STATENS GEOTEKNISKA INSTITUT
SWEDISH GEOTECHNICAL INSTITUTE

# Measures to manage climate change in Sweden

## Altered rainfall and sea levels

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Varia 619

LINKÖPING 2011

Photo (cover): Ramona Bergman, Swedish Geotechnical Institute

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ISSN | 1100-6692
ISRN | SGI-VARIA--11/619--SE

Dnr SGI | 1-0812-0884
Project nr SGI | 13895

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# 1 FOREWORD

This report is a very simple analysis of possible measures to reduce risks associated with changes in precipitation patterns, and in particular floods due to increased precipitation and sea level rise. For each measure there is a short overall description, what is generally positive and negative with each action, and where to find more information / lessons learned. The compilation does not provide detailed information for each action, but the intention is to obtain an overview of some of the steps you can take. This list, prepared under the EU Interreg IVB project Strategic Alliance for integrated Water Management Actions (SAWA), is meant to be used by the public and as a first step for planners in municipalities. Then one should proceed to find more detailed descriptions and analysis of a sample of relevant measures.

# 2 INTRODUCTION

In Sweden, as everywhere, we will over the next century have an elevated temperature as a result of expected climate change (SOU 2007:60). Globally there will be a sea level rise, in northern Sweden this is compensated by the elevation of the land while it becomes a net sea level rise in the rest of Sweden. Large parts of Sweden will be affected by increased annual rainfall and a change in precipitation patterns.The expected climate change will give secondary effects such as landslides, forest fires, spreading of pollutants etc. (SOU 2007:60). The influence of heavy rainfall alone may in some cities create overfilled storm water systems and flooded streets. Precipitation and spring floods may also create high flows in rivers which in turn can flood areas and in combination with a high sea level the problems can be even greater. The society needs to be adapted and the adaptation can be performed in several different ways depending on which problem is in focus.

This list was developed within EU interreg project SAWA (Strategic Alliance for integrated Water management Actions) and the focus lies on measures related to change in precipitation and sea level rise, including secondary effects such as landslides and erosion.

A first step for society to adapt to a changing climate is to identify vulnerable objects and to what extent they can be affected. For this several tools may be used. After identifying a city's or building's vulnerable points, one can choose a strategy to work with. We have chosen to focus on the following three strategies (3R): resistance, resilience and retreat. The strategies/measures can be more or less suitable for the specific situation depending on the different conditions in each city.

- **Resistance**

Resistance is a system's ability to avoid interference. It is a valuable factor before a system suffers from a disorder (Klein, et al., 1998). Resistance is also the degree of change in a system when it's surroundings change (Knapp et al., 2001). If the system has a good resistance it is not affected and changed when there is a disturbance in the surroundings. With a resistance strategy one chooses measures that keep the water away from the city or building.

- **Resilience**

Resilience is a sensitive system's ability to respond to the consequences of a disturbance. Resilience is important to a system after it has been affected (Klein et al., 1998). After a disturbance disappears resilience is also the degree and the speed at which a system can return to the state it had before the disturbance (Knapp et al., 2001). An example of resilience strategy is to allow water to enter the city and be affected by the disturbance for a limited period. With a good resilience the city can quickly return to its original state.

*Attack*

Attack means that water is not only allowed (resiliency) but also used for construction or other activities. For example, as in one of the concepts being discussed for the Free Port of Gothenburg City (Moback, 2011), water is used by the use of innovative and proven technology. The water is treated as a surface suitable for construction with e.g. floating houses. Many of the solutions used are the same as described in resiliency, but attack may require more elaborate and complex structures, which means more demands for monitoring, maintenance and control.

- **Retreat**

With this strategy one lets a city or district retreat from an area at risk of flooding (SPUR, 2011). For example one is only allowing new buildings in a safe zone and may move the most vulnerable and valuable buildings and facilities to a safe distance or altitude. The strategy includes soft measures by imposing a minimum level of construction, beach protection or other restrictions. Retreat can give a long and safe protection, though the cost may be high if the city already is well established with many constructions close to the water. The most important tool for this, as for the other measure forms, is planning.

The following compilation of measures first describes general steps to adapt a community. These are under the headings planning, resistance and resiliency. Many of the actions described in resiliency can be used in the attack-strategy, but they may then require more elaborate and complex designs. The general steps are followed by physical measures that can be taken for individual properties. Finally some examples of non-structural measures that can be taken with a focus on individual properties are shown. Non-structural measures denote e.g. planning, a way of acting, economical preparedness etc. while structural measures denote concrete prevention constructions.

Our goal is not to completely describe but to give a comprehensive overview of possible measures that could be taken, shortly describe known advantages and disadvantages and where to find more information and experiences.

*Table 1 Three different strategies with example of threats and measures*

| Strategy | Example of threat | Example of structural measure |
|---|---|---|
| Resistance | - Water level rise | - Wall<br>- Barrier<br>- Dam |
| Resilience | - Water level rise<br>- Heavy or persistent precipitation | - Adapted buildings<br>- Optimized storm water system |
| Retreat | - Water level rise<br>- Heavy or persistent precipitation | - Move buildings, build further away from the threat<br>- Wetlands as a barrier |

# 3 PLANNING AND MONITORING

Apart from specific structural measures, a well thought out planning for the whole city could be more efficient, sustainable and safe in the long run and some costly measures could be avoided.

Concerning water two primary threats to cities have been identified which are included within the project SAWA: direct (heavy or persistent) precipitation and water level rise in lake/sea/river. To reduce the risk one can reduce the danger, consequence or both. To mitigate the risk appropriate strategies have been suggested. In the strategies resilience and retreat the buildings are planed more efficiently and in a long-term perspective. Restrictions and building codes could also be included. These strategies are suitable for a municipality’s master plan, which is a comprehensive plan for the municipality's long-term vision. Within the strategy resilience one could for example mitigate the effects of direct precipitation through an optimized storm water system.

One can also take measures to reduce the danger at one place by taking measures in other places. For example, one can customize a water system by take measures that delay (retention), store (storage) or reduce the outflow (discharge) upstream so that large masses of water do not affect a more vulnerable area downstream. This can be done through a good regional or national planning. International planning is needed for some rivers. Several of the measures that in this report are described on a local level (dikes, retention reservoirs, multi-functional surfaces, etc.) can also be used for much larger areas. If large catchment areas are to be managed, good planning is required that takes place in cooperation between municipalities and other stakeholders affected by the measures taken.

