Deliverable 5.4.2

A planning instrument for an integrated and recipient/impact based CSO control under conditions of climate change

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Title

A planning instrument for an integrated and recipient/impact based CSO control under conditions of climate change

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Summary

Motivation

Combined sewer overflows (CSO) impair the quality of urban surface waters around the world. Future change, in particular global warming, is expected to worsen the situation further in many urban areas.

To improve the quality of urban surface waters, tools are needed to support decision makers in the assessment of CSO-related impacts and possible mitigation measures. Apart from finding solutions to current problems, it is important that these tools also allow the adaptation of these solutions to future change scenarios to be prepared for likely developments.

Objective

The present report suggests a model-based planning instrument for the assessment of CSO impacts on receiving surface waters under different sewer management and climate change scenarios. The suggested planning instrument couples a sewer and a surface water model for which boundary conditions can be changed depending on the studied scenario. The simulated CSO impact is then analysed via a coupled impact-assessment tool.

The selection of appropriate model approach, assessment guideline and scenarios depend on the local conditions regarding the sewer system, the surface water type and the relevant CSO impact. Accordingly, the report aims at giving a general overview of available models, assessment guidelines, as well as sewer management and change scenarios, which allows setting up a planning instrument for a wide range of local conditions.

How to use this report

The present report serves as a step-by-step-manual for setting up an impact-based planning instrument for CSO control:

1. Assessment of possible impacts of CSO, depending on local receiving surface water bodies (*chapter 2.1*)
2. If this assessment shows the need for a planning instrument, sewer and surface water models should be selected depending on type of impact, type of sewer system and type of surface water body (*chapters 2.2 and 2.3*).
3. Selected models need to be run, validated and possibly calibrated separately and as coupled tools (*chapter 2.4*).
4. Scenarios are defined consisting of (i) CSO management solutions, depending on impacts of CSO that should be mitigated and sewer system characteristics (*chapter 3.2*) and (ii) global or local change to be accounted for depending on the local situation (*chapter 3.1*). The instrument can be used to test sensitivity of CSO impacts to different scenarios or for concrete planning of measures, including cost (*chapters 3.3 and 3.4*).

Use of the manual is exemplified in a case study for Berlin for each of the above steps. Application of the Berlin planning instrument will be demonstrated in Prepared Report D 1.3.2, due in February 2013.

Contents

1 Approach

Combined sewer overflows (CSO) can create severe problems in receiving rivers, lakes and coastal water bodies, regarding ecosystem quality and human use. While existing legal regulations typically focus on CSO emissions, national initiatives increasingly suggest or require CSO mitigation strategies that aim at reaching a certain water quality goal in the receiving water bodies (Germany: Borchardt et al. (2001), UK: FWR (1998), Austria: ÖWAV (2007), USA: EPA (1995), Switzerland: Krejci et al. (2004)). As a result planning instruments are needed to couple sewer planning with the expected effects in receiving surface water bodies.

CSO pressure on surface waters may change due to local changes (urbanization, water use, surface water regulation, changed sewer management, etc.) or global warming (more intense rainfall events, higher temperature in receiving waters, etc.). While climate change, as well as its potential impacts, remain uncertain and direct responses to uncertain projections may not be sensible, it is important to be prepared for what may happen in the future. Following this notion, the EU project PREPARED proposes the use of scenarios to test the effect of possible countermeasures under possible climate or local change (Ashley and Tait 2011). Before implementation of concrete measures, it is suggested to test whether planned countermeasures would still work under possible climate change scenarios. Consequently, applicable CSO planning instruments should allow independent and combined evaluation of countermeasures and expected change scenarios.

