Discovering climate change with maths

Flooding in Urban Areas

The hydrological cycle is affected by urbanization (Appendices I, II and III). In cities most of the ground is impermeable due to the high number of buildings, pavements, roads and cars. These objects have consequences for water drainage systems. High urban density leads to soil compaction which reduces infiltration capacity, as well as to loss of natural retention capacity in sites such as wetlands. Further consequences are reduced surface storage capacity and decreased evapotranspiration.

Prevention and response

Drainage systems are an essential feature of urban planning. Some of these systems will be as old as the buildings in the city and will have served the city for centuries, whilst in newer neighbourhoods they are likely to have been installed with state-of-the-art materials and design knowledge. Drainage systems have a maximum water transportation capacity (the rate at which water can be dispersed) and a maximum water storage capacity (the amount it can hold within a location). The overloading of drainage systems leads to flooding, posing serious risks to human safety, public infrastructure and private property. During flood events, there can be a risk of contamination of the run-off water through heavy metals, oil or sewage. Providing drinking water to people's homes becomes an even bigger challenge when an area is submerged, especially if this is nearby to drinking water storage facilities. The far reaching range of impacts means that it is essential for agencies from many areas to communicate and collaborate, in order to provide an integrated response to the risk.

Case

As a low-lying coastal town with many canals and rivers, the city of Malmö faces big challenges managing water flow. In the long term, there is the threat of sea level rise due to climate change: as the global temperature increases, the water molecules move more quickly, because they need more space, causing the volume of the water to increase. Additionally, the overall water volume in the oceans is increasing due to the melting of arctic ice. As a consequence we can expect a global sea level rise of 0.26 - 0.98 m by the end of the century (Stocker et al., 2013, p. 25). In Malmö, sea levels are expected to rise by 0.22 - 0.66 m by 2100 (Malmö Stad, 2012, p. 18).

What is climate change adaptation?

"Climate change adaptation means that contrary to reducing greenhouse gas emissions, focus is instead on introducing measures that either alleviate or prevent the effects of climate change or derive some benefit from possibilities it might bring" (Malmö Stad, 2012, p. 4).

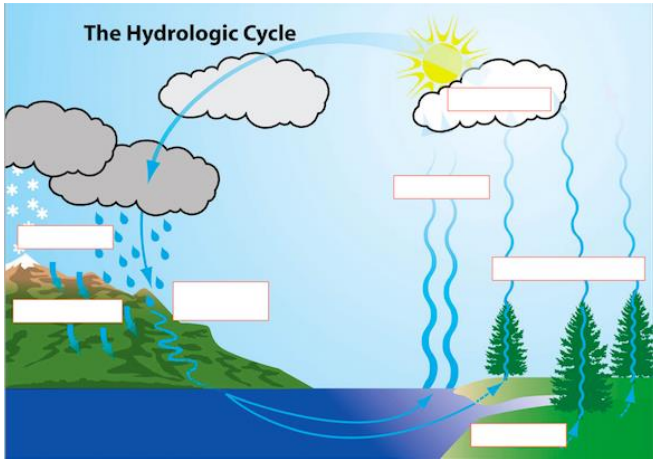
With the onset of climate change we can also expect that extreme weather events such as storms to be likely to happen with more frequency, intensity and variability. Because warmer air is able to hold more water, heavier rainfall is anticipated. For the city of Malmö, these changes in a global climate can cause problems of storm downpours leading to flash flooding. As a recent example, on the 30th and 31st of August (2014) 100 millimetres of rain fell in just

36 hours, double the amount that normally falls over the whole of August (The Local, 2014). As of 2010, the highest recorded rainfall in Malmö over a 10-min period was 21mm and the highest recorded rainfall over 30min period was 41mm (Bengtsson & Milloti, 2010).

Malmö's authorities are implementing a Climate Adaptation Strategy to prepare the people and city's infrastructure for the onset of climate change. The strategy's main aim is to reduce the impact of the threats of sea level rise, extreme precipitation and heat waves (Malmö Stad, 2012). One way this is being done is by increasing the amount of vegetation in low-lying areas and river banks, which can absorb collected water whilst also serving the purpose of cooling the city during hot spells. Furthermore, the municipality is working on protecting sites that are prone to flooding such as tunnel entrances, the water and sewage system and underground car parks. Key infrastructure elements such as electricity and telecommunication plants are also prioritized. A key component of the Climate Adaptation Strategy is the importance of collaboration and communication between relevant agencies (such as the Real Estate Office, Social Resource Department, Environment Department, Water and Waste municipality Authority and so on).

Alongside all the measures implemented by the municipality, a resilient city also needs its citizens to act responsibly within the community, which means active contribution to city planning and development, especially on the neighbourhood level; e.g. the Building-Living Dialogue Project for the Western Harbour (Malmö Stad, 2012, p.10; for more examples see, p. 25-26).