In the planning for new buildings a mix of the three strategies are proposed (resist, resilience and retreat). For existing buildings the strategy resistance is proposed, but also resilience. For example an optimized storm water system could be a suitable strategy for some areas.

## 3.1 Basis for spatial planning

There are various documents and tools that can be used in the planning process. Important documents are previous plans and studies but also new knowledge and the knowledge available in the area. This may consist of special knowledge which depends on local knowledge from property owners, operators and officials. It may also consist of data in the form of climate scenarios, surveys, mapping and other site-specific data. For example, an elevation database could be a good basis to start from in the planning to adapt a city, or a specific area, to flooding (Swedish Board of Housing, Building and Planning, 2010a; MSB, 2010c).

A flood map shows which areas that may be susceptible to various water levels. The maps can also show blue spots, where water accumulates during heavy precipitation or when the water level drops. The map can be used for several purposes. It may be used to mark areas that can be used to delay water and show which roads could be used as waterways. In Denmark the maps are called "mulighedskort" (possibility maps) and are used to prioritise in relation to the demands concerning delay of water when new buildings are constructed (Swedish Board of Housing, Building and Planning, 2010b; MSB, 2010b; Terra Firma, 2011).

Other useful documentation is for example maps showing the extent to which the soil is paved in connection to a stream (e.g. "Towards a Green Infrastructure Framework for Greater Manchester"). To these maps a flood-mapping can be linked (Swedish Board of Housing, Building and Planning, 2010b; Pasche, 2009).

These documents can be further refined or developed by computer programs in which various scenarios with sea level and precipitation are simulated and visualized.

## 3.2 Measures that can be used in spatial planning

In order to prioritize and to select a solution, various decision support tools and combinations of such can be used. These tools can be used together with relevant documentation to identify the most sustainable solutions.

Communication during the process can be crucial for how sustainable a decision will be. Examples and suggestions for tools that can facilitate the communication and decision process with focus on a changing climate are summarized in toolboxes (e.g., Andersson-Sköld et al., 2011a; Jonsson and Simonsson, 2011; MSB, 2006).

In addition to the methods and tools that describe, simplify and systematize the decision-making process, laws and regulations are important tools. Master and detailed plans under the PBL (Planning and Building Act) are among the most important instruments. The Swedish Board of Housing, Building and Planning's report "Climate adaptation in planning and construction - analysis, actions and examples" (Swedish Board of Housing, Building and Planning, 2010a) and SGI Varia 608 (Rydell et al., 2011) contain a compilation of existing legislation that one can benefit from but also must take into account when planning. The law on protection against accidents indicates that a municipality should establish an action program for prevention and rescue services. An action program has three main purposes: to be a policy document, to be a document where the public get insight and information, and act as a planning basis. Since the action programs are based on local conditions, there is no general answer what they should look like but a common ground is that they should be designed on the basis of the local spectrum of risks (Swedish Board of Housing, Building and Planning, 2010a).

## 3.3 General non-structural measures

In addition to spatial planning of an area or a city one can plan efforts to raise knowledge, awareness and preparedness to prevent and mitigate the consequences of possible floods. Examples of non-structural measures are:

- Action program in case of flooding
- Plan a clear accountability, collaboration and actions within and outside the municipalorganization
- Information, education and training
- Forecast and Warning system
- Monitoring
- Insurance and other financial preparedness
- Evacuation plan
- Management plans for floating debris / material
- Recovery plan

These measures are organization dependent and need to be built up by, with and for local key actors.

## 3.4 Follow-up and maintenance

As important as planning is monitoring, inspection, review and maintenance. This applies to all measures proposed, i.e. both structural and non-structural. All major structures illustrated in this collection require continuous maintenance and control. The more complex construction, or organization, the more frequent monitoring, reviewing, testing, inspection and maintenance of the structure and organization has to be. When carrying out an action program one must also include a plan for monitoring, inspection and maintenance. This should in principle extend to the construction's final disposal. This may not be reasonable for structures with very long life but, in principle, the plan shall also include the management of risks in the long run.

Even for relatively simple measures maintenance and inspection is required. For example, both debris, plant material, soil and other materials such as ice can be carried downstream, or in other ways obstruct the water passages leading to flooding. To avoid this, one must regularly clear the waterways. To prevent ice plugs one can regulate tributaries to postpone ice unloading. One can also have channels on the side of passages, or dredge narrow passageways. If ice plugs do form one may need to burst it. Manual ice-breaking and sawing are further methods that can be used (MSB, 2010a). Although it requires continuous effort this is a relatively inexpensive measure.

# 4 RESISTANCE

Resistance is a sensitive system's ability to avoid interference. The classical methods are structural methods such as barriers, embankments and dams. These measures are usually large, heavy and complex structures, whose foundation requires well thought through and often advanced measures.

In addition, these structures often need to be located where soil conditions are complicated with thick layers of soil consisting of clay, silt, sand and organic soil. For example, they can be localized in the outer parts of bays, watercourse estuaries and other water bodies.

During a prolonged flood water infiltrates into the soil layers underneath the slope towards the watercourse and gives an elevated water table, which reduces the soil strength. When the water against the submerged slope falls away, the elevated groundwater table doesn't decrease at the same rate. The ground water sinks away particularly slowly in dense, fine-grained soils like clay and silt.

If a heavy construction is built the weight of the construction becomes an extra load which can affect the stability in a negative way and may lead to subsidence. Besides deficiencies in the construction, subsidence can also lead to that the intended level of protection is not achieved.

The combination of a heavy construction, such as an soil embankment, and an elevated groundwater water table can trigger landslides. Similarly, stability problems can arise if the land area is elevated with heavy masses of soil in order to prevent flooding.

If a structure is placed on filling without a sealing screen, leakage can occur through the soil layers beneath the construction and thereby adversely affect the stability.

Stability problems can also exist behind a construction if high flows or water levels occur in combination with high rainfall, which means that land behind a dike may have an elevated water table.

In addition, the soil layers at the sites where construction is carried out can be contaminated. This entails the risk that contamination will spread into the environment in connection with the foundation work.