The following report aims at supplying a manual to build such a CSO planning instrument for a wide range of situations, always focusing on CSO impacts in the receiving surface water. The approach of the planning instrument is outlined in Figure 1. At the heart of the planning instrument is a coupled model tool (orange boxes), which follows the series of reactions caused by a heavy rain event:

i) in a first step, the occurrence of CSO and connected overflow volumes and substance loads are simulated with a *sewer model*,
ii) in a second step, the effects of the discharged volume and pollution loads on hydraulics and water quality in the receiving water body are simulated with a *surface water model* and
iii) in a third step, the changed hydraulics or water quality in the affected surface water body is evaluated with respect to ecological status or impaired human use with an *impact assessment tool.*

To use the model tool as a planning instrument (i) expected future changes, such as local effects of global warming or increased urbanization (yellow boxes in Figure 1) and (ii) realistic CSO management options (blue boxes in Figure 1) need to be defined and translated into changes in model boundary conditions. It is suggested to use the planning instrument in Figure 1 for decision support in the following order (stopping depending on the needs of decision makers):

1. A sensitivity analysis is performed regarding different types of management options and probable changing drivers. This step allows (i) testing whether the planning instrument is actually sensitive for the present planning question and (ii) narrowing down potential management strategies to options which may cope with (changed) settings.
2. For more concrete planning, realistic solutions are combined into scenarios to find optimal measures for the (known) status quo. These concrete scenarios are compared in terms of their relative improvement of critical parameters, as well as estimated cost (green box in Figure 1). If the chosen scenarios do not meet political goals (if present), management scenarios are adapted and the model tool is rerun.
3. In a further step, optimal solutions are tested under expected change scenarios to allow preparation to a likely future. Again, several cycles of the planning instrument may be necessary to fulfil political goals.

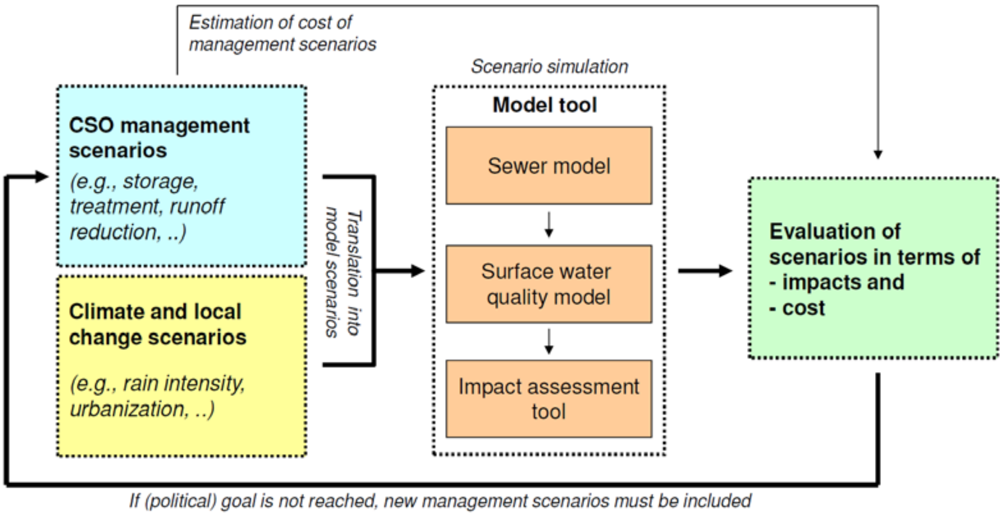


Figure 1: Schematic structure of the planning instrument. External boundary conditions (such as global warming or changed water use) are yellow, CSO management scenarios are blue, the model tool is orange and the actual output of the instrument is green.

The present report supports the reader in establishing such a planning instrument for an integrated and recipient/impact based CSO control by covering each step of the schematic structure in Figure 1. The set-up of the model tool is described in section 2, with suggested solutions for each type of impact and surface water. In section 3 a way to define scenarios regarding mitigation options and global change is suggested. To improve readability, each subsection exemplifies the general suggestions with the chosen approach for the Berlin urban water system.

The application of the Berlin planning instrument for a sensitivity analysis (point 1 above) will be demonstrated in EU Prepared Report D 1.3.2.

2 Model tool for CSO impact assessment

2.1 Immission-based impact assessment

2.1.1 Possible impacts of combined sewer overflows

Although impact assessment is the last step of the actual application of the model tool (orange boxes in Figure 1), the type of impact needs to be known to choose appropriate models and management scenarios. The identification of possible problems from CSO is the most crucial step in establishing an impact-based CSO planning instrument (or finding that no planning instrument is needed) and cannot be omitted.

