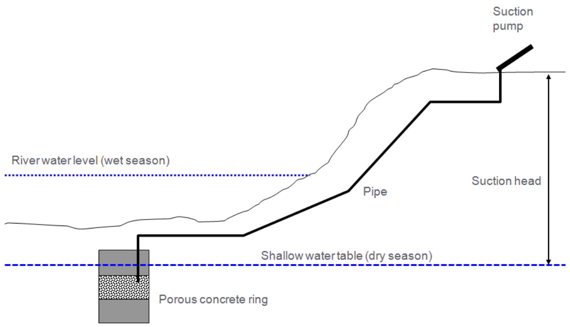

Figure 11: Riverbed well with offset handpump
Eric Fewster, BushProof

[135] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.47
[136] See: Foley, M.G. (1978). Scour and Fill in Steep, Sand-bed Ephemeral Streams. *Geological Society of America Bulletin*, Vol. 89, pp. 559-570. See also: Republic of Kenya; Democratic Republic of Sudan. (1981). *Road A1: Kenya-Sudan Road Link Lodwar-Juba. Hydrogeological Survey*. Ministry of Transport and Communications, Kenya; Roads and Bridges Public Corporation, and Regional Ministry of Communications, Transport and Roads, The Democratic Republic of Sudan. Norconsult AS (Kenya), Nairobi, Kenya.
[137] Nissen-Petersen, E. (2000). *Water from sand rivers: a manual on site survey, design, construction and maintenance of seven types of water structures in riverbeds*. pp.34-36. RELMA, Nairobi, Kenya.
[138] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.54.

Riverbed infiltration galleries

Overview:
This category includes horizontal channels that take water from a riverbed to a collector well in the riverbank, making them suitable for abstracting water in areas where conventional hand-dug wells would get flooded, and where the height of the riverbank would be too high to permit the use of an offset suction pump (see Figure 12). Infiltration gallery channels are often screens (slotted or perforated pipes) that are inserted horizontally into a riverbed, but equally infiltration galleries can be made from channels with graded gravel as long as sediments are not washed into the collector well. Where screens are used, the screen diameter tends to be larger than that used normally for jetted/driven wells.

Key techniques for siting:
- Infiltration galleries are often installed in shallow or fine sediment beds where there is poor permeability or lack of sand depth – in this case, the length proves to be advantageous.[139]
- They can be sited in areas where riverbanks are too high to allow manual or motorized suction pumps to operate.
- There should be water remaining in the riverbed throughout the dry season.
- Make it in a degrading river section where there is no deposition = coarser grains and no silt deposits blocking flow.[140]
- Construct where riverbanks are alluvial since otherwise rock breaking techniques may be required.[141]

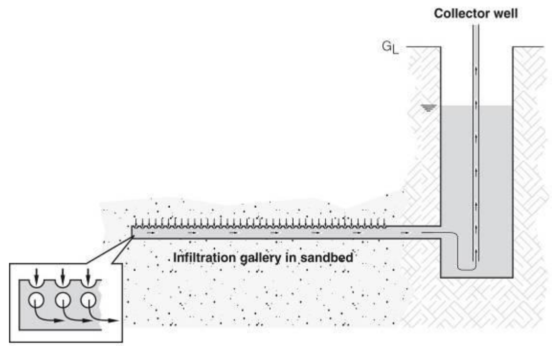

Figure 12: Infiltration gallery
Image courtesy of WEDC. © Ken Chatterton. In: Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK.

Key techniques for construction & implementation:
- The length of screen required will be greater for an infiltration gallery than for a jetted or driven well – this is because in an infiltration gallery, water flows to the collector well under hydraulic head rather than being pumped out with a suction pump. Diameter of screen used is typically 75 – 300 mm PVC and varies from a few metres up to several hundred metres in length. Layouts vary according to the river widths.[142] Yields are typically 15 litres/min/metre, but depends on depth from river to sump.[143]
- Ensure that galleries are dug deep enough to allow enough flow during the dry season. In practical terms, this means aiming for at least 1 metre depth within the saturated zone. If more than one pipe is installed, distance between pipes should not be less than 3 metres.[144]
- The top of the gallery should be ideally 1.5 metres minimum from the riverbed surface. This is so that:
    - There is at least a minimum of infiltration that occurs from surface water during the wet season when the river is flooded
    - That there is less chance that the well shaft and pipework will be washed away in a flood event. Sand becomes mobile to a certain depth which differs for different rivers but has been recorded to be normally between 0.66 and 2 metres in seasonal riverbeds.[145]
- Graded gravel needs to be placed under and over the pipe to minimize clogging with sediments.
- Water from infiltration galleries runs to collector wells above the maximum flood level, from where it can be abstracted with a handpump or motorized pump. The collector well is a hand-dug well which acts as a waterproof chamber – it is dug deeper than the infiltration gallery to allow water to enter by gravity and to allow enough storage volume.

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[139] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.44
[140] Pickford, J. (ed) (1991). *The Worth of Water: technical briefs on health, water and sanitation*. Practical Action Publishing, London. p.92.
[141] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.68
[142] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. pp.48-49.
[143] Pickford, J. (ed) (1991). *The Worth of Water: technical briefs on health, water and sanitation*. Practical Action Publishing, London. p.92.
[144] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.51.
[145] See: Foley, M.G. (1978). Scour and Fill in Steep, Sand-bed Ephemeral Streams. *Geological Society of America Bulletin*, Vol. 89, pp. 559-570. See also: Republic of Kenya; Democratic Republic of Sudan. (1981). *Road A1: Kenya-Sudan Road Link Lodwar-Juba. Hydrogeological Survey*. Ministry of Transport and Communications, Kenya; Roads and Bridges Public Corporation, and Regional Ministry of Communications, Transport and Roads, The Democratic Republic of Sudan. Norconsult AS (Kenya), Nairobi, Kenya.

Riverbed jetted & driven wells (shallow boreholes)

Overview:
This category includes short small diameter cylindrical screens (slotted or perforated pipes) that are inserted into unconsolidated sediments using water pressure or physical force, usually vertically or obliquely (see Figure 13). Digging is not needed in this case, so really these are shallow boreholes. Since unconsolidated alluvial sediments are often found in areas that are prone to flooding, this technique therefore allows a more rapid, cheaper and easier method of well construction / upgrading in flood zones compared with other techniques.

Key techniques for siting:
- Due to pumping requirements, it is best to site these wells:[146]
    - Within 30 metres of the pump location.
    - In areas where there are no high banks and where maximum floodwater height is lower than these banks – this is so that suction pumps can still operate (effectively will abstract water between 6 – 7 metres height).
- There should be water remaining in the riverbed throughout the dry season.

Key techniques for construction & implementation:
- Ensure that aprons have deeper foundations at the edge to resist floodwater erosion (see ‘Traditional hand-dug wells’ section for details).
- Ensure that there is a good seal between the pipe and apron, to prevent surface water leaking through the apron around the pipe.
- The screens and pipework should be ideally 1.5 metres minimum from the riverbed surface. This is so that:
    - There is at least a minimum of infiltration that occurs from surface water during the wet season when the river is flooded
    - That there is less chance that the well shaft and pipework will be washed away in a flood event. Sand becomes mobile to a certain depth which differs for different rivers but has been recorded to be normally between 0.66 and 2 metres in seasonal riverbeds.[147]
- Screens used can be anywhere from 32 to 200 mm in diameter, and only 0.5 – 1 metre in length. For jetted wellpoints, they are commonly made from plastic. For driven wellpoints, they are made from steel and require wingtips on the pointed end.[148]
- Jetting (also known as washboring) is one method of installing a screen into the saturated sand layer. This technique has been used as a flood prevention strategy after flooding in coastal areas in Madagascar resulted in many hand-dug open wells being contaminated by floodwater – here the low cost of jetting permitted a high density of boreholes and handpumps to be installed per head of population (one per 5-10 neighbouring households).[149] There are various forms of jetting, with various pipe sizes. Key techniques are outlined below:[150]
    - About 1,000 litres of water is required, possibly more depending on ease of procedure and size of sediment particles. This water can be brought with a bowser, or can be created using a hole dug into the ground and lined with a plastic sheet.
    - A 2” Honda suction pump (600 litres/min) is normally used for both jetting and well testing, although larger capacity pumps will enable deeper jetting but will use more water per minute.
    - During the jetting process, water emerges from the end of the jetting pipe and flows upwards to ground level. If the flow of water stops (e.g. water runs out, or to change a pipe), in most circumstances the sand around the jetting pipe/screen will collapse, after which it is impossible to re-start the flow of water to the surface. However, in some cases the hole will remain open – only in these cases can you add another pipe and continue jetting, but otherwise the depth you can install the screen is dependent on the length of jetting that can be done in one go without stopping the pump.
    - Digging a large pit to the water table is advantageous since:

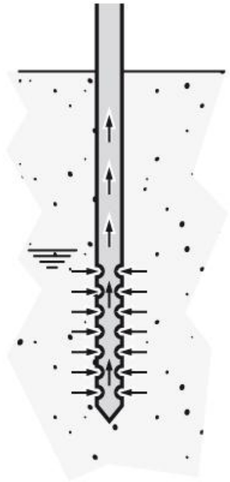

Figure 13: Jetted / driven well point Image courtesy of WEDC. © Ken Chatterton. In: Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK.

[146] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.47
[147] See: Foley, M.G. (1978). Scour and Fill in Steep, Sand-bed Ephemeral Streams. *Geological Society of America Bulletin*, Vol. 89, pp. 559-570. See also: Republic of Kenya; Democratic Republic of Sudan. (1981). *Road A1: Kenya-Sudan Road Link Lodwar-Juba. Hydrogeological Survey*. Ministry of Transport and Communications, Kenya; Roads and Bridges Public Corporation, and Regional Ministry of Communications, Transport and Roads, The Democratic Republic of Sudan. Norconsult AS (Kenya), Nairobi, Kenya.
[148] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. pp.44, 71-81.
[149] Mol, A.; Fewster, E.; Osborn, K. (2005) *Ultra-rapid well construction: Sustainability of a semi-household level, post-emergency intervention*. Maximizing the benefits from water and environmental sanitation, 31st WEDC International Conference, Kampala, Uganda, 2005. p.2
[150] Based on personal experience of Eric Fewster, BushProof.

    - In collapsing sands, you can jet to the base of the pit, after which you can glue extra pipes onto the screen to reach ground level = deeper well achieved.
    - The chance of losing the water column is minimized due to less pressure head that the water must overcome in order to flow to the surface. With higher pressure heads (i.e. more distance from water level in ground to ground level), the water is more likely to choose the path of least resistance, which at some point will be to go into the aquifer rather than come to the surface. In such a case where you lose the water column in collapsing sands, the well will be finished at that depth.
  - A screen can have a ball valve at the end – in this case, the jetting pipe and screen are made from the same piece. Alternatively the screen can be separate from the jetting pipe, where the jetting pipe creates the hole and then is removed once the screen is installed to required depth.[151] If a screen with valve is chosen, care should be taken if installing handpumps as the ball valve has a tendency to open over time letting in sand.
  - Flow velocity around the screen should be maximized. This can be done by adding a layer of perforated drainage pipe around the screen, followed by geotextile. Additionally, a gravel pack should be created around the screen. This can be done by:
    - Throttling the pump speed down once the screen is at the required depth – this will remove fines while allowing coarse sediments to settle around the screen
    - For sand rivers that have a significant clay content, permeability in the riverbed will be low, and yields will also be low. Increased flow velocity into the well can be created by making a large gravel pack around the well shaft – this gravel pack consists of aggregate and stones (rather than the traditional type of small diameter gravel pack used in boreholes).[152]

[151] Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK. p.82
[152] Trials in Kenya showed that flow increased from 1,350 to 10,800 litres/hour with the addition of gravel around the screen. Source: Eric Fewster.

Boreholes

Overview:
These are small diameter wells that tap water in shallow to deep aquifers, and are equipped with a handpump or motorized pump.

Key techniques for siting:
- When choosing well or borehole site, choose non-floodable zone, and a location that is not on a major drainage route. Normally boreholes should be sited at a sufficient distance away from sources of contamination, and this includes ponding surface water. For microbiological contamination, the distance from the source of contamination (e.g. latrine) to the water intake (screen) needs to be sufficient so as to pose a “low” to “very low” risk – this translates into a minimum of 25 days of potential travel of pathogens in the ground. Travel time is influenced by porosity, hydraulic conductivity (permeability) and hydraulic gradient. For medium size sand with an average porosity, the distance equivalent to 25 days is around 30 metres, but this can increase to over 100 metres for coarser sediments. However, the distance from contamination to water intake can reduce significantly where the screen intake is at a sufficient depth – this is due to greater variation of aquifer properties in vertical directions than lateral, meaning that a borehole with handpump could be placed very close to a latrine with low risk. However, screen depth must increase with increased extraction rate.[153]
- Boreholes can be an option for water supply in safe / refuge areas as part of a prevention strategy.[154]

Key techniques for construction & implementation:
- Ensure that an apron has been constructed – experience shows that without an apron, floodwater can more easily contaminate the groundwater.[155] Ensure that aprons have deeper foundations at the edge to resist floodwater erosion (see ‘Traditional hand-dug wells’ section for details).
- When building in floodable areas is unavoidable, construct in such a way that the water source does not become contaminated directly with surface water. The exact construction will depend on the flood level in the area:
    - Construct a raised slab, the top of which is higher than the maximum flood level. Where water extraction is with handpumps, the raised slab can be constructed with additional steps to allow access to the slab (see Figure 14). Alternatively, a mound can be built to raise the slab and handpump.[156]
    - In addition to a raised structure, ensure that construction of the casing above the water table is watertight – this is in order to avoid any possible short-circuiting of floodwater that infiltrates into the ground around the borehole casing:
        - Ensure a clay or cement grout has been added between borehole wall and casing 1.5 metres. In the case of borehole rehabilitation or flood-proofing, where the borehole casing has been extended up to the level of raised structure, the grout should also cover any joint or connection between the old casing and new extension.
        - Borehole casing should be properly connected together.
- If for whatever reason it is not possible to raise the slab high enough to avoid some floodwater, you should accept that inundation is sometimes going to take place. Although this might not be ideal, keep in mind that a flooded but protected water source will still

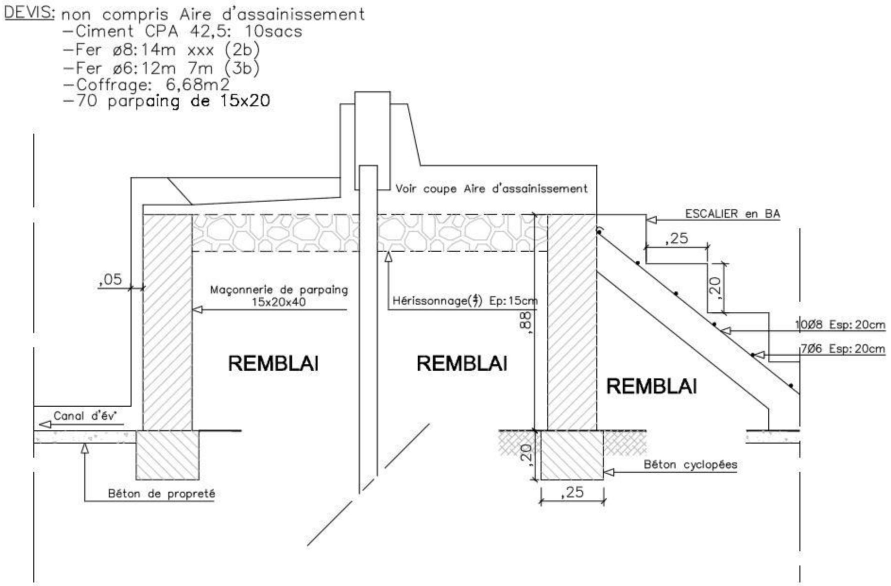

Figure 14: Flood-proofed borehole apron, Madagascar
Medair

[153] Lawrence, A.R.; McDonald, D.M.J.; Howard, A.G.; Barrett, M.H.; Pedley, S.; Ahmed, K.M.; Nalubega, M. (2001). *Guidelines for assessing the risk to groundwater from on-site sanitation*. British Geological Society, Keyworth, UK.
[154] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.16
[155] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.5
[156] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.159

most likely have better quality water than other unprotected water sources that have not been flooded (which might be considered better options during a flood).[157]

- If installing handpumps, contamination risk can be minimized by choosing a handpump that has its spout above the highest water level and / or choosing a lower risk pump, as well as ensuring that the pump base is fixed to slab properly and that the slab has been properly cured (see ‘Handpumps’ section for details).

[157] McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.15

Urban water distribution

Overview:

Urban infrastructure is different from that in rural areas, as is the flood's effect on it – it therefore has a dedicated section here that examines the effect of flooding on urban water supply and distribution (for information on water treatment works, see relevant section). Within the area of urban water supply, this section will deal only with water distribution networks – water supply that is not urban-specific (e.g. bottled water distribution) may also be valid for urban areas but is covered in other sections. Water distribution mains often have leaks, and together with intermittent pumping and reduced pressures in the system that might occur after a flood event, there is the possibility of contaminated water entering the water pipes – this could come from contaminated floodwater or from sub-surface contamination from leaking sewerage pipes that pass close to water pipes.

Key techniques for construction & implementation:

- There is a need to get municipal supplies up and running as soon as possible after a flood event. This is so that pipes remain pressurized and prevent the ingress of contaminated water, but also so that the urban population continues to have access to water which they are used to in order to prevent the use of alternative sources. When water gets cut off, people may opt to take water from alternative water sources – these sources may be unsafe as a result of flooding, and / or may be unsafe due to being unprotected and used by large numbers of people), which can lead to disease outbreaks. This is what was diagnosed as a primary cause of the cholera outbreak in some of Zimbabwe's urban areas during 2008-09.[158] To help keep the distribution network functioning:
    - Attention needs to be given to prevention and response work at the level of the water treatment plant, in order that sufficient treated water continues to be available for the distribution network (see 'Urban water treatment' section).
    - Pipes and related infrastructure (e.g. chambers and valves) can be uncovered, displaced or washed away after a flood. This can be due to soil erosion or saturated ground causing flotation and movement of pipes.[159] Strategies to deal with and prevent this are:
        - Where a pipe exits a static structure, a series of rocker pipes can connect the water pipes to the static structure (see Figure 15) – these allow some movement in case of ground subsidence due to flooding.[160, 161]
        - Repair and commission any damaged pipes starting at or near the water source / supply and working to the ends of the lines. Select pipeline sections that can be easily isolated using existing valves – keep in mind that the maximum length of pipe that can be repaired, flushed and pressure-tested is about 1,000 metres.[162]
        - Installing valves at all junctions as a preparedness strategy would allow limited sections of the network to be isolated in case of repair work that needs to be carried out on damaged pipes. By their design, looped distribution systems also cause only certain sections of the network to be cut off during repairs, as compared to branched systems where longer sections downstream may be affected by repair work.
        - It is important to have access to the municipal water network plans.[163] Often network plans are not available locally or have not been updated – a prevention strategy would be to work together with the municipal water provider to update these plans and have them available as part of a flood response strategy.
        - Where pipes must be exposed to cross gullies / streams, construction needs to be sufficiently robust to resist the effects of flooding that would cause high water flows in the gullies
    - Damage to pumping and electrical equipment is common in a flood situation (electrical engines, pumps, starters, or switchboards).[164] This can be addressed through:
        - Repair to affected equipment – experience has shown that often equipment or parts can be salvaged and made to function for the short-term.[165] It is therefore a good idea to keep a roster of electro-mechanics that can be called upon to fix problems in booster pumps after a flood event. [166,167]

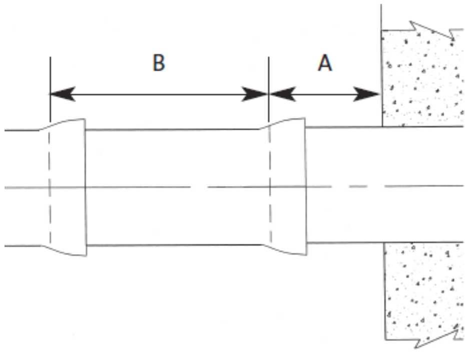

Figure 15: Rocker pipes
Saint-Gobain Pipelines (2006) *Pipe & Fittings - Water & Sewer: Design Guide.* Saint-Gobain, Ilkeston, UK

[158] Handzel, T. (2009) *Evaluation of WASH Cholera Response to 2008-09 in Zimbabwe. Draft Report*. Centers for Disease Control and Prevention, Atlanta, USA. p.4
[159] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[160] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.115
[161] Saint-Gobain Pipelines (2006) *Pipe & Fittings - Water & Sewer: Design Guide.* Saint-Gobain, Ilkeston, UK. p.41
[162] For guidelines on assessment, repair, pressure testing and flushing, see: Kayaga, S. (2005) *Rehabilitating small-scale piped water distribution systems*. WHO notes for emergencies, Technical Note no.4. WHO, Geneva, Switzerland.
[163] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[164] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[165] As happened after floods in Mozambique. See: McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.14

        - Any equipment (e.g. booster pumps) should always have standby capacity in the case of damage or repair.
        - It may also be possible to add additional protection around such elements (e.g. raise them up or put barriers around them).
- In case the piped water supply is interrupted, there are some preparedness and response strategies that can reduce the risk of alternative unsafe water sources being used:
    - Existing water storage & distribution mechanisms could be adjusted during flooding periods:
        - Service reservoirs for flood-prone urban areas could be designed with a larger capacity than would normally be needed (e.g. greater than 24 hour daily demand) in order to provide a buffer in case of a cut in water supply coming from the water treatment plant.
        - Existing service reservoirs can be kept as full as possible so that if supply is cut, the most can be made of the existing storage.[168] This can be part of a flood response strategy prior to and during times when flooding is likely to occur.
        - Where a flood event would cause a cut or reduction in water supply from the water treatment plant, a previously-planned rationing strategy could be implemented. This could include allowing water to flow to residential areas at certain times only, as well as possible restrictions on water used for industry according to prior agreement with these users.
    - Alternative water supplies (e.g. boreholes) can also be constructed at strategic points according to population numbers as a preparedness strategy.[169]
        - Priority for these supplies should be high-density parts of town, as well as areas where pressure is known to be low during normal times.
        - It could be that new water points are not needed if there are existing water sources that could be used in case of an emergency – in this case, a preparedness plan would be to identify such water points and carry out protection work (e.g. apron / slab) so that they could easily be converted into a safe pumped water supply during the emergency (e.g. agricultural wells were converted in such a way during floods in Haiti).[170]
        - A system of water tankering together with mini distribution set-ups in affected areas is a possible intervention in place of alternative water supplies. This equipment needs to be available immediately after a flood, as does the finance since tankering is an expensive option. However, lessons learned from previous flood emergencies indicate that it is not good practice to rely too heavily on water tankering as a strategy.[171] This is partly because roads are not always accessible to vehicles after a flood due to damage to the road surface or presence of debris. Where such systems are set up:
            - Do not lay temporary distribution networks in floodwater.[172]
            - Ensure that water tanks are put on sturdy structures – experience from the past shows that tanks in emergencies can often placed on weak structures such as the roofs of buildings that may not be able to support the weight.[173]
            - Ensure that all the tankered water reaches the beneficiaries – this could be achieved through involving beneficiaries to help verify the number of deliveries and quantity of water delivered each time, but also having a flag on the water truck may discourage the driver from looking for some extra cash on the side.