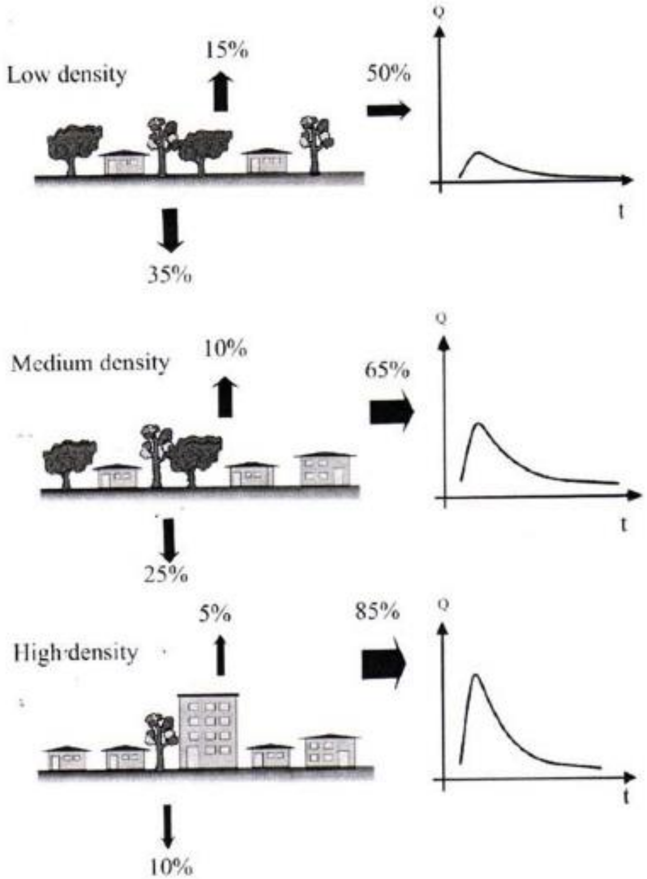
Appendix I: The Hydrological Cycle



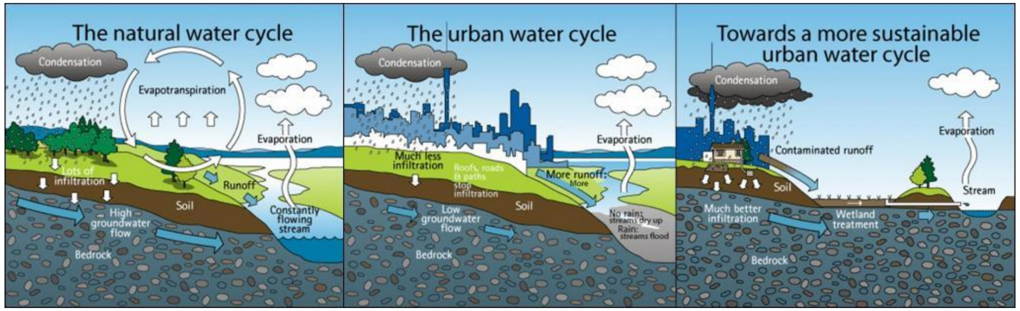
Source: SSWM, 2012.

Appendix II: Effects of urbanization on urban storm-water run offs

Source: Delaware River Basin Commission. http://www.state.nj.us
Source: based on Butler & Davis, 2004, in Parkison, 2005: 5



Appendix III: Natural, the urban and a more sustainable urban water cycle in comparison



http://www.sswm.info/category/implementation-tools/wastewater-collection/hardware/surface-runoff/stormwater-management

Appendix IV: Maths solutions

1a) 12 hours
Either graphical: *f(t) =0 => t=0 v t=12*
or calculate: *f(t) = 0 =* $-\frac{1}{2} * (t-6)^2 + 18$

1b) Integration
$f(t) = -\frac{1}{2} * (t-6)^2 + 18 \;=\; -\frac{1}{2} * t^2 + 6t$
$F(t) - \frac{1}{6}\, t^3 + 3\, t^2$ -> integrate from 0 to 12

=> 144 [0.1 mm] = 1440 mm $* \frac{1\text{ m}}{1000\text{ mm}}$ = 1.44 m = $1.44\,\frac{\text{m}^3}{\text{m}^2} * \left(\frac{1000\text{ dm}^3}{1\text{ m}^3}\right)$

= $1440\,\frac{\text{dm}^3}{\text{m}^2}$ = $1440\,\frac{\text{l}}{\text{m}^2}$

1c) The water would be standing 1440 mm = 1.44 metres high in the container.

2a) $g(t) = 10\,\frac{l}{h * m^2}$ -> integrate

$G(t) = 10\,\frac{l}{h * m^2} * t$, for t=12 => *G(12) = 120* $\frac{l}{m^2}$

2b) F (12) - G (12) = 1100 mm
The flood is 1.1 metres high.

3a) Binomial Function: $P\,(x \geq r) = \binom{n}{r} * \,p^r * (1-p)^{n-r}$, for n=100, r=1, p=0.01
P = 0.63 = 63 %

3b) p=0.014
P = 0.76 = 76 %

Appendix V: Suggestion for interdisciplinary collaboration between Maths and Social Science

To link this class with real-life decision-making, we highly recommend combining it with a special lesson in social sciences class. A brief outline is provided below.

At the town-hall meeting for climate change adaptation in Malmö, a mayor (teacher) talks about challenges related to climate change (link with the maths class), about the work done by Malmö municipality and the planned measures (see Malmö Stad, 2012, p. 26 for a list of them). He/she also says that though the municipality is sure that each of the measures is necessary, they need public participation to properly allocate the available budget.

Stakeholder roles are assigned to students in groups (see Malmö Stad, 2012, p. 13 for actual stakeholders involved, but it is also advised to include NGOs and industry for learning purposes), each with a unique blend of perspectives: technical solutions or behavioural change, personal/group concerns, care for social inclusion or environmental justice etc. Each role is explained on a sheet of paper with 1-2 paragraphs: what is the role about, what they care for and what might be the measures they would be interested in.

Within their groups, students can discuss the list of measures (simple version: suggest the measures they would work with, more complicated: choose from a list) and then the group representative joins the town hall meeting and defends their point of view on the issue.

This would be followed by the discussion involving the whole class about presented decisions, e.g.:

- Are these long-term or short-term solutions?
- Would the decisions benefit the whole city or only part of it?
- Would the benefits be distributed fairly across neighbourhoods?

Finally, each student would vote on his / her three top solutions, giving scores from 1 to 3. The winners will be calculated based on the total score. Finally, the class can reflect on the issue of decision-making in times of uncertainty and urgency of climate change.

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