Impacts from CSO can be divided into i) acute or short term impacts usually appearing after single CSO events and ii) long term impacts that follow a larger series of events. Depending on the type of the receiving water body, different impacts are expected (Table 1).

Table 1: Expected major CSO impacts in different surface water types, adapted from Borchardt et al. (2001) and Rossi et al. (2004)

	Impacts	**small streams [1]**	**medium to large streams [2]**	**regulated, slow-flowing lowland rivers [3]**	**lakes**	**sea**
short term	Hydraulic stress	✓				
	Ammonia toxicity	✓		✓	(✓)[5]	
	Oxygen deficits			✓	(✓)[5]	
	Turbidity	✓	✓		(✓)[5]	
	Temperature	✓				
	Pathogens	✓[4]	✓[4]	✓[4]	✓[4]	✓[4]
long term	Accumulation of sediments/toxins			✓	✓	✓
	Eutrophication			✓	✓	✓
	Structural deficits	✓				
	Aesthetics	✓	✓	✓	✓	✓
	Xenobiotics	✓		✓	(✓)[5]	

[1] Average runoff $Q < 0.1\ \text{m}^3\ \text{s}^{-1}$; width < 1 m; average flow speed v = variable

[2] $Q > 0.1\ \text{m}^3\ \text{s}^{-1}$; width > 1 m; $v > 0.5\ \text{m s}^{-1}$

[3] $Q > 0.1\ \text{m}^3\ \text{s}^{-1}$; width > 5 m; $v < 0.5\ \text{m s}^{-1}$

[4] only relevant if water body is used for bathing

[5] only relevant for very small lakes where CSO structures are unlikely to be approved

A more detailed overview on the different impacts of CSO is given in the following paragraphs.

Hydraulic stress can be the result of abruptly increased discharges that induce a movement of the river bed and drifting of benthic organisms. It is the main CSO-related problem in rivers of the lower mountain range (Borchardt 1992).

Ammonia toxicity is a problem when high concentrations of NH_4^+ (predominantly originating from sewage) coincide with high pH-values > 8.5 that push the acid-base equilibrium towards highly fish-toxic NH_3.

Oxygen deficits can be the result of both, the immediate degradation of organic compounds or ammonium in the water column or the delayed degradation after settling of particulate compounds to the river bed. Lacks in dissolved oxygen (DO) can influence the behaviour of aquatic organisms and lead to fish kills when concentrations are sufficiently low, exposition sufficiently long and/or frequency of occurrence sufficiently high. High temperatures and elevated ammonia concentrations intensify oxygen stress (Downing and Merkens 1957; Milne et al. 1992).

Turbidity: Negative impacts of elevated turbidity due to high concentrations of total suspended solids (TSS) have only been reported for salmonid fish and can affect their blood physiology, respiration, reproduction and growth (Bash et al. 2001).

Temperature increase due to CSO is only a problem in very small streams if rain fall occurs when the catchment surface is significantly heated, typically around noon (Krejci et al. 2004). The effects of high temperature are (i) a decrease of oxygen solubility (Weiss 1970), (ii) an acceleration of microbiological processes leading to oxygen consumption (Kalff 2003) and (iii) an elevated toxicity of several substances (e.g. PAHs, heavy metals) (Cairns et al. 1978). Moreover it can directly affect sensitive organisms (e.g., Elliott 1981).

Pathogens do not directly harm aquatic organisms but may harm humans when water bodies are used for bathing and recreation. Apart from acute concentrations after single CSO events pathogens can also accumulate in the sediments (Borchardt et al. 2003).

The *accumulation of sediments* after a longer series of CSO events can lead to clogging of the river bed and leave behind silted, anaerobic substrate conditions (Krejci et al. 2004). Some toxins like heavy metals can accumulate both in the sediment and in the food chain (Borchardt et al. 2003).

The *eutrophication* potential of CSO is usually minor to that of wastewater treatment plants or agriculture. Even so it cannot be neglected completely. Especially in flow-regulated rivers, lakes and the sea phosphorus and nitrogen loads of CSO can add significantly to local algae growth (Borchardt et al. 2003).