For all the structures described in this section, it is very important that the soil conditions are well investigated, that consideration is given to the stability and subsiding problems and that the foundation is very well thought out. Many require advanced foundation measures. That is, all heavy structures (barriers, stationary walls etc.) should be dimensioned so that no landslides could be caused and subsidence is prevented.

## 4.1 Movable flood barrier

**Figure 1 Barrier in river Thames (Worldsteel, 2010)**

**Figure 2 Maeslantbarrier at Rotterdam (Delta Marine Consultants, 2010)**

A moveable barrier can e.g. be located at the mouth of a river which is adjacent to an ocean or bigger lake. The barrier can protect the society against a more temporary water level rise in the sea or lake. There are several different designs of a movable barrier. The Maeslant barrier at Rotterdam consists of two floating curved steel gates that automatically are moved to the river channel when the water is on the rise, Figure 2 (Keringhuis, 2010). In river Thames (London) there are nine concrete piers with ten mobile ports located in depressions in the riverbed. With a forecast of upcoming high water levels the gates can be rotated 90 ° and form a barrier, Figure 1(Environmental Agency, 2010).

**Generally positive:** The barrier can protect a city from occasional floods without permanently changing the conditions surrounding the river. Ecosystem, shipping and possibly drinking water supply need not be affected in a significant way compared to permanent barriers. It is also one measure that will protect the whole city.

**Generally negative:** However, the measure will lead to some change in the ecosystem. It can also cause problems when smaller rivers transport so much water into the main river that it is impossible to keep the barrier closed without flooding the city from inside. A floating barrier requires functioning electricity supply, is expensive, complicated and requires continuous maintenance. Lack of maintenance can lead to defects in the construction. Major defects may lead to unwanted consequences such as a barrier that breaks.

**Geotechnical aspects:** Moveable barriers are heavy and complex constructions which need consideration concerning stability and subsidence during the foundation, and may need advanced foundation measures.

**Information/experience:**

- Information about the barrier in Thames from the Environmental agency in Great Britain: http://www.environment-agency.gov.uk/homeandleisure/floods/38353.aspx
- Keringhuis (2010), http://www.keringhuis.nl/engels/home_flash.html
- In Arvika municipality there are plans for a barrier between Kyrkviken and Glafsfjorden. Here is a report from The Network of river security:http://www.arvika.se/download/18.28d09043124fe680ea280004986/Effekter+p%C3%A5+By%C3%A4lvens+vattensystem.pdf

## 4.2 Non-movable flood barrier

**Figure 3 Afsluitdijk in the Netherlands (Nedwater, 2011)**

A solid barrier is designed so that water inside and outside will be separated. It means that the water that possibly enters the bay through rivers regularly needs to be drained outside the barrier. It could possibly be done through the locks used to enable ships to get in and out. The barrier can also be built wide so the top can be used for other purposes. Example of a solid barrier is Afsluitdijk in the Netherlands where a bay has been separated from the North Sea, Figure 3. On top of the barrier, which is 32 km long, is a European highway (Deltawerken, 2010; Wikipedia, 2010).

**Generally positive:** A solid barrier may work well for a bay where the river flows are low. You can also use the top side of the barrier for transportation, thereby using the barrier for additional advantage. It is a solid and robust design that you know will be in place in case of rising water levels. The possibility to build houses close to water becomes greater when you know you have the protection of a solid barrier.

**Generally negative:** Ecosystems can be influenced to a large extent when the exchange of water becomes difficult or impossible and the water quality may get worse. The level of protection could be lower than intended e.g. because of subsidence. The construction could also give a false sense of security. It can be a costly design and the construction requires maintenance. Lack of maintenance can cause the barrier to break with huge consequences. The basin inside may also be filled if there is high flows in connecting rivers. Pumping systems may then be needed, which could be a weakness in the system if there is power failure.

**Geotechnical aspects:** Non-moveable barriers are heavy constructions where the foundation is sensitive for subsidence which can mean that intended level is not achieved. The construction needs great consideration concerning stability and subsidence and well thought through and advanced measures for the foundation.

**Information/experience:**

- Deltawerken (2010) http://www.deltawerken.com/Why-this-twist/307.html
- Wikipedia (2010) http://sv.wikipedia.org/wiki/Afsluitdijk

## 4.3 Soil embankment

**Figure 4 Soil embankment (Trelleborg Municipality, 2010)**

Soil embankment is a permanent measure that provides protection against a certain water level rise. A soil embankment can be built with geo textile fabrics, fillers and a very coarse material that prevents erosion (Trelleborg AB, 2010). The water pipes that cross the embankment must be able to be closed manually or be equipped with check valves so that no leakage occurs through the barrier (MSB, 2010a).When putting up a barrier it is desirable to have pumps, so that water flowing in from behind the barrier (e.g. through rain, sewage systems) can be pumped outside. Pumping systems require maintenance and depending on the volume of water that needs to be pumped the life length varies.

**Generally positive:** It is a relatively inexpensive measure that can relatively easily be removed or built higher. Depending on the design it can be a positive element as walking path and a positive feeling through the greenery.

**Generally negative:** Soil embankment does not suit any urban environment and there can be major consequences if an embankment fails. If measures are needed to avoid subsidence, like pillars or piles, it may be more costly and more problematic to achieve a certain level.

**Geotechnical aspects:** A soil embankment is a heavy construction and may cause subsidence which can lead to that the intended level is not achieved. The construction needs great consideration concerning stability and subsidence and well thought through and advanced measures for the foundation.