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[166] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.8.
[167] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009.
[168] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.14.
[169] This was the case in Bulawayo, Zimbabwe, and was thought to be one of the reasons contributing to the lack of an outbreak in the town. See: Handzel, T. (2009) *Evaluation of WASH Cholera Response to 2008-09 in Zimbabwe. Draft Report*. Centers for Disease Control and Prevention, Atlanta, USA. p.4
[170] Etienne, F. (2009) *Technical WASH Review in Gonaïves. Haiti, 8 – 19 March 2009.* Global WASH Cluster Learning Project, New York, USA. p.17
[171] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[172] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009
[173] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009

Urban water treatment

Overview:
Urban infrastructure is different from that in rural areas, as is the flood's effect on it – it therefore has a dedicated section here that examines the effect of flooding on urban water treatment. Water treatment plants in urban areas can also get flooded, which ends up hampering treatment processes, resulting in either less water or insufficiently treated water being delivered to the distribution network. Other water treatment options, which sometimes apply in both rural and urban environments, are discussed in the section 'Water treatment - other'. It is essential that the water treatment plant is able to continue to supply an adequate quantity of treated water into the distribution network, in order to allow continued pipe pressurization, and also to prevent people using contaminated alternative sources (see 'Urban water supply & distribution section').

Key techniques for siting:
- Avoid siting water treatment works in flood zones.
- Having a few small water treatment works, rather than one big one, can spread risk when considering flood events.[174]
- If the force of floodwater is sufficient then intakes, dams and other structures related to the treatment plant can become damaged by erosion around the installations. This can sometimes be avoided by proper siting.
    - For dams, failure of the spillway could result in failure of the complete dam.[175] When constructing valley dams specifically (i.e. those in a seasonal watercourse), the rule of thumb is not to build small reservoirs (below 10,000 m^3) in catchments larger than 400 ha (1,000 acres) because otherwise the amount of overflow is excessive to the point of creating washed-out spillways.[176]

Key techniques for construction & implementation:
- As a prevention strategy, there needs to be a continuous power supply created for the water treatment plant.
    - This can either be separate generators, or a dedicated line and agreement with the electricity generation provider that will ensure prioritization of supply during power shortages.
    - The foundations of poles carrying power lines to the treatment plant can be reinforced, as these can get eroded causing the power lines to come down which cuts off supply.[177]
- A sufficient stock of chemicals needs to be kept on site, in case of problems getting supplies in after a flood. The quantities to be kept in stock would depend on the maximum length of flooding, which will vary in different locations.
- Any equipment (e.g. booster pumps) should always have standby capacity in the case of damage or repair.
- If the force of floodwater is sufficient then intakes, dams and other structures related to the treatment plant can become damaged by erosion around the installations.
    - For the water treatment plant, constructing embankments around wastewater treatment plants can prevent floodwater accessing the plant and compromising capacity.
    - For dams, a summary of advice for adequate construction is given in the sister document to this one on resilient WASH for drought-prone areas,[178] some parts of which are presented here which relate specifically to damage from floodwater:
        - In general, small dams tend to fail much more frequently than larger dams, and this seems due to poorer siting, lack of design, poor construction techniques and lack of maintenance.[179] One example in Sudan demonstrates this where breached dam embankments were attributed to a gross underestimation of the runoff volume, as well as poor overall design.[180] Proper design, construction and maintenance are therefore important. The following are guidelines used for hillside dams maximum 3m high, where water is retained by an embankment.[181] For heights over 3m, other guidelines are available.[182]

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[174] When there were floods in Tewkesbury (UK) a few years ago, a major problem was that a large centralised works (The Mythe) was flooded, affecting many people over a period of 17 days. See: http://www.bbc.co.uk/gloucestershire/content/articles/2007/07/23/flood_news_latest_feature.shtml

[175] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.

[176] Nissen-Petersen, E. (2006) *Water from Small Dams: A handbook for technicians, farmers and others on site investigations, designs, cost estimates, construction and maintenance of small earth dams*. DANIDA. p.63.

[177] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.

[178] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands. pp.69-73

[179] Mufute, N.L. (2007) *The development of a risk-of-failure evaluation tool for small dams in Mzingwane catchment*. MSc thesis. University of Zimbabwe, Harare, Zimbabwe. p.10.

[180] Dijk, J. A. van (1995) *Taking the Waters. Soil and water conservation among settling Beja nomads in Eastern Sudan*. African Studies Centre Research Series No.4. Aldershot: Avebury (Ph.D. thesis). p.218.

[181] Smout, I.; Shaw, R. (1999). Technical Brief 48. Small earth dams. In: Shaw, R. (ed). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London, UK.

[182] Nelson, K. D. (1985) *Design and Construction of Small Earth Dams*. Inkata, Melbourne, Australia.

- Design should prevent overtopping of dam crest. Water level should be 1m less than dam crest – e.g. for 3m high dam, normal water level (known as D) should be 2m high, leaving 0.5m for floodwater level (= height of spillway) and at least another 0.5m as a safety margin for water rising due to wind/wave action and wear and tear on the dam crest. Note that these are final dam levels, and that during construction an additional 10% is added to the design to allow for settlement after construction.[183]
- The dam crest should be 10% higher at the centre (convex shape) so that in case of catastrophic overtopping, water will escape from the edges which will require less repair work. [184]
- Dam embankment needs to be protected both upstream and downstream. This can be done by covering with topsoil and planting spreading grasses (e.g. couch, star or Kikuyu grasses) to protect against erosion. In arid and semi-arid areas where grasses may not grow without irrigation, it has been suggested to cover the embankment with graded rocks (riprap) with maximum size of 600mm. [185]
- Protect upstream slope: a floating timber beam secured 2 metres from dam will do this (needs to be replaced every 10 years), also stone or brush mattress on upstream slope will reduce erosion. Graded rocks (riprap) has been also suggested to protect the upstream slope, with maximum size of 600mm.[186]
- The spillway is what prevents the dam from overtopping during high flows, as happens during a flood event. Failure of the spillway could result in failure of the complete dam, so its design requires some attention.[187]
  - The spillway outlet needs to be made robust enough to resist erosion (see section on siting). It can be made from concrete, but a cheaper way is to use a grassed spillway. If grass will not grow well, riprap (graded rocks) can be used. Velocity not to exceed 2.5 m/s. Spillway inlet widths vary according to the flood flow, but minimum width to be 5.5 metres. The spillway needs to be kept clear from debris as this has resulted in overtopping in the past.[188]
  - The spillway channel should not allow erosion of the dam structure, and ideally should be lined, with walls to channel the water in the right direction. In place of lining, grass again will suffice – short perennial grasses (e.g. Kikuyu grass) planted in contour lines with 30cm spacing will resist erosion, or another way is to build low stone masonry walls at 2 metre spacing which can act as a staircase to slow down floodwater.[189] The end of a lined spillway channel needs to have a cut-off down to solid ground or should terminate on rock, in order to prevent undercutting of the channel. Spillway slope should be 1 : 33.[190]

- Damage to pumping and electrical equipment is common in a flood situation (electrical engines, pumps, starters, or switchboards).[191] However, experience has shown that often equipment or parts can be salvaged and made to function for the short-term.[192] Keep a roster of electro-mechanics that can be called upon to fix problems in the water treatment plant after a flood event.[193,194] Where electrical equipment and pumps are most at risk (e.g. in sub-surface rooms such as below filter beds), an idea could be to install high capacity drainage pumps in these areas to drain floodwater in case of a breach in the flood defenses.
- As a prevention strategy, technical staff at the water treatment plant should receive training in what to do during an emergency.[195]
- After a flood, water quality is likely to change. Therefore the water treatment works needs to have capacity to conduct daily jar tests & other water quality analysis in order to keep dosing chemicals at the correct quantities.
- Where it is impossible to improve existing water treatment infrastructure, it might be applicable to try the promotion of water treatment at household level (see 'Water treatment – other' section).

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[183] Smout, I.; Shaw, R. (1999). Technical Brief 48. Small earth dams. In: Shaw, R. (ed). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London, UK. See also: www.fao.org/docrep/W7314E/w7314e0q.htm

[184] Nissen-Petersen, E. (2006) *Water from Small Dams: A handbook for technicians, farmers and others on site investigations, designs, cost estimates, construction and maintenance of small earth dams*. DANIDA. p.62.

[185] Mufute, N.L. (2007) *The development of a risk-of-failure evaluation tool for small dams in Mzingwane catchment*. MSc thesis. University of Zimbabwe, Harare, Zimbabwe. p.13.

[186] Mufute, N.L. (2007) *The development of a risk-of-failure evaluation tool for small dams in Mzingwane catchment*. MSc thesis. University of Zimbabwe, Harare, Zimbabwe. p.13.

[187] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.

[188] Smout, I.; Shaw, R. (1999). Technical Brief 48. Small earth dams. In: Shaw, R. (ed). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London, UK.

[189] Nissen-Petersen, E. (2006) *Water from Small Dams: A handbook for technicians, farmers and others on site investigations, designs, cost estimates, construction and maintenance of small earth dams*. DANIDA. p.63.

[190] Mufute, N.L. (2007) *The development of a risk-of-failure evaluation tool for small dams in Mzingwane catchment*. MSc thesis. University of Zimbabwe, Harare, Zimbabwe. p.13, 37.

[191] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.

[192] As happened after floods in Mozambique. See: McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.14

[193] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.8.

[194] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009.

[195] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13.

Water treatment - other

Overview:
Water treatment in most settings will be one of two types – either treatment at source (e.g. centralized treatment – which can be one-off or continuous treatment, or batch treatment into individual containers at the source), or treatment at point of use (e.g. household water treatment). Some of these below have been used previously in urban settings (e.g. shock chlorination of wells, or distribution of household water treatment products), so that is why this section is not called 'rural water treatment'.

Key techniques for siting:
- Promotion of water treatment can be a good idea in some flood zones where flooding is a regular occurrence, and / or where it is difficult to improve existing water source infrastructure to avoid flooding. Treatment at source can be done wherever the water is used and accessed by people, but experience shows that the reach of such interventions and limited quantity of water treated, means that household water treatment is often something that should be carried out in conjunction with source treatment.[196] Also in areas where there is a likelihood that people will use floodwater for domestic purposes regardless of existing water sources such as wells, the pre-existence and widespread use of some kind of household water treatment method can reduce risk of disease after floods.

Key techniques for construction & implementation:
- There are various treatment methods of water sources that have been tried during and after flood events:
  - Shock chlorination: this is where the well or borehole water is dosed at a rate of 50 – 100 mg chlorine per litre of well water. It is a one-off intervention after the flood has subsided, in order to deal with any contamination from surface water that may have occurred. A key element of this is speed of intervention – in order to reduce the amount of contaminated water consumed, wells in the area need to be treated within days of the flood. Depending on the type of floodwater that entered the well, it may be necessary to empty the well volume and/or even clean the walls prior to chlorination, but this will increase the time to cover the area so more teams and equipment will be necessary in this case. It is important to keep in mind that disinfecting water sources that are poorly protected (e.g. no apron, low headwall, no pump) or that take water from a contaminated source (e.g. a shallow contaminated aquifer) will not necessarily improve water quality due to recontamination in the short term[197] - studies from Bangladesh that investigated the effectiveness of spot chlorination of shallow boreholes after a flood event indicated no difference in levels of thermotolerant bacteria before or after spot chlorination, and no difference between wells that were chlorinated and those that were not.[198]
  - Ongoing treatment of source water: this is where water is treated repeatedly at the source to treat contaminated water, such as in the case where the flooding continues in the vicinity of the water source thereby contaminating it, or where the groundwater quality is compromised by factors like stagnant water or latrines. There are many different methods of treatment available, some as package treatment units which are available on the market, but it is important that the method or package chosen should take into account the water quality to be treated, as various parameters can influence the effectiveness of the treatment process (e.g. turbidity will require a stages in the treatment process to remove it, and pH can affect treatment processes like coagulation and chlorination). Given the high cost of some package treatment plants, it has been suggested based on experience in previous flood situations where water would be used for tankering, then it would have been more cost-effective to drill a borehole instead, which could provide non-turbid water where the only treatment required would be chlorination – this would provide a water source after the floods recede. The short duration of most floods also mean that such expensive units might not be used for very long.[199]
    - Where floodwater is treated directly, a treatment set-up will probably need to cope with both turbidity and microbiological contamination, as floodwater is likely to be both muddy and contaminated. To remove turbidity, standard treatment processes such as settlement, coagulation / flocculation, rapid sand filtration will work, as will multi-stage filters (e.g. membrane filters) that come with some package treatment kits (but with some problems – see below). To remove any remaining microbiological contamination, the next stage is disinfection which will usually be chlorination due to its ongoing residual protection effect after the initial treatment. However, there are some key points to keep in mind when operating treatment set-ups like this in flood zones:
      - Since emergency conditions inherently contain many unknown factors, it is impossible to anticipate many of the physical and chemical problems which will be encountered during emergency water treatment. Experience from previous flood events has shown that technical expertise to modify the operations of an

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[196] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.6
[197] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.5
[198] Luby, S.; Islam, M.S.; Johnston, R. (2006) Chlorine spot treatment of flooded tube wells, an efficacy trial. *Journal of Applied Microbiology* 100 (2006) 1154–1158.
[199] Luff, R,; Dorea, C. (2012). Bulk water treatment unit performance: for the cameras or the community? *Waterlines* Vol.31 No.1/2 January/April 2012. p.64

imported emergency water treatment unit according to actual raw water quality is necessary in the initial stage, and that following adequate training the operation should be handled by local personnel.[200, 201]

- Imported package treatment kits (or 'bulk water treatment units') are often not adequately designed to cope with the level of suspended solids often found in emergency situations – the focus instead seems to be on the ability to deliver water to a high level of microbiological purity (often past what is required in the country it is deployed in) using sophisticated membrane technologies, rather than designing them to cope with a range of turbidities. The result can be that plants get clogged quickly, resulting in smaller quantities of water than what the plants are rated as being able to produce, as happened during the Pakistan floods of 2010 – an example was where one plant was only producing 15% of its theoretical capacity, which meant that the cost per cubic metre increased even further. While the onus might be on the manufacturers to produce a system that works in the field (e.g. more work should be done by manufacturers to have their kits independently tested and verified under a range of conditions), the onus is equally on agencies that do not consider this vital aspect of floodwater when sending such kits to the field (technical capacity should be available for procurement and operation, and more consideration should be given to cost-effectiveness and accountability).[202]

- Where non-turbid groundwater is treated directly, chlorination alone will be sufficient. This can be done either as:
  - Batch chlorination in tanks or storage containers – suitable for where a motor pump is used to lift water in bulk, but also suitable for handpumps. Batch chlorination is where the tank or storage container volume is known, and where chlorine is dosed at a rate sufficient for that volume.
    - Where water is lifted using a motor pump of some kind, chlorine is added to the tank at the start of pumping, and tank outlet is closed.
    - For handpumps, bucket chlorination can be an option where a trained chlorinator is stationed at the handpump with chlorine solution and a syringe, in order to dose containers as they are filled up. The dose will vary according to the container volume. This has been proved as a useful immediate source treatment method during cholera outbreaks.
  - Online chlorination in pipes – suitable for where a motor pump is used to lift water in bulk, but also an option for handpumps. Online chlorination is where chlorine is dosed in the pipe at a rate sufficient for the pump flow rate.
    - Motor pumps: where a suction motor pump is used, dosing can be done on the suction side of the pump – here the equipment needed is a container for the chlorine solution, a flow meter,[203] a valve to regulate flow of chlorine,[204] and a connection to the suction pipe. Where a submersible pump is used, a chlorine dosing pump can give a constant or proportional injection of chlorine into the discharge pipework, depending on the type of dosing pump – here the equipment needed is the dosing pump, a container for the chlorine solution and a connection to the discharge pipe.
    - Suction handpumps: alternatively, online hand pump chlorination of suction hand pumps has been tried out in certain flood settings where there were many existing handpumps that extracted water from contaminated shallow groundwater. Here the equipment needed is a container for the chlorine solution, a tube from an intravenous (IV) drip with a wheel flow adjuster (the one that normally comes with the IV tube), a non-return valve to connect with the IV tube,[205] a short section of rubber tubing which has an internal diameter equal to or just narrower than the outside diameter of the IV tube, and an epoxy glue to seal the rubber tubing to the pump body. To assemble, the non-return valve is attached to the IV tube and sits inside the chlorine solution, the IV tube is then fed through a hole made in the chlorine container lid but the wheel adjuster is

Figure 16: Online chlorination of suction handpump
Rasal, P. (2008) *Online chlorination of hand pumps, Supaul District, Bihar*

[200] Reiff, F. (1982) *Floods and water supplies: lessons learned in Ecuador*. PAHO/WHO Virtual Disaster Library.
[201] Luff, R,; Dorea, C. (2012). Bulk water treatment unit performance: for the cameras or the community? *Waterlines* Vol.31 No.1/2 January/April 2012. p.63
[202] Luff, R,; Dorea, C. (2012). Bulk water treatment unit performance: for the cameras or the community? *Waterlines* Vol.31 No.1/2 January/April 2012. pp.56-57, 64-65
[203] Such as a variable area flow meter – see http://www.ipsflowsystems.com/pmdownloads.htm for examples
[204] Such as a needle valve – see http://www.ipsflowsystems.com/pvcudownloads.htm for examples
[205] Non-return, check or foot valves can be used – see http://www.ipsflowsystems.com/pvcudownloads.htm for examples - but it needs a way to connect to the IV tube, probably by way of a compression connection.