Structural deficits: In small streams the degradation of river morphology can be the long term effect of recurrent hydraulic stress leading to erosion and/or clogging of the river bed (Krejci et al. 2004).

Deficits of *Aesthetics* are commonly caused by solids which are obviously of sewage origin and which are of sufficiently large size to be visible to the naked eye (i.e. faecal solids, toilet tissue, condoms, sanitary towels, plastic release strips, cotton buds, etc.) (FWR 1998).

Xenobiotics like pharmaceutical active compounds (PhACs) or polyaromatic hydrocarbons (PAHs) can affect the hormonal balance of fish or have an carcinogenic effect on both aquatic organisms and humans (Meador et al. 1995). Weyrauch et al. (2010) showed that concentrations of xenobiotics in the lowland River Spree can rise significantly due to CSO. According to Birch et al. (2011) the concentration of polyaromatic hydrocarbons (PAHs) in CSO can be up to 2,000 times higher than quality standards for surface waters.

For most of the CSO impacts listed above some kind of model approach exists that can be implemented in a planning instrument as depicted in Figure 1. For example, discharge, ammonia, DO, TSS and nutrients are simulated by almost every sewer and surface water quality model nowadays in use. For assessing CSO impacts regarding temperature, pathogens and xenobiotics often more specific or self-tailored model approaches - especially for sewer simulation - are necessary. However, several case studies for such model applications have been published (Birch et al. 2011; Mccorquodale et al. 2004; Weatherbe 1994). Solely impacts like structural deficits or aesthetics are hard to quantify even with measurements and can only be modelled indirectly via hydraulics or transport of suspended solids. As a result, chapters 2.2 and 2.3 focus on model applications / approaches for short term impacts and eutrophication.

2.1.2 International guidelines for the assessment of CSO-related impacts in rivers

The assessment of CSO-related problems is often difficult, because (i) CSO impacts may not be captured in classical monitoring programs and (ii) existing long-term water quality thresholds may not be applicable for short exposures. While CSO are mentioned in the Water Framework Directive (EU 2000), no explicit approach is suggested. However there are national guidelines in the UK (FWR 1998), Germany (Borchardt et al. 2007) and Switzerland (Krejci et al. 2004), as well as scientific studies (e.g., Lammersen 1997) which give practical advice on impact assessment for different kind of ecosystems. Although most guidelines have been developed for rivers and streams they could also be applied to lakes or the sea, as long as the occurring organisms are adressed by the chosen quality standards.

All of these guidelines are not implemented by national legislation and have more th character of a recommendation than of a mandatory regulation. Anyway they are valuable tools when it comes to CSO impact assessment and the development of mitigation measures. Table 2 shows a list of existing guidelines suitable for the assessment of different types of water bodies and different possible impacts.

Table 2: National recommendations and approaches for CSO impact assessment

Short name	Country	Considered impacts	Considered water bodies	Type of threshold	Reference
BWK M3/M7	Germany	Hydraulics, TSS, DO, NH_3, nutrient loads, pathogens	salmonid spawning rivers of the lower mountain range, lower mountain range rivers, lowland rivers	concentration-duration-frequency-thresholds, annual loads, percentile thresholds	Borchardt et al. (2001; 2007)
STORM-Guideline	Switzerland	Hydraulics, temperature, turbidity/TSS, DO, NH_3, nutrient loads, accumulation of sediments, pathogens, aesthetics	small and medium streams with elevated flow speed	concentration-duration-frequency-thresholds, annual loads, annual number of exceedings	VSA (2007), Krejci et al. (2004)
ÖWAV-RB 019	Austria	Hydraulics, NH_3, DO, TSS, accumulation of sediments, pathogens, aesthetics	no specification	concentration thresholds	ÖWAV (2007)
UPM-Manual	UK	DO, NH_3, aesthetics, pathogens	Salmonid rivers, cyprinid rivers, "marginal" cyprinid rivers	concentration-duration-frequency-thresholds and/or percentile thresholds	FWR (1998)
Lammersen-approach	Germany	DO, NH_3	Salmonid and cyprinid rivers	concentration-duration-frequency-thresholds	Lammersen (1997)