**Information/experience:**

- MSB (2010a) Swedish Civil Contingencies Agency, http://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Begransa-skador/
- Sandviken municipality has a flood protection plan: http://www.terrafirma.se/%C3%96SP%20-%20Gysinge%20bruk.pdf
- Dahlman, M. (2011) Information about Kristianstad municipality’s plans with flood protection. http://www.kristianstad.se/Upload/R%C3%A4ddning%20S%C3%A4kerhet/dokument/Skydd%20mot%20%C3%B6versv%C3%A4mningar/Nordv%C3%A4stra%20vallprojektet/Information%2009.pdf
- Trelleborg AB (2010), http://www.trelleborg.com/sv/Media/Trelleborgsvarld/Hemligheten-som-haller-Hamburg-torrt/

## 4.4 Wall of concrete or stone

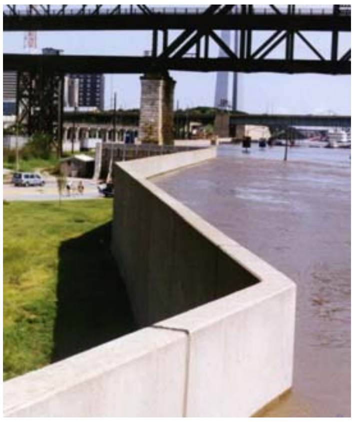

**Figure 5 In 1993 in St. Louis District (USA) a concrete wall prevented a flooding of the area, USACE (2011)**

One way to keep water out is to set up a traditional wall which can consist of concrete or stone. In connection with the construction the water pipes which cross the embankment need to have the possibility to be closed manually or be equipped with check valves so that no leakage occurs inside the barrier (MSB, 2010a).

**Generally positive:** It is a stable solution that one knows is in place and provides a secure protection provided it is maintained correctly. The risk is less that human or technical failure should occur in the acute phase. If it is a broad concrete/stone wall, it can also serve as walking path and can aesthetically fit in an urban environment.

**Generally negative:** A concrete/stone wall can depending on the design create a barrier between people and water and make an area less attractive. There can be major consequences if a wall breaks.

**Geotechnical aspects:** Possible effects of the wall are the same as for soil embankment.

**Information/experience:**

- MSB (2010a), Swedish Civil Contingencies Agency, http://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Begransa-skador/

- Sandviken municipality has a flood protection plan for Gysinge bruk: http://www.terrafirma.se/%C3%96SP%20-%20Gysinge%20bruk.pdf

- New Orleans is protected by a wall which is 200 English miles long and partly consists of concrete. In 2005, the Storm Katrina reach the city which resulted in parts of the wall breaking and it became a large-scale disaster. Experiences and lessons learned are collected: http://www.ce.berkeley.edu/projects/neworleans/report/CH_1.pdf

- About.com Architecture (2010), http://architecture.about.com/od/damsresevoirs/ss/floodcontrol.htm

## 4.5 Height adjustable wall

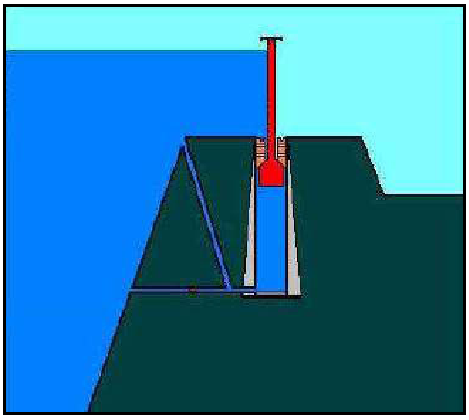

**Figure 6 Height adjustable wall (Flood barrier, 2011)**

An alternative to permanent walls, which also do not need people's immediate response, is a structure that raises automatically at high tide, creating a protection, Figure 6. There may be several different designs that work with the same basic principle, i.e. the embankment is raised automatically by the rising water (Terra Firma, 2008). In connection with the construction the water pipes which flow across the embankment need to have the possibility to be closed manually or be equipped with check valves so that no leakage occurs inside the barrier (MSB, 2010a).

**Generally positive:** It is a temporary solution that does not need (acute) human intervention to function. It also works without electricity. At low tide the construction possibly does not need to be visible and can also be aesthetically appropriate to have in an urban environment.

**Generally negative:** The design requires continuous monitoring and maintenance to maintain the function.There can be major consequences if the wall fails. As a vertically adjustable wall it may be assembled in sections, and thereby it may leak in the joints. It is also uncertain how well it works in a cold climate and with icing. Electrical wires might be useful to de-ice the construction.

**Geotechnical aspects:** This could also be a relatively heavy construction that can lead to subsidence or trigger a landslide.

**Information/experience:**

- MSB (2010a), Swedish Civil Contingencies Agency, http://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Begransa-skador/

- Terra Firma (2008), http://www.goteborg.se/wps/wcm/connect/4fedc300421651cc936ef73d2a09bb7a/Extremt+v%C3%A4der+Tepor%C3%A4ra+skyddsvallar.pdf?MOD=AJPERES&CONVERT_TO=URL&CACHEID=4fedc300421651cc936ef73d2a09bb7a

## 4.6 House as floodwall

Figur 7 Venice (Photo R Bergman, 2009)

Figur 8 Venice (Photo: R Bergman, 2009)

One way to build near the water is to construct the house foundation so that it can serve as protection against high waters, e.g. in Lauenberg Germany or Venice Italy, Figure 7, Figure 8. When rebuilding or constructing a new house it can be built to cope with water by adjusting the first floor to either be flooded or resist water. Between buildings so called twietes (alleys) can been constructed with stairs that make it possible for people to get down to the water both at high and low water level. The water pipes which exit outside the buildings need to have the possibility to be closed manually or be equipped with check valves so that no leakage occurs through the barrier (MSB, 2010a).

**Generally positive:** It is a measure that combines an attractive location for buildings with a protection against water level rise. The measure with it's twietes creates proximity to the water at both low and high tide. At low tide one could have walking paths along the foundations. It is a stable solution with stone and concrete, and with good maintenance it has generally a long life.

**Generally negative:** If special measures aren't taken to raise the flexibility of the construction it is not flexible. That is, like walls, barriers and other complex solutions it can often not (in a simple way) retrospectively be adapted to changing conditions such as climate change. It could be possible to build a wall between the houses in the alleys to further create a higher limit for water protection. Periods with frequent high water can possibly make the foundations and walk path covered with algae and other aquatic organisms that may make the area at low tide less attractive.

**Geotechnical aspects:** Depending on the weight of the house landslides can be triggered in the same way as with embankments/walls, because of increased load on the ground. As for all buildings the construction's foundation is dependent on the soil's properties and complex solutions with high foundation costs might be needed.