also kept inside the container, then the IV tube is connected into the short section of rubber tubing which itself has already been attached with the epoxy glue into a hole drilled into the suction area of the pump body (i.e. below the foot valve – see Figure 16).[206] When the pump is used, the dosage of chlorine needs to be sufficient to result in 0.5 mg/litre free residual chlorine in water containers after they have been filled. Problems with this system however were that the dosage (and therefore contact time) varied according to the vacuum generated, which varied according to the speed of pumping, and also that regular monitoring was needed.[207]

- There are various household treatment methods of water, some of which have been tried out more than others after flood events. In spite of the potential issues with promoting household water treatment during an emergency (see below), they do have the advantages of being a good option for dispersed populations that would not be effectively reached through bulk water treatment, as well as being much more cost-effective (e.g. coagulant-disinfectant sachets cost $0.03 / person / month compared to $1.5 / person / month for a typical bulk water treatment unit).[208] Things to consider regarding household water treatment in flood situations are:
  - The uptake of household water treatment tends to be low in the acute phases of an emergency, with 20% being the maximum documented uptake. After the tsunami of 2004, despite the wide availability of certain household water treatment products, uptake during the initial phases was low for several reasons, including the fact that tankered water was supplied initially, an initial focus on water quantity over quality, as well as the fact that training and follow up was difficult given the overwhelming competing demands on human and material resources.[209] The tsunami experience seemed to indicate that introducing new household water treatment technologies during the first 3 months of an emergency may at times be inappropriate, especially for those emergencies where the scale of damage and numbers affected are significant, and that it might be a more appropriate response once people start to settle more into a camp setting or when they return home.[210] This was confirmed in Madagascar after a distribution of sodium hypochlorite solution by helicopter to flooded villages days after a flood event. In this case, the scale of the disaster (with other competing work demands) and lack of resources meant that information regarding the product was only ~~be~~ given by radio and written messages, as well as pictorial instructions in the local language included as part of the bottle label. While this might appear sufficient, in reality this information was not enough and an evaluation found that a more intensive on-ground training and follow-up was needed. The result was that although people did end up using the product, there was a delay of up to 1 week after the distribution before people used it – this was attributed to cautiousness over a new technology which people were unfamiliar with, uncertainties about how to use it and because they were not familiar with the donor.[211] Cambodia provides another example of where household water treatment was promoted after a flood – here the products were not used well because of lack of knowledge of how to use them, confusing instruction leaflets, and the fact that people did not like the taste of the treated water.[212] This goes to show that heavy input into training is needed when doing such distributions.
  - However, uptake of household water treatment in subsequent stages of the emergency has proved to be worthwhile, as long as initial user training is carried out together with follow-up training, since this is known to increase the uptake of technologies.
    - During distribution, carry out a user training on the reasons for using the product, how to use it and how to maintain it.
    - Since the products may not come with instructions, at least not in the local language, an instruction flyer can be printed and given out to each family to help people remember how to use the products – the flyer should be printed in the local language and if possible should have diagrams to make it illiterate-friendly. However, the flyer should act only as a memory aid rather than the primary method of instruction, which should always be direct training and follow-up.
    - Follow-up training is known to increase the uptake of technologies. Although a direct comparison cannot be made, it is indicative that a single training when giving out sodium hypochlorite is known to result in between 3 – 20% uptake in various emergencies, compared with an uptake of 76.7% in Haiti with annual follow-up training. Similarly with PuR (a coagulant-chlorine sachet), uptake after a single training ranged from 10 – 54%, compared to between 89 – 95.4% after follow-up trainings.[213]
    - Water quality surveillance at household level can help confirm proper use of the products after a distribution, and should be part of the hygiene promotion response. Volunteers and technicians that carry out follow-up training can be the ones who are trained to provide surveillance of water quality such as by monitoring concentrations of residual chlorine in water.[214]
  - The choice of technology will depend on what type of water is likely to be treated in the house, as various parameters can influence the effectiveness of different treatment process, with turbidity and pH being among the most important.

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206 Rasal, P. (2008) *Online chlorination of hand pumps, Supaul District, Bihar.* Sets of equipment are available from Aquaplus Water Purifiers (www.aquaplusltd.com)
207 Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. pp.22-23
208 Luff, R,; Dorea, C. (2012). Bulk water treatment unit performance: for the cameras or the community? *Waterlines* Vol.31 No.1/2 January/April 2012. pp.58-59
209 Lantagne, D.; Clasen, T. (2009) *Point of Use Water Treatment in Emergency Response*. London School of Hygiene and Tropical Medicine. London, UK. p.6, 56.
210 Clasen, T.; Smith, L. (2005) *The Drinking Water Response to the Indian Ocean Tsunami, including the role of Household Water Treatment.* World Health Organization, Geneva, Switzerland. p.25
211 Fewster, E. (2004) *Evaluation report for MAD08,Maroantsetra, Madagascar- 29 November – 20 December 2004 - An evaluation of the MAD08 project, covering: jetting, sand filters & emergency phase distribution & well chlorination.* Medair, Ecublens, Switzerland. pp.4-12
212 Oxfam (2001) *Emergency flood response orientation. 16th – 17th October 2001*. Phnom Penh, Cambodia.
213 Lantagne, D.; Clasen, T. (2009) *Point of Use Water Treatment in Emergency Response*. London School of Hygiene and Tropical Medicine. London, UK. p.6, 44.
214 OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK. p.2

        - Turbidity: if the raw water will mainly be clear but microbiologically unsafe water (e.g. from an open well that was flooded once), then most products will work well. However, if the water is likely to be turbid (e.g. people are likely to use floodwater directly), then certain products will not perform as well as others. It is probably worth keeping in mind when choosing a product, that no household water treatment product is perfect – each has its own advantages and disadvantages – and while some may not perform well with turbid water, in all probability they will help reduce the pathogen load in the water sufficiently so as to reduce the likelihood of contracting a water-borne disease.
            - Liquid or tablet chlorine-generating products (without a coagulant) – the recommended dose is sufficient to inactivate pathogens up to a certain turbidity, after which the chlorine will be consumed by the particulates in the water with the possibility that some pathogens will escape inactivation. Since pathogens can still remain protected by the dirt particles in the water which can prevent the chlorine to make contact with the organisms, it is unclear what the maximum level of turbidity should be for use of chlorine-generating products, and this may well vary depending on the nature of particles causing the turbidity.[215] There has been some concern about the effect of carcinogenic by-products (e.g. trihalomethanes, or THMs) when chlorinating turbid water, but field research in Kenya showed that THM production was below WHO guidelines values when water up to 305 NTU was treated with a household chlorine product[216] – it is therefore safe to treat water up to at least this level of turbidity, which represents common conditions in the field. In any case, the effect of THMs is a long-term concern, whereas illnesses associated with ingesting pathogens may cause acute health problems, so concerns about THMs are only valid where the products would continue to be promoted and used for years.
        - pH: if the raw water has a low or high pH, then certain treatment processes using coagulants and chlorine can be affected.
            - For water with a pH lower or higher than the range of 6 – 8, aluminium sulphate as a coagulant will not work well and higher doses will be required, increasing the likelihood of aluminium residual levels that are higher than WHO guideline values being carried over in the treated water. In such a case, coagulant/chlorine sachets containing ferric sulphate might work better.
            - For water with a pH higher than 8, the effectiveness of chlorination may be compromised, since to be effective either dosage and / or contact time need to be increased, which may not be possible to control easily at household level. In such a case, alternatives to chlorine-generating products may be sensible.[217]
    - The choice of technology will also depend on other factors (e.g. cost, user friendliness, whether the product is for emergency use in the short term or is to be introduced for longer-term use, how transferable the product is to the permanent location, and what mechanisms exist for sustainable long-term use such as availability of consumables, cost and affordability).[218]
    - Experience shows that non-availability of household NFIs can become a bottleneck in using household water treatment methods (i.e. NFIs distributed later than HWTS products), and that there is a need for good coordination between provision of WASH NFIs and water treatment options.[219] Provision of WASH NFIs therefore needs to be as rapid as the distribution of household water treatment products.
    - There should be coordination among agencies when doing NFI distributions – not only to avoid duplication, but also to agree a standard kit to avoid jealousy. With regard to household water treatment products, standardisation can reduce confusion that might come about as a result of distributing different brands of the same type of product (e.g. coagulation/chlorination sachets that treat differing volumes of water).[220]
- Having a flood response strategy in place can aid the speed of treatment after flooding has occurred. For example, having stocks of treatment chemicals, pumps and equipment means a rapid start in the case of shock chlorination. Another example might be to aid the introduction of several household water treatment technologies in the area gradually through pilot trials, marketing/awareness raising, and support to enterprises selling products – for those people who remain in their homes during a flood, this kind of preventative response is probably most effective.[221]

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[215] There is still debate on this issue, since dosage guidelines for such products do not seem to adequately factor in turbidity, and where stated maximum acceptable turbidities vary between organizations (e.g. 1 to 100 NTU). A large proportion – but probably not all – of the bacteria in water with 100 NTU will be inactivated, so while not perfect, it will reduce the pathogenic load and will be better than untreated water, although may produce more of a chlorine taste because of the combination of chlorine with the organic matter. This debate is based on personal communication with Sarah House, who raised this issue with relevant partners promoting chlorine-generating products for use as household water treatment. The Sphere Project (2011) has concluded that it is possible to chlorinate up to 5NTU, but that double dosing might be possible for short periods of higher turbidity – see: The Sphere Project (2011) *The Sphere Project – Humanitarian Charter and Minimum Standards in Humanitarian Response.* Practical Action Publishing, Rugby, UK.

[216] Lantagne, D. S.; Blount, B. C.; Cardinali, F.; Quick, R. (2008) Disinfection by-product formation and mitigation strategies in point-of-use chlorination of turbid and non-turbid waters in western Kenya. *Journal of Water and Health*, 06.1,pp.67-82.

[217] The Nepali government had to research alternatives to chlorine-generating products when water was found to have a pH of 9.1. See: Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.6

[218] Clasen, T.; Smith, L. (2005) *The Drinking Water Response to the Indian Ocean Tsunami, including the role of Household Water Treatment.* World Health Organization, Geneva, Switzerland. p.25

[219] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. pp.7, 25

[220] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.12.

[221] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.7.

Hygiene promotion & WASH NFIs (Non-Food Items)

Overview:
Hygiene promotion should not be looked at separately from water supply and sanitation. It encompasses much more than the dissemination of messages about handwashing – rather it is a thread that should be encouraged in each area of a WASH programme, since it includes ensuring the optimal use, care and maintenance of water and sanitation facilities, and can be a mechanism to involve affected populations in the design and delivery of an effective and appropriate response through dialogue, participation and feedback.[222,223] As such, a water supply project without hygiene promotion is likely to be a lot less effective.

Key techniques for siting:

- Consider where the hygiene promotion will need to be done – people affected by floods will not only be present in one area such as a displaced camp, but also people will remain in their homes or stay with host families. Hygiene messages need to reach as many of these people as possible.

Key techniques for construction & implementation:

- Floodwater can carry significant amounts of faecal contamination from broken or overflowing excreta disposal facilities, so a key message should be that people will need to clean any household surfaces and possessions that have been inundated by this floodwater. Other messages to disseminate will be the standard ones used in hygiene promotion (use safe water, dispose of excreta safely, wash hands at critical times) with a focus on reducing the transmission of faecal-oral diseases, which have the most health impact after flood events.[224]
- Consider how to get messages out to people – if there are displaced people who are not accessible, consider if there are other ways to get messages to them (e.g. letter to the village leaders, radio messages).
- Try to consult potential recipients on what WASH NFIs they require – doing that ensures that local priorities and cultural considerations are taken into account, while getting an idea of what recipients have already or could provide. This consultation should happen with men, women and children.[225]
    - One aspect of WASH NFIs that is essential and non-negotiable[226] is menstrual hygiene material, yet it is one that has been neglected during flood emergencies in the past. Along with other household and personal items, women may not have been able to bring these materials with them yet there are several important reasons why it is important that women have access to these materials in an emergency.[227] Therefore agencies need to ensure that sanitary pads for menstrual hygiene are included in an NFI kit. However, the type will depend on local preferences so consultation is essential (e.g. do women use re-usable or disposable pads, what size/shape/colour?).
    - Another NFI that might tend to be omitted is a mosquito net, yet these may also be needed in flood displacement situations, where people may be more at risk of mosquito bites, especially given the quantity of water in the area. However, they should not be given out without correct instruction (see below).[228]
- A rapid distribution of essential materials is necessary after a flood event in order to coincide with the distribution of any household water treatment products, which might be distributed separately first. Yet on the other hand, consultation may take time. A compromise is to carry out a two-phase distribution, where core items are distributed first (e.g. basic hygiene items such as soap and water containers), with a second distribution of items following consultation (e.g. sanitary pads, razors) – the assessment for the second distribution can happen during the first distribution or as a separate activity.[229, 230] A stock of NFIs can be kept at strategic locations (such as flood shelters) as part of a flood response strategy[231] might help speed up distributions.
- Keep the gap between distribution of NFI items and hygiene promotion as short as possible, so that people receiving the items know how to use them properly. Previous experience after floods in India has shown that because of this gap, items in the kits were not used effectively.[232]
- NFIs should not only be given to men, as is often the case. Women need to be involved in both the consultation on kit contents, as well as the distribution itself.[233]

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[222] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.6
[223] Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland.
[224] Morgan, O.; Ahern, M.; Cairncross, S. (2005) Revisiting the tsunami: health consequences of flooding. *PLoS Med* 2(6): e184. pp.491-492.
[225] Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland. p.42
[226] For example, provision of menstrual hygiene material is a non-negotiable standard of the UNHCR.
[227] House, S.; Mahon, T.; Cavill, S. (2012) *Menstrual Hygiene Matters, A manual for improving menstrual hygiene around the world*. Draft version. WaterAid, London, UK.
[228] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13.
[229] Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland. p.42
[230] Sow, S. (2009) *Technical Briefing for Emergency Response: Hygiene promotion in flood settings.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3.
[231] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13.
[232] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13

- There needs to be good coordination between engineers and hygiene promoters,[234] and those that design the NFI kits should consider NFI use in relation to hardware. For example, if reusable menstruation pads are distributed, then privacy and facilities for washing and drying these pads will be needed. Experience in past flood events demonstrates the embarrassment and shame that girls and women can feel having to wash sanitary pads in floodwater near the home, and that in some cultures a flood event will make them more vulnerable.[235] In terms of health, during the 1998 Bangladesh floods, adolescent girls reported perineal rashes and urinary tract infections because they could not properly wash themselves, and launder and dry menstrual cloths in private.[236]
- Training and follow up training to householders regarding the proper use of certain NFIs is essential for proper use and uptake. For example, during distributions of household water treatment products it has been proven that training is essential for uptake of new technologies (see 'Water treatment – other'), and sometimes women have not used sanitary pads because they were unfamiliar with the type distributed.[237]
- Certain NFIs (such as, but not limited to, household water treatment products) may not come with instructions, at least not in the local language. Therefore an instruction flyer can be printed and given out to each family to help people remember how to use the products – the flyer should be printed in the local language and if possible should have diagrams to make it illiterate-friendly. However, even with written text there is usually someone in each household that can read so this may be adequate.[238]
- Standardized NFI kits can reduce confusion and the need for diverse information campaigns,[239] and effective coordination among agencies can achieve this.
- Where people have been displaced by floods and live in camps, there needs to be good camp management to monitor populations which can be dynamic, so that latecomers do not miss out on distributions of NFIs.[240]
- Post distribution monitoring should be carried out to find out if what was given out was needed, and whether it has been used or not. A simple monitoring form can be used to gather such data.
- WASH sector professionals need to coordinate closely with the shelter sector regarding NFI distributions. Priority needs are not only WASH-related, and often shelter is going to be a priority to safeguard people's health (e.g. plastic sheeting to cover things or keep dry when sleeping on wet floors of communal buildings, or other NFIs relevant to those who remain on the roofs of their houses).

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[233] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. pp.7, 27

[234] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. p.7

[235] Rashid, S.F.; Michaud, S. (2000) Female Adolescents and Their Sexuality: Notions of Honour, Shame, Purity and Pollution during the Floods. *Disasters*, 24: 54–70. doi: 10.1111/1467-7717.00131

[236] Woods, L.N. (2006) Behaviour change communication in emergencies: a toolkit. Unicef Regional Office for South Asia, Kathmandu, Nepal. p.61

[237] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13

[238] Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland. p.42

[239] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13

[240] Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India. pp.7, 25

Excreta disposal systems

Urban sewerage networks (off-site excreta disposal)

Overview:
Off-site excreta disposal systems are those that transport sewage and wastewater away from where it is generated, in order to be treated off-site. Due to the infrastructure needed to achieve this, these are often systems only found in urban environments. Because the infrastructure (and the flood's effect on it) is different from on-site excreta disposal, it therefore has a dedicated section here. Note that there are also other methods of on-site excreta disposal that are not urban-specific (e.g. septic tanks) but which may also be valid for urban areas (see 'On-site excreta disposal' section). In urban areas, both the sewerage system that transports the excreta and wastewater, as well as the wastewater treatment works, are vulnerable to floods. This section will deal only with the sewerage systems that transport the wastewater. Sewerage systems can have various problems as a result of flooding – a lack of water due to difficulties on the water supply, treatment and distribution side due to a flood can affect the wastewater systems because less water will be available for flushing, but equally there can be too much water in a sewerage system causing water to back up into houses and access points, causing cross-contamination of surfaces, water pipes and water tanks.[241]

Key techniques for siting:
- Manholes can be sited with their tops above likely flood level.
- Sewers need to be buried where possible, and sewers that cross gullies need adequate support.

Key techniques for construction & implementation:
- There is a need to get the municipal wastewater system up and running as soon as possible after a flood event. This is in order to allow people continued access to the off-site disposal system, but also to reduce the possibilities of overflowing sewage contaminating surface floodwater. To help keep the distribution network functioning:
  - Attention needs to be given to keeping the urban water supply, treatment and distribution functioning, in order that sufficient water continues to be available for the distribution network in order to supply water for toilet flushing (see 'Urban water distribution' and 'Urban water treatment' sections). It could be that the sewerage network and wastewater treatment plant are relatively unaffected by a flood directly, but lack of water supply will cause a secondary problem where the water systems have been affected.
  - Sewerage pipes and related infrastructure (e.g. chambers and valves) can be uncovered, displaced or washed away after a flood. This can be due to soil erosion or saturated ground causing flotation and movement of pipes. Strategies to deal with and prevent this are:
    - Where a pipe exits a static structure, a series of rocker pipes can connect the wastewater pipes to the static structure (see Figure 15) – these allow some movement in case of ground subsidence due to flooding.[242, 243]
    - Repair and commission any damaged wastewater pipes, starting at the wastewater treatment plant end and working towards the household connections.
    - Manhole covers should be secured if there is a risk of the sewers taking excessive flows that lift the manhole covers. Manholes without covers in place then create hazards for people and vehicles.
    - It is important to have access to the municipal sewerage network plans. Often network plans are not available locally or have not been updated – a prevention strategy would be to work together with the municipal wastewater department to update these plans and have them available as part of a flood response strategy.
  - Sewerage pipes can also become full of water and overflow into houses and streets via house connections or access points in the system. This can be avoided through:

Figure 17: Flap valve for sewer pipe
http://www.rainwatershop.co.uk/contents/en-uk/d8.html

[241] Few, R.; Ahern, M.; Matthies, F.; Kovats, S. (2004) *Floods, health and climate change: a strategic review*. Working Paper 63. Tyndall Centre for Climate Change Research, Norwich, UK. pp.78-79
[242] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.115
[243] Saint-Gobain Pipelines (2006) *Pipe & Fittings - Water & Sewer: Design Guide.* Saint-Gobain, Ilkeston, UK. p.41

- Installing flap valves to sewage discharge pipes to prevent floodwater accessing the sewer pipes and causing secondary flooding (see Figure 17), but these will need periodic inspection to check that solids do not affect their operation.[244] However, in many developing countries they are not installed.[245]
- Installing one-way drainage valves at household level to prevent full sewerage pipes from flooding properties.