Concerning acute impacts BWK M3/M7, the STORM-Guideline, the UPM-Manual and the Lammersen-approach use concentration-duration-frequency-thresholds for DO and NH_3 to take into account the highly dynamic nature of CSO events. These thresholds bear in mind that the damage caused to aquatic organisms does not solely depend on concentrations but also on the duration and the return frequency of adverse effects. The longer an organism is exposed to a certain kind of harmful situation the lower the tolerable concentration. Likewise, the same pollutant concentration leads to a higher degree of damage, the more frequently it occurs.

The Austrian guideline ÖWAV-RB 019 does not allow assessment of acute impacts in such detail. It does not specify the kind of ecosystem that thresholds can be applied to and neglects the importance of duration or return frequency of harmful conditions.

Concerning pathogens all approaches listed in Table 2 refer to the thresholds defined by the Bathing Water Directive (EU 2006) (BWD). For lakes and coastal waters that are not subject to any of the CSO guidelines, the BWD standards can be applied directly.

Apart from the guidelines listed in Table 2 there are other protocols that highlight the negative effects of CSO but are of no practical use for impact assessment. For example, the CSO Control Policy of the United States (EPA 1995) gives recommendations for monitoring and modelling of CSO but does not provide any thresholds for further impact assessment.

Most guidelines set priorities to the acute impacts of CSO since they are generally most severe. Impacts like the accumulation of sediments, eutrophication or aesthetics are only considered in some of the guidelines and proposed approaches are usually much simpler.

For instance, eutrophication of standing waters is assessed in the STORM and BWK M3/M7 guidelines via thresholds for annual nutrient loads. For a more detailed assessment of the trophic situation in a given standing water body, eutrophication indexes (e.g., by EPA in the USA or by LAWA in Germany) can be applied, which take into account several indicators, such as transparency, phosphorus or chlorophyll-A. When using indexes, typically mesotrophic or better conditions should be aimed at.

2.1.3 *Example: Acute impact assessment for the Berlin section of the River Spree*

When applying immission-based guidelines to local situations one should firstly be aware of the water body type that is looked at and secondly of the kinds of impacts that are likely to occur. In the following sub-chapter an introduction to the characteristics of the Berlin River Spree and a first pre-assessment on the expected acute CSO-impacts for the inner city river stretch will be given. It will be followed by a detailed description of the adopted assessment method for the most severe impacts. In the following the term "Berlin River Spree" refers to the 16 km long, CSO affected stretch of the river Spree that crosses the Berlin city centre from south-east to north-west (see map in Figure 2).

2.1.3.1 *The Berlin River Spree and its expected CSO-related impacts*

The Berlin section of the River Spree is a regulated lowland river (width: 50 to 70 m, depth: 2 to 3 m) mainly populated by cyprinid fish like european perch (Perca fluviatilis) or common roach (Rutilus rutilus) (Leszinski and Schumacher 2009). It has an average monthly discharge between 12 and 45 m^3 s-1 (time period: 2000 to 2010) and flow velocities between 6 and 24 cm s-1. It is affected by approximately 180 CSO outlets discharging into the River Spree and its side channels over a river stretch of 16 km. See Figure 2 for a map of the city, its main waterways, the limits of the combined sewer system and the position of the CSO outlets.

Figure 2: Map of the city of Berlin, the combined sewer system and its waterways. The River Spree crosses the city centre flowing from south-east to north-west. The light red area represents the part of the city drained via a combined sewer system. Red dots indicate the position of CSO outlets along the Spree and its side-channels.