**Information/experience:**

- MSB (2010a), Swedish Civil Contingencies Agency, http://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Begransa-skador/
- Manojlovic N., Pasche E (2008) http://library.witpress.com/pages/PaperInfo.asp?PaperID=19304

## 4.7 Regulate watercourses with dams

**Figure 7 A smaller dam that can regulate the water (Willem Vervoort, 2010)**

Small dams can be used to control small streams. For some cities and areas, small rivers' water supply can play a role in the flood problem and therefore it may be easier if the stream flow temporarily could be stopped upstream. Both smaller and bigger watercourses can be regulated with dams to decrease the possibility of floods in areas down stream.

**Generally positive:** One can be in control of the water and regulate it after an upcoming situation.

**Generally negative:** A dam needs maintenance and control. Regulating the water can give a negative impact on the surrounding natural ecosystem. Space is needed upstream the dam to accumulate the water. There is also a possibility that the dam will fail.

**Geotechnical aspects:** A pond may be of very different sizes. The dam construction must be adapted to the prevailing geotechnical conditions. The function of the pond, that is to stop the flow or release water results in fluctuation of water levels upstream and downstream of the dam. This fluctuation may affect soil stability negatively. See the geotechnical aspects on page 10.

**Information/experience:**

- Boyer D. (2009)
  http://www.wpuda.org/publications/connections/hydro/Chehalis%20River.pdf

## 4.8 Temporary protection

**Figure 8 Temporary pallets (Geodesign AB, 2010)**

**Figure 9 Tube wall with air bags (Geoline Ltd. 2011)**

Temporary protection can be a complement to permanent measures and also be an option if the land is not suitable for heavy constructions. It can also be a cheap solution. There are several different types of temporary barriers, for example pallets Figure 8, sacks of soil, smaller soil embankments and tube walls with air bags Figure 9 (Terra Firma, 2008). Choice of technology can depend on the expected water level, materials available within the required distance, conditions in the foundation and extent of the dike (MSB, 2010a). The protection can either be planned in advance, with a storage that one knows will fit on certain routes, or one could contract with someone who carries the protection to site, and possibly build up the dikes when necessary (Terra Firma, 2011). When putting up a barrier it is desirable to have pumps, so water flowing in from behind the barrier (e.g. through rain, sewage) gets outside.

**Generally positive:** It is a relatively inexpensive measure that does not leave a permanent change to the environment. Since it is used for short periods it does not wear as much as a permanent barrier and may possibly be more easily to repair when not in use.

**Generally negative:** It may take time to bring up the measure and human fault can cause the barrier to fail. It is possible that a temporary wall can't handle high water levels during a long period. If it is necessary to often set up a temporary barrier the running costs and emissions associated with the build up and disassembly can be relatively high.

**Geotechnical aspects:** Lightweight temporary measures are a better alternative to permanent soil embankments, but it depends on the geotechnical conditions. Heavier alternatives, like sand bags, can contribute to causing a landslide.

**Information/experience:**

- MSB (2010a), Swedish Civil Contingencies Agency has a list of different methods. http://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Begransa-skador/
- Terra Firma (2008),http://www.goteborg.se/wps/wcm/connect/4fedc300421651cc936ef73d2a09bb7a/Extremt+v%C3%A4der+Tepor%C3%A4ra+skyddsvallar.pdf?MOD=AJPERES&CONVERT_TO=URL&CACHEID=4fedc300421651cc936ef73d2a09bb7a
- Åsele Municipality got help from Aqua Barrier to temporary protect with pallets. http://www.geodesign.se/old/seaqasele.shtml

## 5 RESILIENCE

Resilience means solutions where the system during a period of time can be allowed to be affected by an adverse event and then recover to it's normal capacity. One example is that we can allow water to enter an area during a limited period and be affected by the disturbance. With a good resilience the area affected can quickly return to its original state after the disturbance.

This section provides examples of solutions that let areas be affected during a limited period. It can be done in various ways, for example by buffer areas that have flooding surfaces and / or design the most worthy objects so that they are not adversely affected in case of water exposure. This section provides examples of several different types of measures that can be used to create resilient solutions. A combination of different measures can give the most effective and sustainable solutions. The most sustainable mix of action solutions is area specific.

Depending on the foundation conditions, several of these measures, like the resistance measures described in the previous section, require large, complex and well thought out foundation measures, and thus also involve significant costs.

### 5.1 Pole houses

**Figure 10 Pole house (Inhabitat, 2010)**

**Figure 11 Pole house (John Koch, 2011).**

Houses can be placed on piers so that they can get close to the water without being affected by water level fluctuations. The measure requires that the areas behind are planned to cope with the flood and that they can return to their original situation after the disturbance. That is, the measure protects the building itself, but is part of a resilient solution for an area. The houses on piers can be constructed so that they always stand in water or so that they periodically have free land under. These designs require that the foundations / cornerstones are adapted to withstand anticipated conditions. Alternatively the house is constructed so that water can not reach the foundation. The buildings can be designed so that they stand on a platform with pillars or have piles that are built into the very foundations (Pole Houses, 2011). With various modifications they can be performed in both cold and hot climate (Inhabitat, 2010c).

**Generally positive:** With well thought through planning of an area houses can be placed on poles and create an aesthetically interesting and exciting development of a city. Houses on poles allow the water to fluctuate freely. Transportation systems can be adapted to both boat traffic and bridges. From a tourism point of view it may be a positive development of a city.

**Generally negative:** It requires maintenance, particularly if the structures are affected by salt water. At low tide the field can be dull, reek, attract vermin and become waterlogged. It is not a flexible solution that, in a simple way, can adapt to changing circumstances in the future. The design must also be sized to cope with cold climates so that ice movements, that may damage or break the piles, are avoided. The cost to minimize the risk can be high and insurance on the house may be high because the risk seems greater than that of traditional buildings. Transportation to and from buildings must operate at different water levels and the VA system has to be constructed in a sustainable manner. The construction is not suitable for areas with high waves.

**Geotechnical aspects:** Depending on the foundation conditions significant foundation measures might be required and thus also a large budget. The foundation construction must be able to withstand variations in water level.