- Sewerage pipes may also have the problem of not having enough water flow to maintain necessary velocities (due to breakdown in water supply due to the flooding) – low flows could also prevent flap valves from opening, leading to accumulation of solids upstream of the flap valve. Even so, the existing sewerage network could still possibly be used with some maintenance to make up for the lack of water velocity:
  - Rodding the drains can help get wastewater get moving in localized areas.[246] This entails having sufficient stocks of rods stocked at a central location to carry out maintenance in such a case.
  - Rodding eyes need to be built into the sewerage network as a preparedness technique, in order to allow rodding to take place (see Figure 18) – these should be placed at all upstream termini, at intersections of pipes, where there are elbows of 45 degrees or greater, at high points in the system, and at 30 metre intervals on straight pipe runs.[247]
  - Where wastewater pipes have to turn 90 degrees or more, then creating this using several 45 degree bends will reduce blockages.[248]
  - User education may also be required about what not to dispose of in wastewater system (e.g. in Zimbabwe, authorities had to make people aware that using sand to clean dishes was resulting in blocked drains).[249]
- Damage to pumping and electrical equipment is common in a flood situation (electrical engines, pumps, starters, or switchboards).[250] This can be addressed through:
  - Repair to affected equipment – experience has shown that often equipment or parts can be salvaged and made to function for the short-term.[251] It is therefore a good idea to keep a roster of electro-mechanics that can be called upon to fix problems after a flood event. [252,253]
  - Any equipment (e.g. wastewater booster pumps) should always have standby capacity in the case of damage or repair.

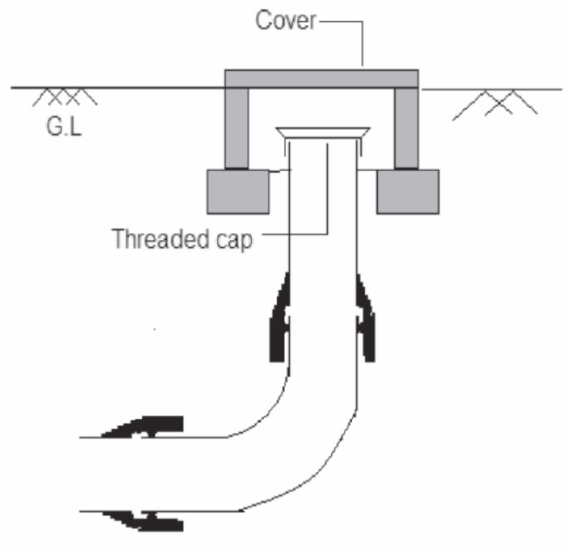

Figure 18: Rodding eye built into the wastewater network
Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK.

- In case the sewerage system is not functioning at all, there are some preparedness and response strategies that could be considered in order to allow continued access to excreta disposal:
  - Alternative on-site excreta disposal facilities could be installed as a short-term measure in local areas where the sewerage network is not functioning (see 'Off-site excreta disposal' section for ideas such as chemical toilets and packet latrines). Priority should be given to public areas due to the probable scale of the need.[254]

[244] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.366
[245] Few, R.; Ahern, M.; Matthies, F.; Kovats, S. (2004) *Floods, health and climate change: a strategic review*. Working Paper 63. Tyndall Centre for Climate Change Research, Norwich, UK. p.79
[246] There was some success with this in urban areas of Zimbabwe, 2009-2010 (author's experience).
[247] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.114
[248] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.115
[249] Author's experience.
[250] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[251] As happened after floods in Mozambique. See: McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.14
[252] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.8.
[253] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009.
[254] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.113

Urban wastewater treatment (off-site excreta disposal)

Overview:
Off-site excreta disposal systems are those that transport sewage and wastewater away from where it is generated, in order to be treated off-site. Due to the infrastructure needed to achieve this, these are often systems only found in urban environments. Because the infrastructure (and the flood's effect on it) is different from on-site excreta disposal, it therefore has a dedicated section here. Note that there are also other methods of on-site excreta disposal that are not urban-specific (e.g. septic tanks) but which may also be valid for urban areas (see 'On-site excreta disposal' section). In urban areas, both the sewerage system that transports the excreta and wastewater, as well as the wastewater treatment works, are vulnerable to floods. This section will deal only with the wastewater treatment plant that treats the wastewater brought by the sewerage system. Wastewater treatment plants can become flooded, causing damage to equipment and affecting the plant's functioning, but also any floodwater from the exiting the plant could also contaminate other areas nearby. Often in low-income countries, these plants have in any case not been properly maintained, so a preparedness strategy would have to first look at regular good practice in terms of the plant's regular functioning prior to looking at any flood-specific measures.

Key techniques for siting:

- Avoid siting wastewater treatment works in flood zones, or in areas where topography could allow any excess water from a flood event at the wastewater treatment plant to contaminate water sources.[255] However, be design, wastewater treatment works are normally sited at low level so that flows can reach the works by gravity, so siting the works in a flood-prone area may be inevitable in some cases.

Key techniques for construction & implementation:

- As a prevention strategy, there needs to be a continuous power supply created for the water treatment plant.
  - This can either be separate generators, or a dedicated line and agreement with the electricity generation provider that will ensure prioritization of supply during power shortages.
  - The foundations of poles carrying power lines to the treatment plant can be reinforced, as these can get eroded causing the power lines to come down which cuts off supply.[256]
- Any equipment (e.g. pumps) should always have standby capacity in the case of damage or repair.
- If the force of floodwater is sufficient then structures related to the wastewater treatment plant can become damaged by erosion around the installations. Constructing embankments around wastewater treatment plants can prevent floodwater accessing the plant and compromising capacity.
- Damage to pumping and electrical equipment is common in a flood situation (electrical engines, pumps, starters, or switchboards).[257] However, experience has shown that often equipment or parts can be salvaged and made to function for the short-term.[258] Keep a roster of electro-mechanics that can be called upon to fix problems in the wastewater treatment plant after a flood event.[259,260] Where electrical equipment and pumps are most at risk (e.g. sewage pumping stations and aeration equipment), an idea could be to install high capacity drainage pumps in these areas to drain floodwater in case of a breach in the flood defenses.
- As a prevention strategy, technical staff at the wastewater treatment plant should receive training in what to do during an emergency.[261]

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[255] Author's experience in Zimbabwe – overflow from a badly functioning wastewater treatment plant in Marondera contaminated the main water reservoir for the town's water supply – this simulated what would also happen in a flood event.
[256] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[257] PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35.
[258] As happened after floods in Mozambique. See: McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001. p.14
[259] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.8.
[260] Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009.
[261] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.13.

On-site excreta disposal (rural and urban systems)

Overview:
On-site excreta disposal systems are those that collect and treat excreta and wastewater away at the place where it is generated – these can exist in both urban and rural settings. Flooding causes people to live in different settings, and this can affect the appropriateness of one intervention over another. The first is an in-situ setting where people remain at home, the second is a displaced setting where people have temporarily moved to a camp setting in a less-flooded or non-flooded area, and the third is a combination of both where people will stay in the camp at night and return during the day to the house to start things like repairs and cleaning. This third combination is common, so any excreta disposal response needs to consider needs in both areas, not only at the camp setting.[262] Camp settings often include improvised shelters such as schools, community buildings, sports halls, stadiums and other such large buildings – while some of these areas may have sanitation facilities, they will probably not have enough capacity for the number of people and will fill quickly and overflow, leading to open defecation. Poor drainage at the site may compound the problems, with excreta drifting around in drainage water. Women may be more affected than men in some cultures due to having nowhere private to use for defecation, with the result that they may wait for dark before going to the toilet and may even alter their food and water intake to reduce the need for defecation[263] – then at night, if security is poor, this may result in gender based violence and sexual assaults on women when they do venture out.[264] For those people that stay at home surrounded by floodwater, excreta disposal is no easier and agencies find it difficult to respond to the needs of these people. An additional complication in either setting is where shallow groundwater is used as a water source, since consideration has to be given to the type of excreta disposal system that will minimize groundwater contamination. This section considers various on-site excreta disposal options for flood settings that are valid for both rural and urban areas, including rapid options for areas where people have been displaced to higher ground, options for those who remain at home, and preventative options for the longer-term.

Key techniques for siting:

- Ideally, the distance from a source of contamination (e.g. leaching excreta disposal facilities) to a water intake (e.g. screen) should be based on the time taken for water to flow through the ground between the two points. The separation needs to be sufficient so as to pose a "low" to "very low" risk – this translates into a minimum of 25 days of potential travel of pathogens in the ground. Travel time is influenced by porosity, hydraulic conductivity (permeability) and hydraulic gradient. For medium size sand with an average porosity, the distance equivalent to 25 days is around 30 metres, but this can increase to over 100 metres for coarser sediments. However, the distance from contamination to water intake can reduce significantly where the screen intake is at a sufficient depth – this is due to greater variation of aquifer properties in vertical directions than lateral, meaning that a borehole with handpump could be placed very close to a latrine with low risk. However, screen depth must increase with increased extraction rate.[265] However, experience from the field indicates that the reality of the situation sometimes does not allow adequate distances to be maintained given the factors above, and that groundwater contamination is likely. In such circumstances, if the shallow groundwater is not used for water supply then the risk from groundwater contamination should be of secondary importance to the provision of excreta disposal facilities.[266]
- In urban areas with a larger scale of the displacement, flooding and population numbers, it is recommended to concentrate efforts to provide excreta disposal facilities in public places, such as markets and transit centres, rather than for individual families.[267] It may be necessary to provide separate facilities for men and women, so that women are not subject to embarrassment or danger from using mixed facilities.
- Safe / refuge areas (places that get less or no flooding) are places to proactively site excreta disposal facilities as part of a prevention strategy. If the area is liable to flood, the type of facility should contain excreta when flooded (e.g. raised latrines with sealed pits).[268] Where suitable, such areas are good places to implement those types of toilet that would be more difficult to introduce in an emergency (e.g. composting toilets).[269]

Key techniques for construction & implementation:

- The priority in any flood situation is a rapid response for the containment of excreta.[270, 271] The first important aspect of this is containing excreta above ground – this can mean clean-up campaigns where there has been open defecation, but also involves reducing the chance of excreta overflowing from latrines or septic tanks. The second part is containing excreta

[262] Johannessen, Å.; Bikaba, D. (2009) *Sustainable sanitation for emergencies and reconstruction situations*. Draft version 1.2. Fact sheet. Sustainable Sanitation Alliance (SuSanA). p.2
[263] As was recorded in Bangladesh. See: Ahmed, S.M.; Husain, A.M.M.; Sattar, M.G.; Chowdhury, A.M.R. (1999) A quick assessment of flood losses and post-flood rehabiilitation needs in BRAC's programme areas. In: *Experiences of deluge: flood 1998. Research Monograph Series, 15.* (eds S.M. Ahmed & H.S. Ahmed), pp. 1-29. BRAC, Dhaka, Bangladesh. p.12
[264] OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK. p.3
[265] Lawrence, A.R.; McDonald, D.M.J.; Howard, A.G.; Barrett, M.H.; Pedley, S.; Ahmed, K.M.; Nalubega, M. (2001). *Guidelines for assessing the risk to groundwater from on-site sanitation*. British Geological Society, Keyworth, UK.
[266] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.98
[267] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.113
[268] Oxfam (2005) *Excreta disposal in flooding and high water table environments.*
[269] Ruberto C.; Johannessen, Å. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop, 11-13 February 2009*. Stoutenburg, The Netherlands. p.7

contamination below ground to avoid cross-contamination of water supplies – however, some of the solutions for flood-prone areas or those areas with high water tables may not be achievable in the short term phase and will only be applicable for the longer-term.

- Where open defecation has contaminated the immediate environment where people are living, clean-up campaigns can rapidly reduce the risk of disease transmission. For this, wheelbarrows, long-handled shovels, gloves and masks can be provided to teams who collect faeces and dispose of them in fenced pits.
- Consultation with the affected population is essential part of choosing a sanitation option – this gets people involved in the decision making and implementation from the start and allows views to be exchanged on siting, design and use of any proposed solution.[272]
- Agencies also need to consider at the design stage how latrines will be emptied and the cost of doing so, since experience shows that facilities constructed for the short-term often end up being long-term facilities,[273] due to people staying longer than planned or to delays implementing other infrastructure. Any immediate sanitation option should be adaptable to longer-term or permanent use – this needs to be part of the emergency planning process,[274] since often funding is not available after about 6 months in an emergency at which point it is too late to try to change the type of latrine.[275]
- Facilitating the use of existing facilities should be the first priority, since the work required may be less than constructing new facilities. Options include:
    - Using an existing sewerage system: part of the sewerage system may have to be isolated if some of it has been damaged, after which temporary latrine superstructures can be installed directly over inspection covers (drophole only needed), or can be located nearby and connected (pipe and flushing system needed – see information on pour-flush toilets). Either way, water is needed for flushing to transport excreta in the large bore sewer – in the case where water for this is not sufficient (e.g. in the drophole version), flushing could be provided once or twice a day from a tanker.[276]
    - Using existing septic tanks: if a sewerage system has been extensively damaged, or where only septic tanks exist, connections could be made to feed into them.[277]
    - Using existing latrines: where there are existing facilities such as what might exist in a school or other building where people have taken up shelter, these should be used where possible. It could be however that they are already full, or will have been under-designed given the number of displaced people. In such a case, latrine emptying could help to increase capacity of these facilities in the short-term, but only if the pit is fully lined and if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Also safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[278]
- Where people have congregated on embankments, care should be taken not to weaken the embankment through the construction of regular pit latrines, as has happened in the past.[279] In such a case, packet, floating or raised latrines may be a more appropriate option.
- For those areas where there is a high water table which is also used as a water source, the current consensus is to build excreta disposal facilities so as to prevent groundwater contamination. Such facilities can also be more resilient to flood events themselves (in order to reduce damage, and also cross-contamination of floodwater), so will be appropriate for areas that flood regularly. However, the investment and time needed for construction for several types means that they may not all be applicable for addressing immediate sanitation problems in Phase 1 (from 0 to 2 months after the onset of the emergency),[280] and that a more pragmatic approach might be needed (see below). Keep in mind that in some cases, it may be more practical to develop alternative water sources instead, and to accept the possibility of groundwater pollution.[281] Where an option might be valid as a Phase 1 emergency response option, it is noted below. The following options can reduce/prevent groundwater contamination:
    - Raised latrines:[282]
        - These are built with part of the pit lining extending above ground:
            - Using various usual construction materials (e.g. concrete blocks), the above-ground part of the lining can be made impermeable to avoid leakage above ground, or can be made permeable if there is a mound built around the latrine into which the liquids in the pit can infiltrate. If constructing a mound, it needs to

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[270] Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.10
[271] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.2
[272] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.105
[273] Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.81
[274] Johannessen, Ǻ.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). pp.1-2
[275] Ruberto C.; Johannessen, Ǻ. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop, 11-13 February 2009*. Stoutenburg, The Netherlands. p.12
[276] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.112
[277] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.112
[278] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. pp.3-4
[279] Ruberto C.; Johannessen, Ǻ. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop, 11-13 February 2009*. Stoutenburg, The Netherlands. p.7
[280] See ‘Overall issues to consider (cross-cutting issues)’ section for definitions
[281] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
[282] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.94-97, 109

be thick enough to prevent leakage onto the ground, made from permeable soil and compacted to have a stable slope of 1:1½.[283] Planting turf on the mound was found to be a good way to help make it more resistant to heavy rain and flooding.[284]

- In addition, the above-ground lining can also be made from any impermeable material – certain kit latrines have been trialled in Haiti where the lining is made from a plastic tank that sits above ground under a raised superstructure.[285]

- These latrines will probably require emptying, due to factors like limited pit volume, higher investment cost in the superstructure, as well as the fact that to move the superstructure once the pit would be full would leave raised pits which would take up space and be an eyesore:
  - Because they will need to be emptied, raised latrines need to be fully lined (otherwise lining only the top 0.5m would be sufficient in some cases to avoid collapsing of topsoil).
  - Emptying by suction tanker is possible only if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[286]
  - In the case of raised kit latrines with portable waste containment tanks, the frequency of emptying might be around twice a month based on recent emergencies, but clearly this will also depend on the exact tank volume and the number of users. Either way, it is likely to be less frequent than other options (such as chemical toilets) and therefore emptying costs might be less. In Haiti, the best configuration was found to be between 3-4 cubicles that emptied into one wastewater tank. Also an innovation on the wastewater tank was trialled in an urban environment in the Philippines, where two $1m^3$ tanks were used – one as the main waste chamber and the second as an overflow tank for effluent. In this way, the system acted like a mini septic tank and emptying took place from the overflow tank.[287]
  - If these latrines are to be used in the longer-term, a system of emptying which is both reliable and affordable must be available for sustainable uptake in the long term.[288]
- To reduce groundwater contamination, ideally the base of pit should be 1.5m above the water table in order to allow some attenuation of pathogens (which are more easily attenuated in unsaturated ground[289]).
- The slab level should be at least 0.5m above the highest water level.[290]
- When these are done on household level as part of a prevention strategy, promotion of raised latrines should not be done in isolation without considering raising the dwelling itself – if the house will flood, people will probably move anyway and will not use the raised latrine.[291]
- Raised latrines may restrict access to some groups (e.g. disabled, elderly)[292] although there should be some solutions in such cases (e.g. handrails or access ramps). People may also feel embarrassed when using raised latrines, because they are visible to others when entering and leaving the latrine.
- Suitable as a Phase 1 response when raised latrines come in kit form (with or without the waste containment tank).[293]

o Bucket latrines:
- This is a type of raised latrine where buckets are placed under the slab to collect excreta. Buckets need to have tight-fitting screw lids for when it is needed to carry the excreta to the disposal site,[294] and can have a disinfectant added after each emptying to reduce odours.[295]
- As with raised latrines, they need a system of emptying and safe disposal of the excreta:

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283 Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
284 Sobhan, A.; Morshed, G. (2009) *Search appropriate latrine solution for flood prone areas of Bangladesh*. Oxfam. pp.4-5
285 Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.70
286 Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
287 Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.74
288 Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
289 Lawrence, A.R.; McDonald, D.M.J.; Howard, A.G.; Barrett, M.H.; Pedley, S.; Ahmed, K.M.; Nalubega, M. (2001). *Guidelines for assessing the risk to groundwater from on-site sanitation*. British Geological Society, Keyworth, UK.
290 Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
291 Bastable, A.; Hoque, E. (2002) Excreta Disposal in high water table and flooding environments. In: Treglown, S.; Harvey, P.; Reed, R. *Planning and Management of Emergency Sanitation: Proceedings of an International Conference, WEDC, Loughborough University, UK, 10th-12th April 2002*. p.57
292 Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
293 See http://evenproducts.co.uk/index.php/developing-the-evenlatrine/ for an example. Also explained in: Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, pp. 67-82(16)
294 Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.76
295 Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3

- Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[296]
- However, the risk of contamination is greater than other latrines due to the frequency of emptying needed as well as more human contact with more receptacles containing excreta – as such this type of latrine should not be considered for medium to long-term use and it should be replaced with an alternative as soon as is practical.[297] Risk to collectors can be reduced by supplying adequate protective clothing (e.g. overalls, gloves and boots) for the work.

  - Suitable as a Phase 1 response due to speed of installation.[298]

- Urine-diversion toilets:
  - This type of toilet can be a good option for flood settings since it separates urine from faeces – this results in a longer latrine life and drier waste which is easier to manage and transport. For flood settings, these will probably be raised latrines which allow the dehydrated faeces to be emptied easily. Urine-diversion toilets can be applicable even in an emergency, where faeces are collected in drums or bags,[299] and may be emptied / transported before complete composting has occurred, while longer-term structures may act more like traditional composting toilets where faeces are collected in alternating sealed chambers with access covers.[300]
  - These latrines need emptying:
    - Where composting has not occurred, safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[301] Where a suction tanker is not used (due to contents being too solidified/dry), emptying has increased risks and proper handling and transport procedures need to be taken including supplying adequate protective gear to collectors.
    - If these latrines are to be used in the longer-term, a system of emptying which is both reliable and affordable must be available for sustainable uptake in the long term.[302]
  - Adding a drying agent (e.g. ash or sawdust) after each use aids desiccation, while ash also raises the pH. However the application of the drying agent is difficult to regulate in an emergency, especially for communal toilets, and coupled with the fact that people often have diarrhoea in emergencies, it seems it might be difficult to keep such a toilet dry.[303]
  - The access hatches for compost should be elevated above the floodwater level and made from concrete to prevent corrosion.[304]
  - Plastic urine-diversion slabs are now available for rapid deployment in emergencies.[305]
  - Suitable as a Phase 2 and Phase 3 response (Phase 2 being between 2-6 months and Phase 3 being between 6-12 months after an emergency).[306]
- Sealed pits:[307]
  - These are latrines where excreta enters a sealed tank with no outlet, located above or below ground. The tank can be made using local materials such as concrete blocks/rings, bricks or plastic tanks, but even so they are relatively expensive to construct.
  - These latrines need emptying:
    - Emptying by suction tanker is possible only if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[308]
    - If these latrines are to be used in the longer-term, a system of emptying which is both reliable and affordable must be available for sustainable uptake in the long term.[309]
  - Those tanks that are built into the water table or in areas prone to flooding, need to be able to resist flotation and the excavation will need to be de-watered (see 'Cholera response' section).

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[296] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[297] Franceys, R.; Pickford, J.; Reed, R. (1992) *Guide to the development of on-site sanitation*. WHO, Geneva, Switzerland.
[298] See 'Overall issues to consider (cross-cutting issues)' section for definitions
[299] Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. Waterlines Volume 31, Numbers 1-2, January 2012, pp. 67-82(16) pp.71, 77
[300] As seen in Bangladesh with a project that constructed raised urine-diversion toilets. See: Delepière, A. (2009) *Case study of sustainable sanitation projects - Household UDDTs after cyclone disaster: Padma & Rohitra villages, Barisal Division, Bangladesh*. SuSanA 2011. pp.3-4
[301] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[302] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
[303] Ruberto C.; Johannessen, Å. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop, 11-13 February 2009*. Stoutenburg, The Netherlands. p.13
[304] Delepière, A. (2009) *Case study of sustainable sanitation projects - Household UDDTs after cyclone disaster: Padma & Rohitra villages, Barisal Division, Bangladesh*. SuSanA 2011. pp.3-4
[305] Johannessen, Å.; Bikaba, D. (2009) *Sustainable sanitation for emergencies and reconstruction situations*. Draft version 1.2. Fact sheet. Sustainable Sanitation Alliance (SuSanA). p.5
[306] See 'Overall issues to consider (cross-cutting issues)' section for definitions
[307] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.101
[308] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[309] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.

    - Where there are many people, concrete culverts closed at both ends and at the joints can be used – installing them with a gradient allows desludging to take place from one end only. Alternatively any tank that can be de-sludged can be used (e.g. an Oxfam tank).[310]
- Floating latrines:
    - These are latrines that float, built for frequently flooded areas where the excreta and urine are collected in sealed exchangeable containers underneath.[311] The advantage of this kind of latrine is that it adapts to varying flood levels using the buoyancy of the drums underneath – this means it can provide a cheaper excreta disposal option where surface or groundwater is not contaminated, compared to raised latrines.
    - These latrines will need emptying:
        - Emptying by suction tanker is possible only if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[312]
        - If these latrines are to be used in the longer-term, a system of emptying which is both reliable and affordable must be available for sustainable uptake in the long term.[313]
        - Where a suction tanker is not used (e.g. if drums are exchanged), emptying has increased risks and proper handling and transport procedures need to be taken including supplying adequate protective gear to collectors.
- Packet latrines / bags:
    - This kind of latrine is simply a bag which people use for defecation, which then is disposed of. They seem to work well where people have the habit already of using bags for defecation. The bag can be degradable with added enzymes to aid degradation and to minimize odours (e.g. PeePoo bag), semi-degradable or non-degradable – although from an environmental point of view it would seem sensible to go with biodegradable bags. Experience from the field of using PeePoo bags showed a high user satisfaction due to the PeePoo bag's ability to contain odour, as well as the fact that using bags addressed security concerns and allowed freedom of access.[314] As such, they were found to be appreciated by those with mobility problems (e.g. disabled people and the elderly) and with protection concerns (e.g. women).[315] As such they tend to be a good option for those that remain at home at locations that are dispersed and difficult to reach.
    - When distributing bags, a container of some kind to hold the bag in place during use is also needed, and this needs to be budgeted and planned for.[316]
    - The parallel construction of male and female urinals was found to be necessary in areas where this system was trialled, since people often needed to urinate but not to pass a stool. Such urinals though can be easily made.[317]
    - Requires a distribution system, and a storage and bag collection system to be in place to avoid bags being dumped indiscriminately and being accessed by scavengers.[318]
    - Suitable as a Phase 1 response due to speed of implementation.[319] If stocks of PeePoo bags are acquired as a part of contingency planning, then keep in mind that they will have a shelf life (they are biodegradable) and will require optimum storage conditions.[320]
- Chemical toilets:[321]
    - These can work well after a flood disaster due to their speed of implementation, as long as there are suppliers of the toilets and contractors to empty the toilets.
    - The cost can be high for the rental and emptying of this kind of toilet, since volumes are small and emptying frequency is higher than for other latrines (e.g. raised latrines with larger tanks) – following the 2010 earthquake in Haiti, the cost was about $20/day initially that reduced to $9/day.[322]

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[310] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.113
[311] Sobhan, A.; Morshed, G. (2009) *Search appropriate latrine solution for flood prone areas of Bangladesh*. Oxfam. p.6
[312] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[313] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
[314] Patel, D.; Brooks, N.; Bastable, A. (2011). Excreta disposal in emergencies: Bag and Peepoo trials with internally displaced people in Port-au-Prince. *Waterlines* Volume 30, Number 1, January 2011, pp. 61-77(17).
[315] Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.70
[316] Patel, D.; Brooks, N.; Bastable, A. (2011). Excreta disposal in emergencies: Bag and Peepoo trials with internally displaced people in Port-au-Prince. *Waterlines* Volume 30, Number 1, January 2011, pp. 61-77(17).
[317] Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, pp.70-71
[318] Patel, D.; Brooks, N.; Bastable, A. (2011). Excreta disposal in emergencies: Bag and Peepoo trials with internally displaced people in Port-au-Prince. *Waterlines* Volume 30, Number 1, January 2011, pp. 61-77(17).
[319] See 'Overall issues to consider (cross-cutting issues)' section for definitions
[320] Coloni, F.; van den Bergh, R.; Sittaro, F.; Giandonato, S.; Loots, G.; Maes, P. (2012) Biodegradable bags as emergency sanitation in urban settings: the field experience. *Waterlines* Volume 31, Number 1/2, January/April 2012, pp. 61-77(17). p.131
[321] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.64

- Smells can be reduced by charging the toilet with a volume (between 30 and 100 litres) of water mixed with chemicals (e.g. sodium hydroxide).
- There is a need for a reliable emptying service:
  - Toilets should be sited so that they are accessible to the large trucks that will probably be used to empty them.
  - Emptying by suction tanker is possible only if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[323]
- Suitable as a Phase 1 response due to speed of implementation.[324]

- Sand-enveloped pit latrines:[325]
  - This type of latrine is where a lined pit is surrounded with an envelope of 0.5m sand in order to reduce the movement of pathogens into the surrounding groundwater. Where the soil type is already sand or clay, there is no need to build this kind of latrine – rather it would be more applicable in places where it is likely that pathogens will move rapidly in the ground, for example in areas with fractures or fissured rock. Using a sand envelope can be combined with a raised latrine construction.
  - They are time-consuming to construct (larger excavation, full lining needed, time to find suitable sand), although a kit lining such as modular corrugated plastic could speed up the process.[326]
  - Suitable more as a Phase 2 and 3 response due to speed of implementation.[327]
- Composting latrines:[328]
  - This type of toilet is similar to the more permanent version of a urine-diversion toilet, and is also referred to as 'EcoSan' where the faeces and urine are used as soil conditioner and fertilizer. Urine is normally separated from excreta, which is allowed to compost over a period of at least 1 year – this means that normally 2 chambers are used in rotation, and that these chambers are above ground to facilitate emptying. They work best where people are already used to them, or where there is agricultural activity in the area that could use the compost.
  - The access hatches for compost should be elevated above the floodwater level and made from concrete to prevent corrosion[329] – this is because the compost needs to be kept dry. Composting latrines have been deemed inappropriate in flood settings previously due to the normal practice of putting the access hatch in the chamber wall, which can allow floodwater to enter.[330]
  - Adding a drying agent (e.g. ash or sawdust) after each use aids desiccation, while ash also raises the pH. However the application of the drying agent is difficult to regulate in an emergency, especially for communal toilets, and coupled with the fact that people often have diarrhoea in emergencies, it might be difficult to keep such a toilet dry. In addition, the type of drying agent to add will have an impact on the final proposed use of the compost – adding ash kills bacteria, can inhibit the composting process, and the compost may not suitable for agricultural use, compared to where sawdust is used.[331] The urine can be taken to a soakpit, or used as fertilizer.
  - These systems require emptying, although the time between emptying is longer than other systems, and the excreta should be safe to handle.
  - Probably more suitable for a Phase 3 response due to the time needed to construct, as well as the time needed to introduce maintenance procedures to users.
- Septic tanks or aqua-privies:[332]
  - These systems are relatively expensive and allow a partial decomposition of excreta, where the wastewater leaving the system will still have a high pathogen load, although not as much as leaching wastewater from other systems – this may be an advantage where contamination of shallow groundwater is an issue. However the system still requires an area for infiltration into the ground. In addition, the pour-flush style toilet pan that usually accompanies septic tanks have the advantage in flood settings that the water seal prevents solids being able to escape from a waterlogged pit.[333] As such, they are suitable for areas that have access to water for flushing

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[322] Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, p.70
[323] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[324] See 'Overall issues to consider (cross-cutting issues)' section for definitions
[325] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.98-99
[326] Johannessen, Å.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). p.6
[327] See 'Overall issues to consider (cross-cutting issues)' section for definitions
[328] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.98-101
[329] As seen in Bangladesh with a project that constructed raised urine-diversion toilets. See: Delepière, A. (2009) *Case study of sustainable sanitation projects - Household UDDTs after cyclone disaster: Padma & Rohitra villages, Barisal Division, Bangladesh*. SuSanA 2011. pp.3-4
[330] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.110
[331] Ruberto C.; Johannessen, Å. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop, 11-13 February 2009*. Stoutenburg, The Netherlands. p.13
[332] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.82-85, 101-102
[333] Bastable, A.; Hoque, E. (2002) Excreta Disposal in high water table and flooding environments. In: Treglown, S.; Harvey, P.; Reed, R. *Planning and Management of Emergency Sanitation: Proceedings of an International Conference, WEDC, Loughborough University, UK, 10th-12th April 2002*. p.57

and / or where water is used for anal cleansing. Normally these are constructed where the volumes of wastewater are too great for a single latrine pit and where there is no existing sewerage system. They are more difficult to build than other latrine pits and will require some design.
    - The top of the tank should ideally be above flood level. Any access hatches should be sealed to prevent contamination of floodwater.
    - These systems require emptying, although the time between emptying is longer than other systems:
        - Emptying by suction tanker is possible only if the pit contents have not solidified too much – in such a case, it may work to add water to liquefy the contents. Safe extraction and disposal of the sludge needs to be considered – the best is to empty into an existing sewerage system or wastewater treatment plant.[334]
        - If these latrines are to be used in the longer-term, a system of emptying which is both reliable and affordable must be available for sustainable uptake in the long term.[335]
    - Those tanks that are built into the water table or in areas prone to flooding, need to be able to resist flotation and the excavation will need to be de-watered (see 'Cholera response' section).
    - Suitable more as a Phase 3 response due to speed of implementation and costs involved.
  - Decentralized wastewater treatment plants:[336]
    - Going a step further than septic tanks, these plants have been designed for decentralized operation for both domestic and industrial applications, where the quality of end wastewater has to comply with more stringent environmental standards, and where wastewater volumes are high. Wastewater and excreta that is flushed with water is treated using mini wastewater treatment plants, which have processes that mimic those in urban wastewater treatment plants – treatment modules that can be combined to make up a system include primary treatment (sedimentation & flotation), secondary treatment (anaerobic treatment in fixed-bed reactors), and tertiary treatment (aerobic treatment in sub-surface flow filters or polishing ponds).
    - Flows that can be treated can vary between 1 and 1,000 m^3/day, and sophisticated operation and maintenance is not necessary.
    - These plants should be constructed above flood level, and may require electro-mechanical equipment to be protected from flooding.
    - Normally a Phase 2 and 3 option, but possible in Phase 1 when using prefabricated tanks that have been developed to increase implementation time in emergencies (2 weeks maximum).[337]
- Given the guidance above, there will be cases where a more pragmatic approach is necessary. The ideal emergency sanitation system in flood settings does not exist, and options must be considered individually which may produce less than ideal solutions given the constraints in the field.[338] Technology choice may have to depend on the context considering things like the available space, the level of displacement and estimated length of stay of the displaced, the available capacity and other considerations such as cultural preferences and the political / social context of the area. For example, flood events may not last long and displaced people will probably return to their homes once floodwater has receded, so non-permanent excreta disposal options may be necessary in displacement camps – therefore some of the options for preventing groundwater contamination may not be applicable due to the time it would take to construct them compared to the greater risk of having those without sanitation using open defecation. So in such cases, excreta disposal facilities may have to be put in, even with a risk of groundwater contamination of a shallow aquifer that is also used as a water source. While not ideal, this will sometimes be the situation in the field. In such cases, the risk can be minimized by:
  - Siting the excreta disposal facilities at a safe estimated distance from the water extraction point (see 'Key techniques for siting' above).
  - Implementing water treatment at the source and/or at household level (see 'Water treatment - other' section).
- Technical options that may not inherently take into account groundwater contamination are numerous, but some types are quick to construct and are often options used in first phase emergency response are given here:
  - Simple latrine pits
    - In areas that regularly flood excessively, tight-fitting lids should be used to prevent excreta rising up and contaminating floodwater.[339] However, tight-fitting lids are not as easy to manufacture as it might seem when considering concrete slabs – often the lid that is cast in the hole of one slab, will not fit another slab very well. This is because of small imperfections and shape changes of the hole in the slab that come about when a slab is finished. A way to ensure tight-fitting lids is to number each lid and slab during construction. Another issue is the use of such lids – often they are not used[340] so user education would need to take place as part of a longer-term prevention strategy.

[334] Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.3
[335] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
[336] BORDA (2012) *Demand-based technical solutions to reduce water pollution by small and medium enterprises and settlements in densely populated areas*. BORDA & BORDA BNS Network, Bremen, Germany.
[337] BORDA (2012) *EmSan: Emergency Sanitation – an innovative & rapidly applicable solution to safeguard hygiene and health in emergency situations.* BORDA & BORDA BNS Network, Bremen, Germany.
[338] Tratschin, R.; Spuhler, D. *Sanitation in Emergencies Overview.* Published on http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/sanitation-emergencies/sanitation-emer-0
[339] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. pp.111
[340] Author's experience.

    - In areas of unstable soil or floodable areas, a simple pit will need to be lined. Kit lining such as modular corrugated plastic could speed up the process.[341] In most settings, the top 0.5m should in any case be lined to avoid collapsing of the topsoil.
  - Pour-flush toilets:[342]
    - This type of toilet works by using water to flush excreta to a pit, and usually by design should feature a water trap which acts as a hygienic seal. Apart from this, their main advantage for flood settings is that the water seal prevents solids being able to escape from a waterlogged pit.[343] They are suitable where water is available for flushing and / or where water used for anal cleansing. It should normally be constructed where people are used to using this type of toilet.
    - The pit can be located directly below the pour-flush pan, or can be offset away from the superstructure and connected with a pipe. The advantages of having an offset pit are that the slab does not have to be self-supporting, and that – in the case where the pit is not emptied – the superstructure does not have to be moved every time since new pits can be dug adjacent to the old pits and it is only the waste pipe that needs to be moved, as seen in the example of raised superstructures built in marshy areas of Myanmar.[344]
    - The pit that is normally built with a pour-flush toilet is one that allows the wastewater to infiltrate into the ground. However groundwater contamination can be avoided by flushing to alternative sites. For example, where several pour-flush toilets are built in the same place, the wastewater can be flushed to one place – this could be a septic tank which allows partial treatment of the wastewater (see above), a sewerage system which will take the wastewater to an off-site treatment location, or a sealed tank which could be emptied.
    - The pit could be constructed using a kit lining such as modular corrugated plastic, in order to speed up the process.[345]
    - Probably more suitable as a Phase 2 and 3 response due to the time needed to construct. However, this will also depend on the cultural preferences, as in some areas other latrines may not be used at all if constructed.[346]
  - Trench latrines
    - These are latrines where one large pit serves several single cubicles.
    - In areas of unstable soil or floodable areas, a simple pit will need to be lined. Kit lining such as modular corrugated plastic could speed up the process.[347] In most settings, the top 0.5m should in any case be lined to avoid collapsing of the topsoil.
  - Overhung latrines
    - These are latrines where simple structures allow defecation directly over an open water source (e.g. river). They are different to floating latrines, in that overhung latrines do not contain waste, whereas floating latrines do.
    - Before promoting this type of toilet, any downstream water use needs to be investigated first in order to analyze relative risks.
- Displaced populations may fluctuate depending on who has started to return home and who remains, so communal/shared facilities are probably more likely in these situations. In order that the facilities continue to be used and that people do not revert to open defecation, it is therefore essential that latrines are monitored and cleaned, and that handwashing facilities and anal-cleansing materials are provided. Paid attendants are probably the best way of doing this in the short term – such people can ensure cleanliness but also can enforce handwashing and ensure that the handwashing containers remain filled.
- Latrines that have been flooded need to be rehabilitated as soon as possible after a flood event. As such, it may be appropriate to provide de-sludging as part of an emergency response – in such a case, appropriate disposal sites for the latrine contents need to be allocated in advance as part of a preparedness strategy.[348]

[341] Johannessen, Å.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). p.6
[342] Harvey, P. (2007) *Excreta Disposal in Emergencies: A Field Manual*. WEDC, Loughborough University, UK. p.80
[343] Bastable, A.; Hoque, E. (2002) Excreta Disposal in high water table and flooding environments. In: Treglown, S.; Harvey, P.; Reed, R. *Planning and Management of Emergency Sanitation: Proceedings of an International Conference, WEDC, Loughborough University, UK, 10th-12th April 2002*. p.57
[344] Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet.
[345] Johannessen, Å.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). p.6
[346] Author's experience after the tsunami in Sri Lanka, 2004.
[347] Johannessen, Å.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). p.6
[348] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.10.

Cholera response

Overview:
Contexts known to be particularly vulnerable to cholera transmission include after flood events in endemic areas.[349] This is due to flooding of excreta disposal systems that can cross-contaminate water sources, as well as the effect floods might have on hindering access to treatment centres.[350] Elements of hygiene/infection control, excreta/wastewater disposal and drainage are included in this section, but because WASH response to cholera situations is unique, it has been covered under a separate section.

Key techniques for siting:
- The unwritten rule of thumb is not to implement a Cholera Treatment Centre (CTC) in a flood zone, but sometimes there is no choice.[351]

Key techniques for construction & implementation:
- A CTC cannot be allowed to flood, due to the risk of contaminated surfaces (bowls, beds, toilets, clothes) getting in contact with surface water which then exits the CTC and possibly transmits cholera to the surrounding area. Therefore the entire CTC ground level needs to be raised above the maximum flood level. To do this, first check for water marks on buildings, ask to see photos of previous floods in the area, and ask local people. To raise the area, you will need to fill the required area with gravel and use roller to compact the gravel.
- Rainwater is classed as low risk,[352] so don't worry about runoff water as long as the CTC is not flooded – concentrate rather on keeping contaminated wastewater from vomit/diarrhoea/washing contained in the wastewater system, and to have a watertight wastewater storage system.
- Wastewater disposal via soakaway is not possible in flood zones or where the water table is very high, so it needs to be kept on site and disposed of using trucks:
    - Calculate water demand based on full occupancy for all uses including toilet flushing, cleaning, laundry etc. Then have a wastewater tank that is large enough to cope with maximum volume in the estimated period between when wastewater tank is emptied, plus a margin for when the truck maybe cannot come (e.g. if it is broken down or cannot come due to flooding on the roads).
    - Water will need to reach the wastewater tank from all of the zones inside the CTC – this means having a wastewater drainage system from all handwashing stations, toilets and washing slabs, which takes wastewater to a tank. Depending on the layout and size of the CTC, it may be that a transfer tank is required at a halfway point, from where the wastewater can be pumped to a larger above-ground tank for final storage before collection. This is because the wastewater pipework that takes toilet wastewater (minimum diameter 3") needs to have a minimum slope of 1% to effectively drain,[353] and with longer distances, this means the inlet to the wastewater tank would end up being too low to allow a practical tank construction, since most of tank would probably be constructed below the water table. While a transfer tank may still have to be constructed partially into the water table, the volume needed for this tank is less, and is more a function of the number of starts per hour of the submersible pump you plan to install.
    - It is important to construct any wastewater tank to be watertight. For above-ground tanks, any leakage of cholera-contaminated wastewater onto the ground surface will pose a health risk, and needs to be avoided. For sub-surface tanks, contamination of groundwater should be avoided, but equally, depending on where the wastewater inlet is in relation to the water table, the tank should also not fill up with groundwater which will then need to be pumped to the final storage tank and disposed of. Such a scenario would unnecessarily increase emptying costs while filling up the storage tank quicker than foreseen, resulting possibly in a full tank prior to it being emptied. To prevent leaks, see the section on 'Construction techniques' and 'Water storage tanks'. For the construction of a tank into the water table, the following techniques also apply:
        - The excavation for the tank should be wider than the proposed dimensions, to allow for shuttering and access on both sides.
        - Use a dewatering pump during excavation and construction, and have a back-up power or fuel supply on hand for the critical phase of laying the concrete below the water table.
        - The excavation can be dewatered by placing the pump in an outer part of the excavation that is dug deeper than the base of the proposed tank – this way the excavation can be kept dry during excavation and casting. It could be that more than one pump is required, depending on the permeability of the water-bearing layer.