**Information/experience:**

- Pole Houses (2011), http://www.polehouses.com/index.cfm?fuseaction=page.display&page_id=19
- Inhabitat (2010c), http://www.inhabitat.com/2005/09/28/pole-houses/

## 5.2 Floating buildings

**Figure 12 Floating house (Inhabitat, 2010)**

**Figure 13 Floating house in Maasbommel (Gouden Kust, 2011)**

Instead of preventing water from reaching the buildings we can accept it and allow the buildings to float. There is a Dutch project in Maasbommel with houses that either float constantly or float up when there is a high water level, figure 15 (Kengen, 2011). There are several companies with design and technique for floating buildings. One technology for the measure is watertight basements which serve as the lifting force. The houses could be anchored at pillars, with chains or cables of rubber that can be extended as appropriate. Instead of the watertight basement it is possible to have houses standing on floating platforms (Svenska Sjöhus, 2010).

**Generally positive:** Many different kinds of buildings can be built on floating platforms. The solution allows the creation of a very close interaction between water and development of a city. The solution is also flexible and can adapt to unanticipated water level rises. If there is a problem with a floating house it does not create problems for the entire city.

**Generally negative:** A risk with floating houses is that the floating platform may break with the risk that the house sinks. The insurance on the house can be high due to that the risk seems higher. Transportation to and from buildings must operate at different water levels and the water and sewage system must function. The construction doesn't suit areas with high waves.

**Geotechnical aspects:** This measure has virtually no negative impact on soil conditions. Depending on the type of structure, various foundations are required and thus costs can vary. The security against landslides in the surroundings must be satisfactory so the buildings won't be affected secondarily.

**Information/experience:**

- Kengen (2010), http://www.verenigingbwt.nl/ufc/file/bwti_sites/028e4669606d529492fc11fc2a11ae1f/pu/W1_8_maasbommel_floating_houses_22november2007.pdf

- Svenska Sjöhus provides ideas on different floating facilities, http://www.svenskasjohus.com/index.php?option=com_content&view=article&id=124&Itemid=144&lang=sv

- Metrohippie have included a film sequence of the construction, http://metrohippie.com/as-modest-mouse-sings-float-on/

- Examples of floating roads/buildings from Dutch Docklands, http://www.dutchdocklands.com/page/70

- Inhabitat (2010a), http://inhabitat.com/2010/06/23/six-flood-proof-buildings-that-can-survive-rising-tides/

## 5.3 Buildings that can withstand water

**Figure 14 A beach house (Monolithic, 2011)**

**Figure 15 Garage in the beach house (Monolithic, 2011)**

One can construct buildings that are either wet or dry protected. Wet protection means that the basement is allowed to be flooded to a certain level. One uses waterproof materials and moves some sensitive equipment to a higher level. There are houses designed to withstand a lot of water by adjusting the first floor to flooding, see figure 16 and figure 17 (Monolithic, 2011). With dry protection water is prevented from entering the building (Ander H. et al., 2009). The difference to house as floodwall is that this measure only protect it self and isn't a protection for a whole area.

**Generally positive:** With dry protection the basement can always be used.

**Generally negative:** With dry protection the water outside may not exceed a certain level. If the water level difference is too high between inside and outside there is a possibility that the house floating force becomes too great. To avoid this, dimensioning, based on expected water levels, should be performed.

**Geotechnical aspects:** The houses are heavy constructions that in itself allow water to flow into the ground floor (garage, etc.). The land around is also allowed to be flooded by water. Just as the option of a soil embankment, etc., it involves risk of subsidence and landslides which mean that special foundation measures might be required.

**Information/experience:**

- Monolithic has a example of a houses built to withstand water level rise among other things, http://www.monolithic.com/stories/beach-front-homes-building-for-wind-water-and-corrosion

- Pasche E. (2009)

## 5.4 Permeable asphalt/coating

Figur 16 Permeable asphalt (Ramsey-Washington Metro Watersheld District, 2011)

Figure 17 Permeable coating (Paving Expert, 2011)

By using permeable coating water may be infiltrated into the ground and stored in a reservoir, and then slowly percolate down deeper in the soil (Pasche E. 2009). If many private property owners in a municipality avoided construction of hard surfaces on their site or use permeable coating it would reduce the load on the storm water system (Swedish Board of Housing, Building and Planning, 2010b). The infiltrated water could also be transported to other sites and storage areas. The measure can alone, or together with other measures, constitute so-called local disposal of surface water (Swedish LOD). How well the method is functioning, and how it affects other functionalities, depends on local conditions, design, management and technology choices (Bäckström, 2005; Miljösamverkan, 2004).

**Generally positive:** Permeable asphalt is similar to conventional asphalt and therefore it makes no difference aesthetically.

**Generally negative:** There may be problems with the life span of the construction because sediment can be trapped in the pores and prevent water to percolate down. The measure is suitable to take care of moderate rain, but not extreme rainfall.

**Geotechnical aspects:** A result of urbanization is usually that the groundwater level is lowered permanently due to hard surfaces. In populated areas with sensitive soil the permeable asphalt / coatings can reduce the risk of subsidence. The permeability facilitates the percolation of water into the soil layers so that the water table more easily can be maintained at original level. Because of worse infiltration effects in clays and fine grained soil this measure has not the same effect in this kind of soil as it has in coarse grained soil. The later are also less sensitive to subsidence. The measure is not suitable in or near slopes with poor stability, since rain water more easily can infiltrate into the soil layers with elevation of groundwater pressure as a result. A higher ground water in the soil layers in combination with slopes can result in poor stability, leading to a landslide.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b). http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf

- Pasche E. (2009)

- Green Road, www.greenroad.net

## 5.5 Subsurface transportation/management of storm water

**Figure 18 Infiltrating ditch (Sustainable Storm water Management, 2010).**

Shallow ditches can be used to infiltrate water into the soil and either be stored on site or be led away by pipes (filter drains). The ditches are covered with permeable material, such as grass (filter strips) or stone. Some trenches can be excavated and filled with permeable material to form a reservoir (filter trenches) (Pasche E. 2009). The measure can alone, or together with other measures, constitute the so-called local disposal of surface water (Swedish LOD).

**Generally positive:** There is a purifying effect of the water that is filtered into the ground.The measures are economically advantageous for the infiltration and delay of storm water (Swedish Board of of Housing, Building and Planning, 2010b).

**Generally negative:** In heavy rain the soil becomes saturated and the function will stop working for the continued influx of water.

**Geotechnical aspects:** As for permeable coating these measure can lead to a lower risk of subsidence. These measures, however, can locally increase the groundwater pressure too much, which can lead to poor stability in any nearby slopes. If stability is poor, storm water can be headed down in tubes and pipes away from the sensitive area.