[349] Oxfam policy briefing. *Acute Watery Diarrhoea and Cholera in the Horn,Central and Eastern Africa: Learning from experience to improve response in the future.*
[350] Bauernfeind, B.; Croisier, A.; Fesselet, J.-F.; van Herp, M.; Le Saout, E.; McCluskey, J.; Tuynman, W. (2004) *Cholera guidelines. 2004 - 2nd Edition*. Médecins Sans Frontières, Paris, France.
[351] Author's experience of implementing a CTC in a floodplain in Les Cayes, Haiti, 2011.
[352] Bauernfeind, B.; Croisier, A.; Fesselet, J.-F.; van Herp, M.; Le Saout, E.; McCluskey, J.; Tuynman, W. (2004) *Cholera guidelines. 2004 - 2nd Edition*. Médecins Sans Frontières, Paris, France. p.22
[353] Based on smooth-walled pipe (e.g. plastic) and a maximum number of 36 fixture units connected to any point in the wastewater pipe, including branches of the main pipe. Slope and/or pipe diameter will increase the number of fixture units possible. See: International Code Council (1998) *The International Plumbing Code: a guide for use and adoption*. International Code Council, Falls Church, USA. pp.24-25 – available online at http://gisceu.net/PDF/U103.pdf.

    - Allow enough time after pouring concrete to allow it to set, before switching off the pumps and allowing the water table to rise. This is in order to allow the concrete to be established enough so that flowing water around the structure will not cause fines in the concrete to be washed out. The time needed for concrete to set sufficiently will vary depending on the temperature (e.g. 8 hours needed at 16°C, compared with 4 hours needed at 27°C).[354]
- A hollow tank constructed in water or saturated soil may be buoyant. Those tanks that are built into the water table or in areas prone to flooding therefore need to be able to resist flotation. Archimedes' principle states that the buoyant force on an object is equal to the weight of the fluid displaced by the object – if the tank is full of water then no fluid is displaced, but given a scenario when the tank is empty and when flooding or the water table reaches the top of the tank, water volume equivalent to the tank volume will have been displaced. In such a case, the downward pressure of the tank needs to be equal to the water that is displaced. This can be done by designing the weight of the tank to counter the buoyancy effect (i.e. increasing the amount of mass concrete used to be so that the weight of floor, walls and roof are equal to or greater than the displaced water).[355] For tanks that are not made from concrete, additional weight can be added using anchors, which are heavy concrete slabs or poles that weigh the tank down – the rule of thumb is that if 70% or more of the tank's storage capacity will be below flood or groundwater levels, then additional anchors will be required.[356]
- A submersible pump is preferable to take water from the transfer tank to the final storage tank, since any possible contamination of the surface from leaking seals is prevented. There are some things to keep in mind however:
    - Choose a pump model that is resistant to corrosion since it will be pumping chlorinated wastewater, which will attack metal.
    - Choose a pump for the design flow rate – this can be done by creating a system curve (done by considering the type, diameter and length of pipe to the final storage tank plus the elevation difference between lowest wastewater level in the transfer tank and the point where the wastewater is pumped into the final tank) and comparing it to pump curves from the manufacturer.
    - A float switch can easily be added to allow automatic emptying of the tank when it gets to a certain level. However, the power source for the pump needs to be sufficient to start it – in some areas, the city power may not be sufficient for this, and a generator is required. In any case, a back-up generator is essential in case of power cuts. Choosing a generator with sufficient power for the pump is needed, but also the same generator may be required to run other power needs for the CTC, so it needs to be sized up correctly to allow the pump to function concurrently with everything else. It is important that the generator is a good quality one, with no power fluctuations, as this can damage a submersible pump.[357] In case of such problems, it is essential to have a standby pump for quick replacement.
    - Plan at the start how to replace a submersible pump once a transfer tank is full of cholera wastewater. Having a rope permanently fixed to the pump and tank cover means that the pump can be recovered easily (steel cable will corrode quickly). From experience after the 2011 cholera crisis in Haiti, it seems better to have a flexible hose connected to the pump discharge outlet since this would allow the pump and pipe to be raised easily – the hose therefore should emerge from the tank at the same point where the access hatch is.
    - The connection from the submersible hose to the pipework leading to the final storage tank should be above ground, to allow easy pump/hose replacement. This connection should include a union (to allow the hose to be disconnected without twisting either the pump or pipe) as well as a non-return valve in the pipework leading to the final storage tank (to prevent backflow of wastewater remaining in the pipes when a hose is disconnected, and also to prevent backflow through the submersible pump each time it stops after each operation – which can damage some pumps).
    - For any pump replacement, full protective clothes, gloves, mask and goggles should be worn.
- There is a risk that the emptying system will pose more risk to the local or other communities by spreading infection through inadequate supervision of the trucking company regarding disinfection of the suction hose, whether or not on the same trip they will also empty other properties, and where they will empty the wastewater. Responsibility lies also with the agency running the CTC, not only with the trucking company. Putting an agency flag on the truck might discourage the driver from making unauthorized stops.
    - Normally all liquids in vomit and diarrhoea buckets should be adequately disinfected prior to disposal. During the 2011 cholera crisis in Haiti, recommendations were to use 100ml of 2% chlorine per 10 litres of wastewater, which is allowed to sit for 10 minutes before being emptied into the wastewater system, followed by another 100ml of 2% chlorine per 10 litres prior to transport.[358]

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[354] See: http://www.engr.psu.edu/ce/courses/ce584/concrete/library/materials/Admixture/Link-settime.htm

[355] For example, a fully-submerged but empty tank with external dimensions (including roof and floor) of 2m x 2m x 2m will displace 8,000 litres of water (= 8,000 kg). The weight of concrete therefore needs to equal to or greater than 8,000 kg. Assuming floor, walls and roof are all 0.15m thick and that concrete has a density of 2,400 kg/m^3, the concrete will have a weight of 7,409 kg. This is less than the displaced weight, so the tank may float. (Workings: roof & floor = 0.15 x 2 x 2 x 2 = 1.2m^3 = 2880kg; walls type A = 0.15 x 2 x 1.7 x 2 = 1.02m^3 = 2,448kg; walls type B = 0.15 x 1.7 x 1.7 x 2 = 0.867m^3 = 2,081kg.)

[356] Hartmann, J.P. (1997) Preventing tank flotation. Article on the web: http://www.petrolplaza.com/technology/articles/MiZlbiYxMDIzNSYmMSYxJiY%3D

[357] In Haiti during the cholera response of 2011, this was the likely cause of an observed submersible pump failure was because it was run on a low quality generator with power fluctuations.

[358] Recommendations of WASH working group in Haiti, 2011. However, this advice may not be consistent with concentrations of chlorine used for other purposes in a CTC, and needs to be reviewed.

Stormwater & wastewater drainage systems

Overview:
Drainage systems include not only drains themselves, but also surface flow and inlet flow to drains. Drains carry not only runoff with a significant amount of solid waste and sediments, but also sewage and wastewater. Drainage becomes more of an issue in urban areas, where in a conventional system a network of pipes or channels drains impermeable surfaces, resulting in faster build-up in flows and higher peak flows, which increases the risk of flooding.[359] Poor solid waste management coupled with poor drainage design can exacerbate any local flooding, especially in urban areas, resulting in damage, cross-contamination from excreta disposal facilities, and increased vector breeding.

Key techniques for siting:

- Drainage channels should be correctly sited according to where water naturally flows after rainfall. To check surface water flow, teams need to be ready to observe flow during storms and immediately after – having good maps and allocating teams beforehand to certain areas will make this more effective. Targeted areas should be those already pre-identified as problem areas. During such observation, sometimes it is immediately clear where the flooding problem originates from as well as possible solutions that are easily implemented but which will reduce flooding.[360] Even where a structured evaluation did not take place, certain effects of the flood may be evident enough to allow preventative measures to take place – for example, where stormwater has created an opening in a road, these are good places to build culverts or sluices during the recovery phase since they show the areas where water will naturally flow to.[361]

Key techniques for construction & implementation:

- Drainage often is low on the list of priorities in terms of WASH, for both rural and urban settings. Yet there are clear impacts on issues such as health, livelihoods, the economy and convenience. Drainage concerns therefore need to become part of a flood preparedness strategy. This means drainage becoming more integrated with town planning initiatives, as well as up-skilling of existing staff – experience shows that drainage is often a missing part of urban planning, and that expertise and knowledge about drainage is lacking in the field.[362] Where drainage does not exist, or has been undersized, work needs to take place to ensure that the drainage system is correctly sized to be able to cope with runoff flow from a catchment flowing at an acceptable velocity – while obtaining reliable rainfall data might be problematic, there are still basic rules of thumb and design practice that could be followed in any case.[363]
- Where local flooding is known to occur, an evaluation can help to identify the problem areas, causes of the flood and possible remedies. An evaluation like this will involve both resident surveys to locate problem areas and depth of flooding, as well as direct observation. Some tips for direct observation of the drainage system include:[364]
    - Check open and closed drains for blockages. Techniques include:
        - For open drains, this will be easier, but even then a simple gauge can be used to quantify the level of blockage compared to an empty drain (e.g. a wooden post on a flat base where free space in a drain can quickly be read off).
        - For closed drains, blockages can be identified by:
            - Finding out if standing water is found in the bottom of the outgoing pipe in a manhole – this could indicate a downstream obstruction
            - Where manholes are spaced less than 30 metres apart, a lamp and mirror can be used to check for obstructions, which should be evident if the lamp shining along the pipe from one manhole is not clearly seen in the mirror held at an angle of 45 degrees at the next manhole, with the observer at the surface.
- After problems have been identified, regular maintenance / clearance of drainage channels should be advocated and implemented.
    - This normally should be carried out by the authorities. However, tools and protective clothing can be provided in the short term so that the community can be involved to get wastewater moving.
    - A follow up evaluation should indicate the rate of solids build-up in channels, showing at what frequency cleaning should take place.

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[359] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.218
[360] Mostly taken from the following publication: Kolsky, P.; Shaw, R. (1999). Technical Brief 57. Surface water drainage – How evaluation can improve performance. In: Shaw, R. (ed). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London. pp.97-100.
[361] ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. p.161
[362] Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK.
[363] For a good overview on design, see: Oxfam (2008). *Low cost drainage for emergencies.* OXFAM Technical Briefs – TB4, draft 1. Oxfam, Oxford, UK.
[364] Mostly taken from the following publication: Kolsky, P.; Shaw, R. (1999). Technical Brief 57. Surface water drainage – How evaluation can improve performance. In: Shaw, R. (ed). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London. pp.97-100.

- Culverts (and other trunk drains) that carry water flow of a natural stream or urban drainage channel under roads or railways can be under-designed and impede floodwater movement, creating local floods.[365] At times long lengths of urban watercourses have been culverted to gain space for urban development, but this is recognized now to increase flood risk, especially where they are too narrow or blocked with debris. Re-opening such watercourses (a practice called 'daylighting') and re-designing trunk drains can reduce flood risk.[366]
- Drainage channels can be blocked with solid waste, which can cause / exacerbate local flooding. There are solid waste management techniques to prevent this (see 'Solid waste management' section).
- The large quantity of silt in runoff water in many non-industrialized countries has implications for maintenance.[367] To partly help deal with this, main drains should normally be designed to be self-cleaning. Design to create self-cleaning drainage channels can be done by:
  - Building drainage channels with sloping sides and a narrow bottom can help maintain a steady flow of water in the channel, regardless of water level. 'Benching' is a refinement of this principle, where a narrow channel is made in the centre of the drain to allow low flows to have adequate velocity, while larger volume flows would use the whole drain width (see Figure 19).[368, 369]
  - Drainage channel slope is also important to maintain adequate velocities, with smaller drains needing a steeper slope. As a guide, small drains 10-15 cm wide will require a gradient of 1% to achieve self-cleansing flow velocity, whereas a drain twice the width should only require half the gradient. For areas where slope will be greater than 1%, scour could occur and in these areas lining is needed, although for slopes up to 5% a partial lining is probably sufficient and will cost less than a full lining.[370] For slopes over 5%, speed of flow will have to be reduced – this can be done by adding steps, or building the drain along the contour to reduce the slope.[371]
  - Lining channels, deterring encroachment and restricting vegetation growth on channel embankments – all of these can all help to maintain flow velocities, meaning fewer blockages.[372]
  - When lining channels is necessary, for those channels that are deeper than 300mm, it is important to incorporate 10mm wide weep holes into the lining to allow water to enter from the surrounding ground. This is to avoid groundwater pressure from overturning the linings or causing water to flow parallel to the drain, causing a parallel channel to appear. Weep holes can be made using short sections of PVC pipe that are embedded into the lining at spaces of not more than 1 metre.[373]
  - Provision of an access track along one side of the drain – this will allow access for maintenance.[374]
  - Use of local materials for lining drains – this means materials will be available and are familiar to use by local people.[375]
- While channel design can help deal with some of the silt through self-cleansing velocities, experience has shown that design alone will probably not deal with all of the silt quantity normally found in runoff water in non-industrialized countries. Therefore enough consideration has to be given to maintenance routines which will have to be set in place to keep water flowing (see 'Solid waste management' section).[376] Design though can still help with this insofar as allowing quick access for maintenance:
  - Open drains, while having some drawbacks in terms of health, may be more desirable from a drainage point

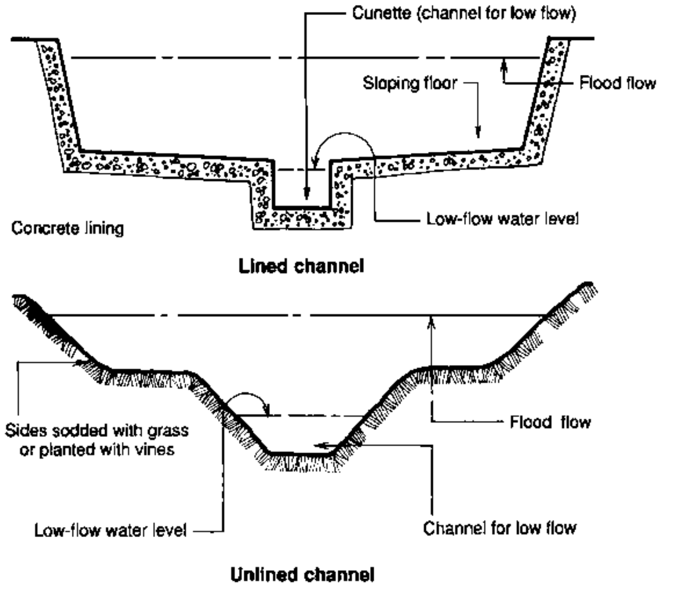

Figure 19: 'Benching' of drainage channels
Cairncross, S.; Ouano, E.A.R. (1991) *Surface water drainage for low-income countries*. WHO, Geneva, Switzerland.

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[365] In Buenos Aires, the cause of flooding was attributed solely to being under-designed. See: Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.24
[366] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.212-213, 365
[367] Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.6
[368] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.552
[369] Cairncross, S.; Ouano, E.A.R. (1991) *Surface water drainage for low-income countries*. WHO, Geneva, Switzerland.
[370] Cairncross, S.; Ouano, E.A.R. (1991) *Surface water drainage for low-income countries*. WHO, Geneva, Switzerland.
[371] Oxfam (2008). *Low cost drainage for emergencies.* OXFAM Technical Briefs – TB4, draft 1. Oxfam, Oxford, UK.
[372] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.552
[373] Cairncross, S.; Ouano, E.A.R. (1991) *Surface water drainage for low-income countries*. WHO, Geneva, Switzerland.
[374] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.552
[375] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.552
[376] Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.47

of view as they can more easily be cleared of obstructions.[377]

- Screens (metal bar screens or 'trash-screens' intended to trap solid materials) and inlets of drainage channels are known from experience to be problem areas for blockage. At times, the problem is not the quantity of solid waste, but that the screens are not designed to be maintained.[378] Any part of the system therefore needs to be conceived with maintenance in mind, and the maintenance required should be provided.

- In urban areas of high-income countries, there has been a move away from conventional piped drainage systems towards more natural or semi-natural methods of draining stormwater through increasing the permeability of surfaces and infiltration rates (see Figure 20). These methods not only help prevent floods by reducing the quantity of water at peak flow, but can also help improve water quality, the physical environment and biodiversity. These practices go by different names, but in the UK are known as SUDS (Sustainable Urban Drainage Systems).[379] Although SUDS is more associated with industrialized countries, it is in fact a very valid concept for low-income countries that have inadequate levels of city-wide drainage infrastructure that are capable of dealing with peak flows using conventional methods.[380] The idea is that floodwater is managed in small, cost-effective landscape features at a local scale. They are designed to both store floodwater and also allow infiltration into the ground. However, most of the parts of such systems will be of limited use where open drains carry sewage in addition to stormwater, due to the higher risk of contamination. Also the soil's infiltration capacity needs to be high enough that infiltration can occur at a fast enough rate. The methods of natural or semi-natural stormwater management include:
  - Inlet control devices to reduce the amount of stormwater entering the drainage system, thereby reducing flood risk. These are probably the most realistic interventions that can be installed as retrofit items in existing urban settings. Examples include:
    - Rainwater storage where water is stored close to where it is collected – this includes both small scale tanks (e.g. water butts) and larger scale storage areas (e.g. rooftop ponding on flat roofs, or water stored in a building basement).[381]
    - Green roofs that help reduce runoff and increase evapotranspiration.
    - Infiltration devices can also reduce the amount of stormwater entering the drainage system by diverting rainwater directly to pervious ground where it can infiltrate directly. These can include soakaways (or well shafts / boreholes that are designed as infiltration devices) where water is infiltrated directly from the roof into the ground (see discussion on soakaways and Managed Aquifer Recharge below), as well as infiltration trenches and inlet devices (see below).

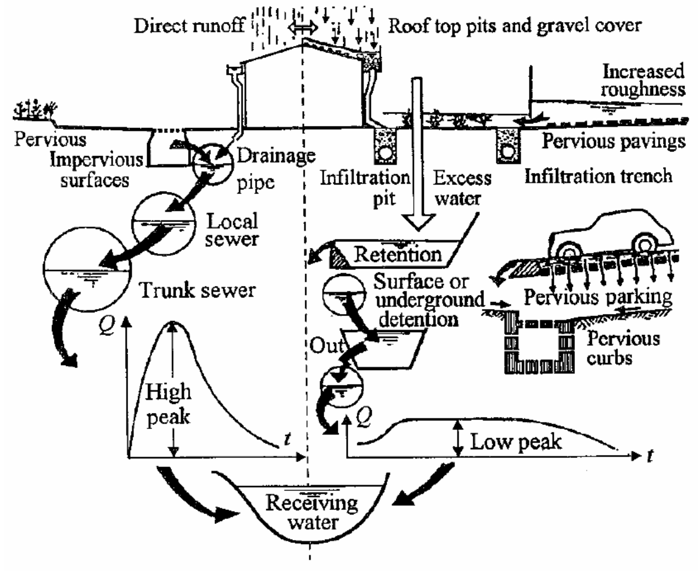

Figure 20: Two concepts for urban drainage – without or with SUDS
Maksimovic, C. (1996) Measurements of Water Quantity in Urban Areas. In: WMO. *Rain and Floods in our Cities – Gauging the Problem.* WMO/TD – No. 741.

  - Vegetated surfaces act to reduce stormwater peaks and trap pollutants and silts. Swales are a form of grass-lined channel typically built beside roads.[382] Areas or strips of grass that are designed into paved areas can act as infiltration areas for the runoff from the paving.[383]
  - Permeable paving is a hard surface that allows infiltration, either through a porous surface (e.g. porous concrete, made with fewer fines in the mixture) or via gaps made in the surface for this purpose (e.g. perforations made in standard concrete blocks).
    - Applications where this is used have been car parks, driveways and lightly-trafficked roads. The sub-base of the paving acts as a storage method for rainwater where it is stored initially in the voids within the granular material, after which it can slowly infiltrate into the ground.
    - Where groundwater quality needs to be protected, the sub-base can be sealed and water can be drained to a pipe; but at a much slower rate than would occur using conventional stormwater drains.[384]

[377] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.366
[378] Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. pp.41-42
[379] For an overview of how to start considering implementing & maximizing SUDS, see: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.232-237
[380] Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.35
[381] A large-scale water storage reservoir example comes from South Korea where an entire floor below ground of a shopping & housing development was made into a rainwater storage area. See: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.242-243
[382] For details of how to create a multi-purpose retarding basin, see: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.231
[383] Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. p.105

   - Issues with permeable paving are that it requires maintenance to prevent blockage over time, and also costs about 30% more than conventional paving due to the need for it to be built on a base. However, permeable paving (perforated blocks or porous concrete) has been proved to produce virtually no runoff (3%) compared to concrete (95%).[385]
   - Existing concrete slabs or blocks that have sand joints have lower runoff figures than concrete (60-78% compared to 95%), so where this type of paving exists, it should be preserved rather than converting to full concrete surfaces where areas are upgraded.[386]
- Detention ponds – these are areas for temporary stormwater storage that are formed from the landscape, with controlled outflow, but which dry out during periods of dry weather.
   - Multi-purpose retarding basins are an effective off-line storage method to reduce flood risk in urban areas. This is where water is diverted from the main channel via an intake structure and channel to the storage area (which is either formed from excavated ground or retaining structures), followed by an outlet with flow control to return water to the river. A spillway or overflow is also built in to the system. These are used for other purposes (e.g. car parking, sports areas) in non-flood periods. One example of this comes from Machida City in Japan, where the storage area includes a sports stadium (see Figure 21). This kind of system works most effectively when there is good control and timing in real time of the inflow and outflow, but this can be complex.[387]
   - Detention basins in malaria-prone areas should be designed to be drained before mosquito larvae hatch (i.e. 1 week or less).[388]
- Retention ponds – these provide storage within a permanent body of water which can be part of the landscaped environment.
- Wetlands – these act as retention ponds to reduce peak flow of floodwater. Floodplains within or immediately upstream of urban areas can be managed to act as periodic wetlands, to which water is diverted or enters naturally.[389]
- Soakaways & infiltration trenches:
   - These are underground structures filled with some kind of granular fill (e.g. gravel) that increase infiltration of water into the ground. Both types are similar in principle, except that trenches are linear and usually have larger surfaces for infiltration. They are designed for areas where the full pit or trench will be above the water table all year, and for areas with suitable infiltration rates. Water enters such structures via drain pipes which can terminate in the form of a perforated section.[390] Pore spaces in the granular material can get blocked by fine particles in the runoff water,[391] so in this case (as with MAR techniques using well shafts or boreholes designed as infiltration devices – see below), water quality entering the soakaway should have a reasonable quality.
   - Inlet structures to infiltration trenches can also be designed to aid infiltration – for example, connecting the inlet area to the trench by means of a perforated pipe that is buried within the granular material in the trench.[392]
- Infiltration basins:

Figure 21: Multi-purpose retarding basin, Japan
Tanaka, T. (2011) The Project for Capacity Development of Jakarta Comprehensive Flood Management (JCFM). Presentation by JICA at the *Workshop on Global flood risk management, 25th - 26th May 2011, Jakarta.* Quoted in: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.215

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384 For details of how to create a multi-purpose retarding basin, see: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.231
385 Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. pp.103, 105
386 Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. p.105
387 For details of how to create a multi-purpose retarding basin, see: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.36, 213-218
388 Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.28
389 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.36, 250-254
390 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.230
391 Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. p.101
392 Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. pp.102-103

    - These are open depressions in the ground that are not filled with granular fill, that allow water to collect there and infiltrate gradually (see below).
- Several Managed Aquifer Recharge (MAR) techniques can also be applied to improving stormwater drainage. While MAR techniques are primarily used for getting surface water infiltrated into the ground in order to recharge aquifers and / or improve soil moisture for rain-fed crops, at the same time they also act as natural ways to reduce stormwater. These techniques will not be detailed in this document, but have been covered in the sister document to this one on resilient WASH for drought-prone areas.[393] MAR techniques include:
  - Infiltration basins – these are large open water ponds that are either excavated or in an area of land surrounded by a bank, and normally will not exceed 15,000m^3. They store rainwater but with the main aim of infiltrating the water to aquifers where it can be extracted using wells or from springs. They are constructed in areas where the base of the pond is permeable and where the aquifer to be recharged is at or near the surface.
  - Contour trenches – these are open trenches (with no granular fill) dug to slow down and attract runoff water which then infiltrates into the soil.
  - Bunds – these are small barriers to runoff coming from external catchments to the field where crops are to be grown. They slow down sheet flow on the ground surface and encourage infiltration.
  - Gully plugs / check dams – these are earth or concrete overflow weirs constructed in natural gullies in the land surface, which impede water with the same result as contour trenches.
  - Leaky dams – these are permeable structures built across seasonal riverbeds which retain flash flood water that has a high silt load. The idea is to retain the high-energy floods and stimulate settlement of suspended sediment behind the dam. Water with a lower sediment load is then available to leak through the dam and infiltrate the downstream riverbed which is not blocked by sediment deposits.
  - Controlled flooding – this is a floodwater harvesting technique where water is diverted from a river, and with the help of diversion structures and canals is spread evenly over a large surface area where it is used for irrigation, filling ponds, watering grazing land and recharging groundwater.
  - Well shafts & boreholes designed for infiltrating water – large diameter wells and smaller diameter boreholes can be used to directly recharge or dilute aquifers where low permeability strata overlie the aquifers and where other infiltration methods are not effective. Water to be infiltrated can come from runoff or roofs. The important thing is that water of high enough water quality is used for this purpose.

[393] For details see: Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands. pp.40-57

Solid waste management

Overview:
Solid waste is often inadequately managed in many areas, so part of a flood preparedness strategy will be to set in place a well managed solid waste collection and disposal system to start with, after which it can be modified to be more resilient to floods. Informal settlements are especially at risk since they are usually neglected when waste management plans are planned and implemented, and have prevailing conditions that aggravate adequate solid waste management (e.g. lack of access to dustbins, irregular collection, and low-lying / vacant lands with narrow roads).[394] Poor waste management and drainage can create problems and health hazards in collective centres and urban areas. The quantity of rubbish, which is added to by packaging of materials supplied by relief agencies, may quickly accumulate, blocking drainage channels and creating ideal breeding sites for rodents, flies and other insects which can become vectors for spreading disease, especially when displaced centres are overcrowded and no waste disposal facilities exist. In addition, pools of stagnant water remain after floodwater recedes, and mosquito and other vector populations can increase.[395] Solid waste also is much denser and more difficult to handle when wet. One under-mentioned aspect of the solid waste problem is also that of silt, which needs to be removed from drainage channels. To address all of this, management of solid waste is necessary, but can also be combined with improvements to stormwater drainage systems for maximum effect.[396]

Key techniques for siting:
- Appropriate solid waste disposal sites need to be allocated in advance as part of a preparedness strategy. Sites designated for disposal of wastes should be in uninhabited areas, away from centres of population, and with good access for vehicles.[397] In urban areas, having several disposal sites in different parts of the city can ensure disposal still continues even when access is hampered by floods, but no non-inert material should be disposed of areas at risk from flooding if possible.[398]
- Any depots, garages and equipment should be located on higher ground as part of a flood preparedness strategy. Fuel reserves can also be maintained for use after a flood event.[399]

Key techniques for construction & implementation:
- Silt is often a less visible but larger part of the solid waste problem in non-industrialized countries. Given a typical situation where there are unsurfaced roads and various ongoing construction projects, it is not likely that silt production can be reduced at source – rather, improved maintenance techniques will be necessary within the drainage system.[400] Design can help solve the silt problem to a degree, through optimizing velocities and creating drainage that is easier to maintain (see section on 'Stormwater & wastewater drainage systems'). However, maintenance routines will still be necessary in order to reduce obstructions and keep water flowing. This can be done through:
    - Regular clearance of drainage channels by the authorities. River dredging to remove sediments and waste has also been used in the past as part of a wider urban flood risk reduction strategy.[401]
- Non-silt waste is the more visible (but perhaps lesser) solid waste problem in non-industrialized countries. As with silt, there needs to be a maintenance routine to reduce obstructions and keep water flowing, but there are also possibilities to reduce the waste at source through better solid waste management and other techniques, such as:
    - Regular clearance of drainage channels by the authorities.
    - A more robust solid waste management system, with improved collection, transport and disposal that also consider how to continue the service after a flood:
        - Adequate numbers of containers for storage of rubbish should be provided, and there needs to be a planned system for the transport and disposal of the rubbish.[402]
        - Collection and transport mechanisms need to be put in place to allow solid waste to be managed without causing an overflow into the streets. One part of this may be a strict and enforced disposal and collection policy to reduce the solid waste problem. Such a policy might enforce rules such as waste being only allowed to be put out on collection days, with penalties for non-compliance.
    - Even with a more robust management of solid waste, it is known that the reality in urban areas is that the authorities usually do not have the capacity to collect all of the solid waste generated – only 50% might realistically be collected on average. This will be especially the case for informal settlements, where operational cost recovery may not be

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394 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.367
395 OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK. p.3
396 As was done as part of a flood prevention strategy in Bamako, Mali. See: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.358-360
397 Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.10.
398 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.362-363
399 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.362-363
400 Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. p.41
401 Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.362-363, 365
402 OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK. p.3

possible for regular waste collection / transport systems. One way around this is to encourage informal sector collectors or community-based systems, which can help increase capacity. Motivating collectors can be done using incentives (e.g. rewards for solid waste delivered),[403] and the mechanisms might be door to door collection with hand carts where access allows this, otherwise community collection points such as outside shops and supermarkets. For any of this to work however, waste pick-up times, frequency and regularity need to be maintained.[404]

  - The amount of waste can also be reduced before it even reaches the drains. A strategy of reducing, re-using and recycling waste can help reduce the amount of certain types of solid waste on the streets, and therefore reduce the likelihood of blockages and therefore flooding.
    - Plastic waste (plastic bags and bottles) are often the waste type that causes the blockages in drains – therefore any system that can incentivize people to reduce, re-use or recycle this waste may be a good strategy to employ to make solid waste management more flood-resilient.[405] Ideas to do this include things like banning plastic bags, charging for plastic bags, promoting re-useable plastic bags, having a system of refund for returned plastic bottles, or recycling the plastic.
    - After a flood, there may be a lot of flood waste that needs to be cleared and sent for disposal. However, practices of re-using and recycling materials at the point of clearance after a flood can help reduce the volume going to landfill, and therefore the pressure on these facilities.[406]
- Engaging with the community is necessary in order to address solid waste issues:
  - Clearance can be carried out by communities. Tools and protective clothing can be issued to members of the community, and the community can be encouraged to clear away mud and debris from areas that suffered flooding.[407] Take care that mud and debris is moved to suitable sites, and will not be left where it may wash back into drainage channels or obstruct drainage in the future.
  - Communication with affected communities through the use of radio, outreach workers and/or posters and leaflets is a key aspect of solid waste disposal.[408] This is because user education may be required about what not to dispose of in wastewater system (e.g. in Zimbabwe, authorities had to make people aware that using sand to clean dishes was resulting in blocked drains).[409]
- Disposal of solid waste is sometimes carried out by infilling low-lying areas – however it might be wise to avoid doing this since once these areas are filled, they cannot act as temporary storage basins during floods (see 'Stormwater & wastewater drainage systems' section).[410]

[403] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.357-360, 368-369
[404] As was done as one part of a flood risk reduction project in Manila, the Philippines. See: Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.362-363, 365, 368
[405] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.353-355
[406] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.367
[407] OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK. p.3
[408] Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. p.10.
[409] Author's experience.
[410] Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. pp.362-363

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Reference	Read	Content
General		
ACAPS (2012) *Disaster Summary Sheets (Draft)*. Assessment Capacities Project, Geneva, Switzerland. Available online: http://www.acaps.org/en/news/disaster-summary-sheet-floods	✓	Gives a general profile of the impact of floods – a good overview of the impact of floods on other disasters and exacerbating factors.
ACF-IN (2008) '*How to Make WASH Projects Sustainable and Successfully Disengage in Vulnerable Contexts: a practical manual of recommendations and good practices based on a case study of five ACF-IN water, sanitation & hygiene projects*.	✓	Review of sustainability issues and WASH projects.
ADPC; UNDP (2005) *Integrated flood risk management in Asia – a primer.* Asian Disaster Preparedness Center and United Nations Development Programme, Bangkok, Thailand. Available online: www.adpc.net/maininforesource/udrm/floodprimer.pdf	✓	Overview of knowledge & experience gained in flood risk management in Asia since 1990
Alam, K. (2008) *Flood disasters - Learning from previous relief and recovery operations*. ALNAP/Provention Consortium. p.2 Available online: http://www.alnap.org/publications/pdfs/ALNAP-ProVention_flood_lessons.pdf	✓	Overview of lessons learned from 20 years of flood relief operations
Batchelor, C.; Schouten, T.; Smits, S.; Moriarty, P.; Butterworth, J. (2009) *14. Climate change and WASH services delivery – Is improved WASH governance the key to effective mitigation and adaptation?* Perspectives on water and climate change adaptation. IRC, The Hague, The Netherlands. Available at: http://www.worldwatercouncil.org/index.php?id=32	✓	Discusses potential impact of climate change on WASH service delivery
Bryant, E. 2005. *Natural Hazards* (Second edition). Cambridge University Press, Woolongong, Australia.		
Cullis, A.; Pacey, A. (1992) *A development dialogue: rainwater harvesting in Turkana*. IT Publications, London, UK.	✓	Useful insight into project design that evolved together with community dialogue.
Durkin, M.S.; Khan, N.; Davidson, L.L.; Zaman, S.S.; & Stein, Z.A. (1993) The effects of a natural disaster on child behaviour: Evidence for posttraumatic stress. *American Journal of Public Health*, 83, 1549-1553. Available online: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1694881/pdf/amjph00535-0039.pdf	✓	Looks at the effect of natural disasters on mental health in children.
Etienne, F. (2009) *Technical WASH Review in Gonaïves. Haiti, 8 – 19 March 2009.* Global WASH Cluster Learning Project, New York, USA. Available online: http://sheltercentre.org/sites/default/files/Gonaives_Technical_WASH_Review_English%20%282%29.pdf	✓	Lessons learned after floods in 2008 in Haiit.
Falkenmark, M.; Fox, P.; Persson, G.; Rockström, J. (2001) *Water harvesting for upgrading of rainfed agriculture. Problem analysis and research needs*. Stockholm International Water Institute.	✓	Useful overview of rainwater harvesting techniques and adaptation to increase water availability.
Ferris, E. (2010) *Earthquakes and Floods: comparing Haiti and Pakistan*. The Brookings Institution, Washington DC, USA. Available online: http://www.brookings.edu/~/media/Files/rc/papers/2010/0826_earthquakes_floods_ferris/0826_earthquakes_floods_ferris.pdf	✓	Gives a comparison between the circumstances and response in two natural disasters.
Few, R.; Ahern, M.; Matthies, F.; Kovats, S. (2004) *Floods, health and climate change: a strategic review*. Working Paper 63. Tyndall Centre for Climate Change Research, Norwich, UK. Available online: http://www.tyndall.ac.uk/sites/default/files/wp63.pdf	✓	Literature review of health impact, adaptation processes and policies relating to flood risk, and how climate change might affect this.
Fewster, E. (2010) *Desk study - Resilient WASH systems in drought prone areas: techniques to improve the resilience of community WASH systems in drought prone areas.* CARE Nederland / Netherlands Red Cross, The Hague, The Netherlands.	✓	Overview of techniques to improve water availability and storage in drought-prone areas.
Government of Yemen (2009) *Damage, Losses and Needs Assessment: October 2008 Tropical Storm and Floods, Hadramout and Al-Mahara, Republic of Yemen*. Government of Yemen. p.64. Available online: http://gfdrr.org/docs/Yemen_DLNA_Report.pdf	✓	Assessment of damages & losses resulting from Yemen floods in 2008.
Hedlund, K. (2007) *Slow-onset disasters: drought and food and livelihoods insecurity. Learning from previous relief and recovery responses*. ALNAP / Provention Consortium. Available online: http://www.alnap.org/pool/files/ALNAP-ProVention_lessons_on_slow-onset_disasters.pdf	✓	Overview of disasters and previous humanitarian interventions.

Hoque, B.A.; Sack, R.B.; Siddiqi, M.; Jahangir, A.M.; Hazera, N.; & Nahid, A. (1993) Environmental-Health and the 1991 Bangladesh Cyclone. *Disasters*, 17, 143-152.		A post-disaster study to assess environmental health conditions.
IPCC (2001) *Summary for policymakers - Climate Change 2001: impacts, adaptation, and vulnerability. A Report of Working Group II of the Intergovernmental Panel on Climate Change.* IPCC, Geneva, Switzerland.	✓	Summary of probable impacts of climate change
Jha, A.K.; Bloch, R.; Lamond, J. (2012) *Cities and flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. The World Bank, Washington DC, USA. p.21	✓	Guidance document on how to manage the risk of floods in a rapidly transforming urban environment and changeable climate.
Koestler, A.G.; Koestler, L. (2011) Hygiene promotion without water – water supply without hygiene promotion: new emergencies after disasters. *35th WEDC International Conference, Loughborough, UK.*	✓	Paper looking at the need for coordination and integrated programming in emergencies.
Morgan, O.; Ahern, M.; Cairncross, S. (2005) Revisiting the tsunami: health consequences of flooding. *PLoS Med* 2(6): e184. p.491. Available online: http://www.plosmedicine.org/article/info%3Adoi%2F10.1371%2Fjournal.pmed.0020184	✓	Review of evidence of health consequences after flooding, and appropriate interventions.
Mwaniki, P. (2009) *Lessons learned in WASH Response during Rural Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. Available online: http://oneresponse.info/GlobalClusters/Water%20Sanitation%20Hygiene/restricteddocuments/Rural_Floods_WASH_Lessons_Learned.pdf	✓	Lessons learned from learning workshop in India and literature review from rural flooding contexts
NWP; Aquaforall; Agromisa; Partners voor Water. (2007) *Smart Water Harvesting Solutions*. Netherlands Water Partnership.	✓	Review of various water harvesting techniques.
Oxfam (2001) *Emergency flood response orientation. 16th – 17th October 2001*. Phnom Penh, Cambodia.	✓	Review of lessons learned in WASH response after Cambodia floods
OXFAM (2008) *Responding to floods and flooding*. OXFAM Technical Briefs – TBN11 (v1, 09-12-08). Oxfam, Oxford, UK.	✓	Overview of typical flood responses undertaken in various contexts
PAHO (1998) *Natural disaster mitigation in drinking water and sewerage systems: Guidelines for Vulnerability Analysis*. PAHO, Washington DC, USA. p.35. Available online: http://www.paho.org/english/Ped/nd-water_mit.pdf	✓	Provides tools for water companies to evaluate components of systems vulnerable to various disasters.
Reed, S.B. (1997) Introduction to hazards. 3rd Edition. UNDP. Available online: http://iaemeuropa.terapad.com/resources/8959/assets/documents/UN%20DMTP%20-%20Hazards.pdf	✓	Presentation of different hazard types.
Roger Young and Associates (2000) *Bangladesh 1998 Flood Appeal: an independent evaluation.* Final Report. Disasters Emergency Committee. Available online: http://www.alnap.org/pool/files/erd-2859-full.pdf	✓	Evaluation of DEC activities after Bangladesh flood of 1998.
Saint-Gobain Pipelines (2006) *Pipe & Fittings - Water & Sewer: Design Guide.* Saint-Gobain, Ilkeston, UK. Available online: http://www.saint-gobain-pam.co.uk/watersewer/index.cfm?page=Product%20Catalogues-287	✓	Design recommendations for pipe installation
Shekhar, A.; Dwivedi, S.; Bhagwat, I. (2010). Ensuring safe water and sanitation during floods in rural communities of Bihar State, India. *Waterlines* Vol.29 No.3 July 2010.	✓	Account of a preparedness project that raised latrines and water points.
Smith, M. (2009) *Lessons learned in WASH Response during Urban Flood Emergencies.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. Available online: http://oneresponse.info/GlobalClusters/Water%20Sanitation%20Hygiene/restricteddocuments/Urban_Floods_WASH_Lessons_Learned.pdf	✓	Lessons learned from learning workshop in Haiti and literature review from urban flooding contexts
The Sphere Project (2011) *The Sphere Project – Humanitarian Charter and Minimum Standards in Humanitarian Response.* Practical Action Publishing, Rugby, UK. Available online: http://www.sphereproject.org/handbook/	✓	Explanation of Sphere standards and indicators.
USAID (2010) *Summary of the World Water Crisis and USG Investments in the Water Sector*, *May 15, 2010.*	✓	Overview of water availability in terms of supply & demand, in relation to the future and climate change.
WHO (2009) *Vision 2030: The resilience of water supply and sanitation in the face of climate change*. WHO, Geneva, Switzerland. Available online: http://www.who.int/water_sanitation_health/publications/9789241598422/en/	✓	Document that recognizes effect of climate change on WASH systems and provides overall advice on increasing resilience
Wijk-Sijbesma, C, van (2001): The best of two worlds. Methodology for participatory assessment of community water services. Delft: *IRC International Water and Sanitation Center Technical Paper Series 38*. p156, p.220		Tested whether participatory approaches that are more demand-responsive & gender- and poverty-sensitive result in water services that are better sustained and used.