**Information/experience**:

- Swedish Board of Housing, Building and Planning, (2010b). http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf
- Pasche E. (2009)

## 5.6 Surface transportation/management of storm water

**Figure 19 Surface transportation (BizzBook, 2010)**

There may be small diversion/conveyance structures along streets, walking paths, between buildings, etc. to get storm water to areas that can dispose of it (e.g. to a delay magazine, infiltration surfaces, etc.) (Pasche E. 2009). It can be difficult to plan green surfaces in a city, because of lack of space and because of topography. In such situations, storm water channels are advantageous (Swedish Board of Housing, Building and Planning, 2010b). For some situations the water transport system also needs culverts for diverting water through road embankments. Roads can be constructed to serve as a transportation channel in the extreme events when it is needed (SPUR, 2011).

**Generally positive:** The transport system can be constructed in various sizes and be adapted to the area's needs.

**Generally negative:** The system may take up much space. Material can also plug culverts and narrow passages.The system requires frequent and ongoing monitoring and maintenance.

**Geotechnical aspects:** Leaking surface lines or clogged open lines can lead to the storm water overflowing out over an area, which can lead to increased groundwater pressure in a slope area with poor stability against landslides. Lighter surface lines can be a beneficial solution for transporting storm water to areas that are better suited to handle large amounts of water.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf
- Pasche E. (2009)
- SPUR (2011), http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

## 5.7 Retention reservoirs

**Figure 20 Storm water pond in Växjö, Sweden (Veg Tech AB, 2011)**

**Figure 21 Storm water pond with art (Göran Nilsson, Movium, 2011)**

Small reservoirs can be designed to take care of storm water for a few hours. In combination with drainage pipes water can be infiltrated (Pasche E. 2009; Swedish Board of Housing, Building and Planning, 2010b). Also bigger reservoirs can be constructed to be able to store storm water during a period of time (SPUR, 2011). The measure can alone, or together with other measures, constitute so-called local disposal of surface water (Swedish LOD). Many small ponds may be needed to get an effect.

**Generally positive:** They are relatively cheap to build and with the right design also relatively easy to maintain.

**Generally negative:** A possible negative effect is that it may require large areas.

**Geotechnical aspects:** A reservoir with impervious bottom and with frequent discharge pipes may have little influence on the surrounding soil. However, the load from a heavy reservoir located inappropriately close to a slope can cause landslides. The construction needs to be adapted to local geotechnical conditions and measures might be needed to avoid subsidence and landslides. There is also a risk of extrusion (pushing up) when the reservoir is empty. In populated areas with subsiding prone soil the measure with local infiltration of storm water can reduce the risk of subsidence. These risks are in most cases not large.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf
- Veg Tech AB (2011), www.vegtech.se
- Pasche E. (2009)
- SPUR (2011), http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

## 5.8 Multifunctional area/ Flooding area/ Green surface

**Figure 22 An area that can be used to collect storm water (Courtesy Fairfax County, 2011)**

**Figure 23 A park with a small stream in Lomma, Sweden (Lomma Municipality, 2011)**

A flooding area could be an area that is allowed to be flooded without permanently changing the area's main function (Pasche E. 2009). You can select areas in a town that can be allowed to be flooded if the water levels rise or it rains heavily. The surface can be either a natural green area that normally is used for other purposes (park, soccer field, etc.), but if needed may be infiltrated with water to a certain degree of saturation. Infiltration works better in sandy soils than clay soils and having plants on the ground makes the water more easily drained and prevents water logging (Swedish Board of Housing, Building and Planning, 2010b). Surfaces can also be designed to serve various purposes, both with and without water, e.g. underground parking lots (SPUR, 2011). The measure can alone, or together with other measures, constitute so-called local disposal of surface water (Swedish LOD).

**Generally positive:** It is an area that can fulfil two or even three purposes. If it is a green area in a city the greenery is considered to be mostly positive, it also contributes to a more consistent climate and can compensate for temperature variations. The third purpose is that you learn to live with water by seeing the impact of precipitation in the area.

**Generally negative:** To dispose water on surfaces that would otherwise be used for other things prevents the normal function of the surfaces, e.g. park or football field for some time after the flooding. There is also a possibility that the storm water is polluted and therefore might leave pollutions on the surface or in the soil after the water has retreated from the area (SPUR, 2011).

**Geotechnical aspects:** The geotechnical risks and advantages are much the same as for reservoirs that are described in previous section.

**Information/experience:**

- Dahlman M. (2011), Kristianstad municipality has in their physical planning discussed flooding areas.http://www.kristianstad.se/upload/Bo_bygga/Samhallsplanering/PDF/Kristianstad%20v%C3%A4xer/FOP_Forutsattningar_sid26_40.pdf

- Inhabitat (2010b). A flooding pond has been constructed in Rotterdam. http://www.inhabitat.com/2009/11/30/waterpleinen-rain-reserviors-a-dynamic-public-spaces/

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf

- Pasche E. (2009)

- SPUR (2011) http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

## 5.9 Green roofs

**Figure 24 Green roof (Scholtens Roofing, 2010)**

**Figure 25 Green roof in Sydney (Water Sensitive Urban Design, 2011)**

Green roofs help to reduce storm water runoff. They also reduce spreading of contaminants. Individuals can use green roofs on their houses and sheds. It is part of the LOD technique (local disposal of water) (Swedish Board of Housing, Building and Planning, 2010b; Pasche E. 2009).

**Generally positive:** More greenery can give a positive feeling to the residents. In winter the roofs provide insulation and in summer they can reduce overheating.

**Generally negative:** Plants can be unreliable and are affected by the surrounding environment. Their life length is uncertain and they require maintenance.

**Geotechnical aspects:** The building in it self must of course be situated in a stabile way.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf
- Veg Tech AB (2011), www.vegtech.se
- London Climate Change Partnership (2006)
- Pasche E. (2009)

## 5.10 Land plants

**Figure 26 Design of Helsinki (Helsinki Municipality, 2010)**

Forest and plants can, under the right conditions, help to absorb water and stabilize the soil. Both the individual homeowner and the municipality may contribute to the LOD technique (local disposal of water) by planting more trees and plants and avoid the use of impervious paved surfaces (Swedish Board of Housing, Building and Planning, 2010b).

**Generally positive:** More greenery in a city is considered to be mostly positive. It also contributes to a more consistent climate and can compensate for temperature variations.

**Generally negative:** Plants can be unreliable and are affected by the surrounding environment. The life length is uncertain and the plants require maintenance.

**Geotechnical aspects:** Land plants are a measure that doesn't affect the geotechnical conditions. Land plant's roots bind the soil and can usually decrease erosion.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf
- London Climate Change Partnership (2006)
- Veg Tech AB (2011), www.vegtech.se

## 5.11 Wetlands

**Figure 27 Board walk in wetland area (Chesco, 2011)**

**Figure 28 Wetland in USA (National Park Service, 2011)**

Wetlands are relatively shallow, vegetated surfaces that constantly keep large amounts of water and have the capacity to temporarily delay water. Storm water pipes and soil drainage may be headed to the wetlands. The area can also receive sludge and purify water before it flows out of the wetland (Swedish Board of Housing, Building and Planning, 2010b) (Pasche E. 2009). Wetlands can be a natural barrier between a city and open water (SPUR, 2011).

**Generally positive:** Wetlands also serve as a nutrient trap and thus help to reduce problems of eutrophication. The areas act as pollution traps and can enhance biodiversity. They also contribute as a recreational area.

**Generally negative:** Wetlands require much space and as a barrier between water and a city much area is needed.

**Geotechnical aspects:** Wetlands are located on low lands adjacent to rivers and other water areas. They themselves don't increase the probability of landslides. Conversely, they can improve conditions at other locations by letting water accumulate in the wetland instead of possibly being transported to places with unstable soil.

**Information/experience:**

- Swedish Board of Housing, Building and Planning (2010b), http://www.boverket.se/Global/Webbokhandel/Dokument/2010/Mangfunktionella_ytor.pdf

- Pasche E. (2009)

- SPUR (2011) http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

- Examples in Sweden, (Swedish Board of Housing, Building and Planning, 2010b):
  - *Myrsjöns våtmarkspark* Nacka municipality
  - *Vallentuna våtmarkspark* Vallentuna municipality
  - *Slottskogens dammar* Göteborgs municipality
  - *Vattenparken* Enköping municipality

# 6 DOMESTIC MEASURES

## 6.1 Structural

### 6.1.1 Small pump in the home

Having a small pump at home pumping water out faster than water flows in can be an important safety measure. However, one should think of the pressure between outside and inside so that the water-saturated soil outside doesn't press too much at the empty cellar floor and defects the floor. One should check if the floor is well adapted to withstand water pressure before installing a pump (MSB, 2010b) (Aviva, 2011).

### 6.1.2 Barrier around windows, doors and air intakes

Barriers that are fitted and ready to be put in place at threat of flooding (Aviva, 2011).

### 6.1.3 Silicone sealant around windows, doors and other openings

The small gaps may need to be sealed so that no water seeps into under e.g. a door. However, if the water is deep outside the house (>1m) the water should be allowed to enter if the pressure could otherwise destroy the building (Aviva, 2011), but this depends on the construction of the house.

### 6.1.4 Beams can be protected by chemical moisture protection

The chemical reduces the risk that water is sucked into the beam (Aviva, 2011).

### 6.1.5 Replace materials in the home with water-resistant material

Particle board can be switched to concrete or treated wood, carpets to tiles, plaster to lime or concrete. The interior of a kitchen and bathroom can be replaced with plastic or steel. Wood doors and window frames can be replaced with plastic and isolation material that doesn't rot (Aviva, 2011).

### 6.1.6 Unidirectional valves for sewage in house/stopper for the drain

If flooding threatens you can put plugs for drains and toilets so that no water flows in that way. The stopper can be a wooden plug or an expanding rubber seal. You can also install one-way valves (MSB, 2010b) (Aviva, 2011).

### 6.1.7 Place some objects in secure places

Some sensitive items do not need to be in the basement/ground floor. Outdoor furniture and other things can be moved so that they do not float away with the water and cause plugs in passages where water flow is needed (MSB, 2010b). Important documents and other sensitive material can be placed on a higher area (MSB, 2010b) (Aviva, 2011).

### 6.1.8 Electrical outlets can be placed higher up

(Aviva, 2011)

### 6.1.9 Raise the floors

(Aviva, 2011)

#### 6.1.10 Permeable asphalt/coating in the driveway

(Swedish Board of Housing, Building and Planning, 2010b)

## 6.2 Non-structural

### 6.2.1 Keep track of water levels and weather forecasts

If you keep track of what normal water level is it will be easier to see when the water rises. To know if the area you live in has been flooded earlier can give you a chance to prepare yourself better. During radio/TV weather forecasts, warnings can be read which can be important information (MSB, 2010b).

### 6.2.2 Home insurance

It could be important to review the terms of the home insurance and see if flood damage is covered. The damages should be photographed and receipts for purchases related to the injury should be saved (MSB, 2010b).

### 6.2.3 Turn off power and gas

When flooding occurs you can mitigate potential impacts by turning off power and gas (MSB, 2010b).

### 6.2.4 Be careful with excavations and dirty water

Pits with water and other cavities, unstable soil and dirty water can cause injuries if you are not careful when a flood hits the area (MSB, 2010b).

### 6.2.5 Have supplies at home/be prepared for evacuation

If you live in an area where there is a risk of natural disaster you can be prepared and have a box of essential supplies tucked away. You can have toiletries, first aid and medicines. A radio, flashlight and batteries are practical to have access to. Faced with a possible evacuation, these items are packed in a bag together with important documents. In the home there can also be canned food and other foods with long durability, maybe also a camping stove and fuel. Blankets, rain gear, boots, candles and matches can ease the situation. Water cans may need to be replenished in order to secure drinking water (MSB, 2010b). If food or other things that can be ingested gets in contact with water due to flooding, it must be boiled before consumption. Medicine that has been in contact with water may need to be discarded to avoid risks posed by contaminated water.

More tips of what to do in case of flooding:

- MSB, http://www.msb.se/sv/Forebyggande/Sakerhet-hem--fritid/Skydda-dig-mot-oversvamning/
- U.S. Department of Homeland security, http://www.fema.gov/hazard/flood/fl_after.shtm

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