Wiles, P.; Selvester, K.; Fidalgo, L. (2005) *Learning lessons from disaster recovery: the case of Mozambique*. Working Paper Series No.12. World Bank, Washington, USA. Available online: http://documents.worldbank.org/curated/en/2005/04/5780422/learning-lessons-disaster-recovery-case-mozambique	✓	Review of lessons learned after disasters – part of a series of 5 case studies
Water sources, supply & treatment		
Aadan, A.I. (1982) *Final report on solar water distillation project. Warbixin iyo gunaanud ee mashruuca kudha sannadka1981ka.* Jamhuuriyadda Dimoqraadiga Soomaaliya.	✓	Experience from building larger scale solar distillation plant.
Alward, R. (1970) *Installation of a solar distillation plant on Ile de la Gonave, Haiti. Internal report No. I.67.* Brace Research Institute, McGill University, Canada.	✓	Experience from building larger scale solar distillation plant.
CARE Yemen (2004). *East of Aden Watercones Pilot Project Report.*	✓	Reviews the effectiveness of Watercone distillation units for coastal communities in Yemen.
Clasen, T.; Smith, L. (2005) *The Drinking Water Response to the Indian Ocean Tsunami, including the role of Household Water Treatment.* World Health Organization, Geneva, Switzerland. Available online: http://www.who.int/household_water/research/tsunami/en/index.html.	✓	Documents experience of household water treatment after the 2004 tsunami
Danert, K.; Armstrong, T.; Adekile, D.; Duffau, B.; Ouedraogo, I.; Kwei, C. (2010) *Code of Practice for Cost Effective Boreholes*. RWSN, St. Gallen, Switzerland. Available at http://www.rwsn.ch/documentation/skatdocumentation.2010-08-23.4523209156/file	✓	Code of practice for effective borehole drilling.
Dijk, J. A. van (1995) *Taking the Waters. Soil and water conservation among settling Beja nomads in Eastern Sudan*. African Studies Centre Research Series No.4. Aldershot: Avebury (Ph.D. thesis).	✓	Study of water conservation measures in Sudan including bunds
Fewster, E. (2004) *Evaluation report for MAD08,Maroantsetra, Madagascar- 29 November – 20 December 2004 - An evaluation of the MAD08 project, covering: jetting, sand filters & emergency phase distribution & well chlorination.* Medair, Ecublens, Switzerland.	✓	Documented the effectiveness of a distribution of sodium hypochlorite to households immediately after a flood emergency.
Foley, M.G. (1978). Scour and Fill in Steep, Sand-bed Ephemeral Streams. Geological Society of America Bulletin, Vol. 89, pp. 559-570.	✓	Data on depth of scour in seasonal rivers
Gale, I. (Ed) (2005) *Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas.* IAH-MAR and UNESCO-IHP.	✓	A document that draws together experience of MAR in semi-arid areas in order to provide examples of good practice.
Handzel, T. (2009) *Evaluation of WASH Cholera Response to 2008-09 in Zimbabwe. Draft Report*. Centers for Disease Control and Prevention, Atlanta, USA.	✓	Excellent analysis of the cause of cholera spread in Zimbabwe, including urban areas
Harvey, B.; Boughen, L. (2009) *Technical learning workshop: WASH response to floods in urban contexts. Workshop findings and way forward*. WASH InterAgency Meeting, Geneva, 27th April 2009.	✓	Summary of findings from a technical learning workshop on WASH in urban floods
Hussey, S.W. (2007) *Water from sand rivers: guidelines for abstraction*. WEDC, Loughborough University, UK.	✓	Good overview of sand abstraction and offset pump options.
Kayaga, S. (2005) *Rehabilitating small-scale piped water distribution systems*. WHO notes for emergencies, Technical Note no.4. WHO, Geneva, Switzerland.	✓	Review of techniques for rehabilitating piped systems in emergencies.
Koninga, J. de; Thiesen, S. (2005) Aqua solaris – an optimized small scale desalination system with 40 litres output per square meter based upon solar-thermal distillation. *Desalination.*		Trials on a solar still producing 40 litres/m^2/day.
Lantagne, D. S.; Blount, B. C.; Cardinali, F.; Quick, R. (2008) Disinfection by-product formation and mitigation strategies in point-of-use chlorination of turbid and non-turbid waters in western Kenya. *Journal of Water and Health*, 06.1,pp.67-82.	✓	Investigates effect of chlorinating turbid water on THM production
Lantagne, D.; Clasen, T. (2009) *Point of Use Water Treatment in Emergency Response*. London School of Hygiene and Tropical Medicine. London, UK.	✓	Documents experience of point of use treatment in emergencies.
Lawrence, A.R.; McDonald, D.M.J.; Howard, A.G.; Barrett, M.H.; Pedley, S.; Ahmed, K.M.; Nalubega, M. (2001). *Guidelines for assessing the risk to groundwater from on-site sanitation*. British Geological Society, Keyworth, UK.	✓	Guidelines for distance from boreholes to latrines.
Luby, S.; Islam, M.S.; Johnston, R. (2006) Chlorine spot treatment of flooded tube wells, an efficacy trial. *Journal of Applied Microbiology* 100 (2006) 1154–1158.	✓	Study showing the ineffectiveness of one-off spot chlorination of boreholes
Luff, R,; Dorea, C. (2012). Bulk water treatment unit performance: for the cameras or the community? *Waterlines* Vol.31 No.1/2	✓	Looks at poor practice in design and

January/April 2012.		selection of bulk water treatment units.
McCluskey, J. (2001) Water supply, health and vulnerability in floods. *Waterlines* Vol.19 No.3 January 2001.	✓	Review of water supply & flooding
Mol, A.; Fewster, E.; Osborn, K. (2005) *Ultra-rapid well construction: Sustainability of a semi-household level, post-emergency intervention*. Maximizing the benefits from water and environmental sanitation, 31st WEDC International Conference, Kampala, Uganda, 2005.	✓	Documented the construction of jetted wells as a prevention strategy after a flood emergency.
Mufute, N.L. (2007) *The development of a risk-of-failure evaluation tool for small dams in Mzingwane catchment*. MSc thesis. University of Zimbabwe, Harare, Zimbabwe.	✓	Analyzed risks of failure in small dams in Zimbabwe.
Nelson, K. D. (1985) *Design and Construction of Small Earth Dams*. Inkata, Melbourne, Australia.		Construction guidelines on earth dams over 3m height.
Nissen-Petersen, E. (2000). Water from sand rivers: a manual on site survey, design, construction and maintenance of seven types of water structures in riverbeds. RELMA, Nairobi, Kenya.	✓	Manual for construction of groundwater dams. Fairly simple overview.
Nissen-Petersen, E. (2006) *Water from Small Dams: A handbook for technicians, farmers and others on site investigations, designs, cost estimates, construction and maintenance of small earth dams*. DANIDA.	✓	Overview of types of open reservoirs & their construction.
Pickford, J. (ed) (1991). *The Worth of Water: technical briefs on health, water and sanitation*. Practical Action Publishing, London.	✓	Construction guidelines on infiltration galleries (Technical Brief 22).
Practical Action. *Solar distillation technical brief.*	✓	Overview of household solar distillation.
Rasal, P. (2008) *Online chlorination of hand pumps, Supaul District, Bihar.*	✓	Technical details of how to make and install an online chlorination system for handpumps
Reiff, F. (1982) *Floods and water supplies: lessons learned in Ecuador*. PAHO/WHO Virtual Disaster Library.	✓	Documented flood response actions after flooding in Ecuador.
Republic of Kenya; Democratic Republic of Sudan. (1981). Road A1: Kenya-Sudan Road Link Lodwar-Juba. Hydrogeological Survey. Ministry of Transport and Communications, Kenya; Roads and Bridges Public Corporation, and Regional Ministry of Communications, Transport and Roads, The Democratic Republic of Sudan. Norconsult AS (Kenya), Nairobi, Kenya.	✓	Survey of sand rivers in Turkana District
Saeed, M.M.; Ashraf, M.; Asghari, M.N.; Bruen, M.; Shafique, M.S. (2001) *Root Zone Salinity Management Using Fractional Skimming Wells With Pressurized Irrigation – Farmers' skimming wells technologies: practices, problems, perceptions and prospects.* Working Paper 40. IWMI, Lahore, Pakistan. Available online: http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR40.pdf	✓	Lessons learned in the implementation of skimming wells for farmers in Pakistan
Shaw, R. (ed) (1999). *Running Water: more technical briefs on health, water and sanitation*. Practical Action Publishing, London, UK.	✓	Construction guidelines on earth dams under 3m height, spring protections and surface drainage.
Tucci, C.E.M. (2007) *Urban Flood Management*. WMO, Cap-Net, APFM, Porto Alegre, Brazil. Available online: http://www.cap-net.org/sites/cap-net.org/files/Urban%20flooding_E_LowRes.pdf	✓	Overview of management of rainwater in urban settings.
Varampath, A.; Patel, T.; Mischke, K. (2008) *South Asia floods - WASH interventions/capacity review: Focusing on key WASH interventions and capacity of agencies to deliver these*. WASH Review - Bihar 2008. RedR India.	✓	Review of safe excreta disposal, hand washing and availability of treated water at household level in a real-time flood emergency
Vilholth, K. (2011) *Cleaning wells after seawater flooding*. Technical notes on drinking water, sanitation and hygiene in emergencies no.15. WHO, Geneva, Switzerland. Available online: http://www.who.int/water_sanitation_health/publications/2011/tn15_cleaning_wells_en.pdf	✓	Advice on rehabilitating wells after seawater flood event.
Watt, S.B.; Wood, W.E. (1979) *Hand Dug Wells and their Construction*. IT, London, UK.	✓	Excellent book on hand dug well construction.
Weert, F. van; Gun, J. van der; Reckman, J. (2009) *Global Overview of Saline Groundwater Occurrence and Genesis*. International Groundwater Resources Assessment Centre (IGRAC), Utrecht, The Netherlands.	✓	Comprehensive overview of salinity in groundwater.
Worm, J.; Hattum, T. van (2006) *Rainwater harvesting for domestic use*. Agrodok 43. Agromisa Foundation and CTA, Wageningen, The Netherlands.	✓	

Excreta disposal		
Ahmed, S.M.; Husain, A.M.M.; Sattar, M.G.; Chowdhury, A.M.R. (1999) A quick assessment of flood losses and post-flood rehabiilitation needs in BRAC's programme areas. In: *Experiences of deluge: flood 1998. Research Monograph Series, 15.* (eds S.M. Ahmed & H.S. Ahmed), pp. 1-29. BRAC, Dhaka, Bangladesh. Available online: http://http.bracresearch.org/monographs/experiences_of_A_deluge.pdf	✓	Investigated the effect of the 1998 floods in Bangladesh.
Bastable, A.; Hoque, E. (2002) Excreta Disposal in high water table and flooding environments. In: Treglown, S.; Harvey, P.; Reed, R. *Planning and Management of Emergency Sanitation: Proceedings of an International Conference, WEDC, Loughborough University, UK, 10th-12th April 2002*. Available online: http://wedc.lboro.ac.uk/docs/research/WEJN4/Emergency_Sanitation_Conference_Proceedings.pdf	✓	Conference proceedings that reviewed best practice in emergency sanitation.
Bastable, A.; Lamb, J. (2012) Innovative designs and approaches in sanitation when responding to challenging and complex humanitarian contexts in urban areas. *Waterlines* Volume 31, Numbers 1-2, January 2012, pp. 67-82(16)	✓	Discusses problems and solutions to rapid implementation of latrine solutions in challenging environments, based on recent field experience.
BORDA (2012) *Demand-based technical solutions to reduce water pollution by small and medium enterprises and settlements in densely populated areas*. BORDA & BORDA BNS Network, Bremen, Germany. Available online: http://www.borda-net.org/fileadmin/borda-net/Service_Packages/Dewats_2010.pdf	✓	Overview of decentralized wastewater treatment solutions.
BORDA (2012) *EmSan: Emergency Sanitation – an innovative & rapidly applicable solution to safeguard hygiene and health in emergency situations.* BORDA & BORDA BNS Network, Bremen, Germany. Available online: http://www.borda-net.org/fileadmin/borda-net/Service_Packages/04EmSan_web.pdf	✓	Overview of decentralized wastewater treatment solutions for emergencies.
Coloni, F.; van den Bergh, R.; Sittaro, F.; Giandonato, S.; Loots, G.; Maes, P. (2012) Biodegradable bags as emergency sanitation in urban settings: the field experience. *Waterlines* Volume 31, Number 1/2, January/April 2012, pp. 61-77(17).	✓	Outlines field experience with packet latrine implementation in Haiti.
Delepière, A. (2009) *Case study of sustainable sanitation projects - Household UDDTs after cyclone disaster: Padma & Rohitra villages, Barisal Division, Bangladesh*. SuSanA 2011. Available online: http://www.susana.org/lang-en/case-studies?view=ccbktypeitem&type=2&id=1183	✓	Looks at a successful project that constructed raised urine diversion toilets for flood settings.
Djonoputro, E.; Blackett, I.; Rosenboom, J.-W.; Weitz, A. (2010). Understanding sanitation options in challenging environments. *Waterlines* Vol.29 No.3 July 2010.	✓	Review of sanitation options for challenging environments.
Forster, T. (2009) *Technical Briefing for Emergency Response: Sanitation in Urban Flood Settings*. The Global WASH Learning Project. Global WASH Cluster, New York, USA. Available online: http://www.bvsde.paho.org/texcom/desastres/wassuflo.pdf	✓	Overview of key issues affecting people during urban floods, including drainage and solid waste issues.
Franceys, R.; Pickford, J.; Reed, R. (1992) *Guide to the development of on-site sanitation*. WHO, Geneva, Switzerland.	✓	Comprehensive overview of on-site sanitation.
Johannessen, Å.; Bikaba, D. (2009) *Sustainable sanitation for emergencies and reconstruction situations*. Draft version 1.2. Fact sheet. Sustainable Sanitation Alliance (SuSanA).	✓	Useful factsheet dealing with sanitation options for emergencies.
Johannessen, Å.; Patinet, J.; Carter, W.; Lamb, J. (2012) *Sustainable sanitation for emergencies and reconstruction situations - Factsheet of Working Group 8*. Sustainable Sanitation Alliance (SuSanA). Available online: http://www.susana.org/lang-en/library/rm-susana-publications?view=ccbktypeitem&type=2&id=797	✓	A factsheet addressing current developments, challenges, gaps and solutions in the planning & implementation of sustainable sanitation for emergencies and reconstruction situations.
Oxfam (2005) *Excreta disposal in flooding and high water table environments.*	✓	PowerPoint from Oxfam showing latrines for flood zones – including the concept of safe zones
Parry-Jones, S. (1999) On-site sanitation in areas with a high groundwater table. WELL factsheet. Available online: http://www.lboro.ac.uk/well/resources/fact-sheets/fact-sheets-htm/lcsahgt.htm	✓	Overview of technical aspects of options in high water table including raised latrines.
Patel, D.; Brooks, N.; Bastable, A. (2011). Excreta disposal in emergencies: Bag and Peepoo trials with internally displaced people in Port-au-Prince. Waterlines Volume 30, Number 1, January 2011, pp. 61-77(17).	✓	Outlines field experience with packet latrine implementation in Haiti.
Ruberto C.; Johannessen, Å. (2009) *Innovations in emergency sanitation. International Water Association (IWA). 2 day workshop,*	✓	Workshop that aimed to come up with useful

11-13 February 2009. Stoutenburg, The Netherlands. Available online: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=958		ideas to improve sanitation practices in terms of sustainability, however still be suitable for emergency situations.
Sobhan, A.; Morshed, G. (2009) *Search appropriate latrine solution for flood prone areas of Bangladesh*. Oxfam. Available online: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=973	✓	A review of latrine options for flood-prone areas in Bangladesh.
Tratschin, R.; Spuhler, D. *Sanitation in Emergencies Overview.* Published on http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/sanitation-emergencies/sanitation-emer-0	✓	Good overview with references about emergency excreta disposal
Hygiene practices		
Ferron, S. (2011) *UNHCR Hygiene Promotion Briefing Pack*. UNHCR, Geneva, Switzerland.	✓	Good overview of all the components of hygiene promotion.
House, S.; Mahon, T.; Cavill, S. (2012) *Menstrual Hygiene Matters, A manual for improving menstrual hygiene around the world*. Draft version. WaterAid, London, UK.	✓	Comprehensive overview of MHM including in emergencies.
Sow, S. (2009) *Technical Briefing for Emergency Response: Hygiene promotion in flood settings.* The Global WASH Learning Project. Global WASH Cluster, New York, USA. Available online: http://www.bvsde.paho.org/texcom/desastres/washpflo.pdf	✓	Review of hygiene promotion actions during first 6 months of flood emergencies.
Woods, L.N. (2006) Behaviour change communication in emergencies: a toolkit. Unicef Regional Office for South Asia, Kathmandu, Nepal. p.61. Available online: http://www.unicef.org/ceecis/BCC_full_pdf.pdf	✓	Document reviewing hygiene promotion in emergency contexts.
Cholera control		
Bauernfeind, B.; Croisier, A.; Fesselet, J.-F.; van Herp, M.; Le Saout, E.; McCluskey, J.; Tuynman, W. (2004) *Cholera guidelines. 2004 - 2nd Edition*. Médecins Sans Frontières, Paris, France.	✓	Guidelines on how to set up a CTC and ORPs for cholera response.
International Code Council (1998) *The International Plumbing Code: a guide for use and adoption*. International Code Council, Falls Church, USA. pp.24-25 – available online at http://gisceu.net/PDF/U103.pdf.	✓	Includes guides on minimum slope requirements for wastewater pipes.
Oxfam policy briefing. *Acute Watery Diarrhoea and Cholera in the Horn,Central and Eastern Africa: Learning from experience to improve response in the future.*	✓	
Industrial pollution		
Balluz, L.; Moll, D.; Diaz Martinez, M.G.; Merida Colindres, J.E.; & Malilay, J. (2001) Environmental pesticide exposure in Honduras following hurricane Mitch. *Bull World Health Organ*, 79, 288-95.	✓	Investigated chemical pollution after flooding in Honduras.
Stormwater & wastewater disposal		
Cairncross, S.; Ouano, E.A.R. (1991) *Surface water drainage for low-income countries*. WHO, Geneva, Switzerland. Available online: http://www.cd3wd.com/cd3wd_40/cd3wd/SOILWATR/WHS050E/EN/B1072_11.HTM	✓	General guidance on surface water drainage in urban low-income settings.
Oxfam (2008). *Low cost drainage for emergencies.* OXFAM Technical Briefs – TB4, draft 1. Oxfam, Oxford, UK.	✓	Drainage recommendations for emergencies, including how to calculate drain sizes.
Reed, B. (2004) *Sustainable Urban Drainage in Low-Income Countries – a Scoping Study. Project Report.* WEDC, Loughborough, UK. Available online: http://www.dfid.gov.uk/r4d/pdf/outputs/R81681.pdf	✓	Overview of the applicability of SUDS for low-income countries.
Construction		
Constantine, T. (2001) *Cracking in Waterproof Mortars*. DTU, Warwick University, UK.	✓	Research done on how to reduce cracking in mortar in rainwater tanks.
Davis, J.; Lambert, R. (1995). *Engineering in Emergencies*. IT, London, UK.	✓	Overview of many different construction practices.
Harvey, P.; Baghri, S.; Reed, B. (2002) *Emergency Sanitation: Assessment and Programme Design*. WEDC, Loughborough, UK.	✓	Information on rebar spacing.
Neville, A.M. (1981) *Properties of Concrete*. Pitman.		All things to do with concrete.