Regarding acute impacts in Table 1, hydraulics might get critical since the discharge after CSO events occasionally rises above the natural annual high water runoff defined for rivers like the Spree in BWK M3 (2001). As shown by simulations with the sewer model InfoWorks CS (WSL 2004), the natural river discharge can be exceeded by the wet weather discharge via CSO outlets by three times. For example, on June 23rd 2010 the simulated overall CSO discharge summed up to a peak of 88 m^3/s leading to a maximum river discharge of 118 m^3/s. Nonetheless, the CSO affected stretch of the Berlin River Spree is not used for spawning and is scarcely populated by invertebrates (Leszinski and Schumacher 2009), which would suffer most from hydraulic stress. Moreover, flow speeds are still comparably low under CSO influence (~0.7 m/s for the above peak flow). As a result hydraulic stress is considered a minor problem for local organisms.

Since negative effects of total suspended solids (TSS) and turbidity have only been reported for salmonid fish no thresholds are defined for cyprinid ecosystems in any of the guidelines. Anyway, two years of continuous measurements at a river point downstream to various major CSO outlets indicate that even the goals defined by BWK M7 for comparably sensitive salmonid fish are far from being exceeded in the Berlin River Spree.

Toxicity of unionised ammonia (NH_3) is not a major issue, since pH in the Berlin River Spree is always low enough to push the acid-base equilibrium to predominantly non-toxic ammonium (NH_4^+). Within 15 years of monthly measurements fish-toxic NH_3 never reached critical levels. Further, continuous measurements over a period of two years show that NH_3

concentrations in the CSO affected stretch of the River Spree are always far from the thresholds proposed by Lammersen (Matzinger et al. 2011) (Figure 3).

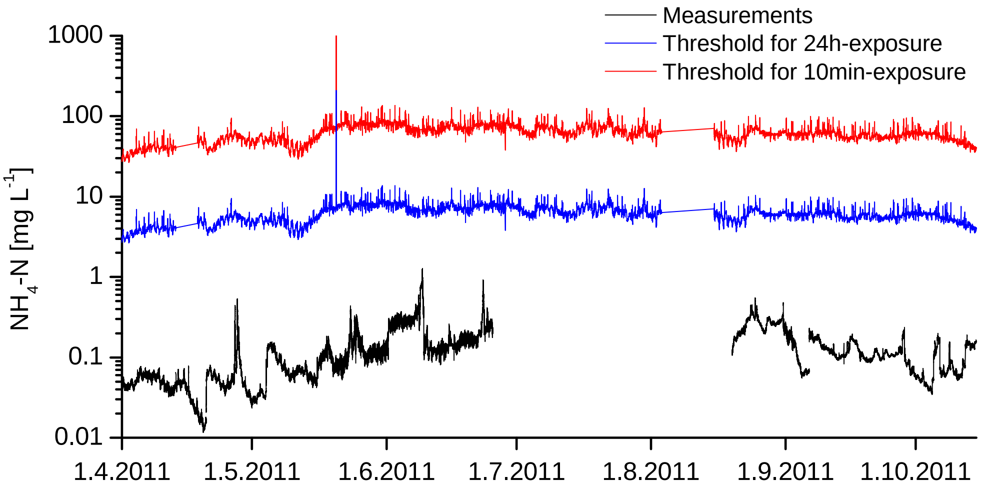


Figure 3: NH_4-N measurements from the Berlin River Spree (black line) and thresholds for exposures of 10 minutes (red line) and 24 hours (blue line). The thresholds for NH_4-N were calculated from critical NH_3-concentrations defined by Lammersen (1997) considering measured pH and water temperature.

Harmful impacts due to changes in temperature are only relevant for small or very small streams (Krejci 2004) and thus can be ruled out for the Spree.

Concerning pathogens the guidelines listed in Table 2 usually refer to the quality standards set by the Bathing Water Directive (EU 2006). The thresholds defined for sufficient water quality (900 cfu/100 mL as a 90%-percentile for E. coli in fresh water bodies) are currently not met by the Berlin River Spree at many monitoring points. However, fish-harming impacts of CSO have priority over hygienic issues, since the River Spree is mostly a shipping channel in the inner city and currently not used for bathing. Still pathogens could gain higher interest in the future.

However, continuously monitored dissolved oxygen concentrations (DO) in the river indicate critical conditions for all guidelines applicable to regulated lowland rivers like the urban River Spree (Riechel 2009a; Riechel et al. 2010).

2.1.3.2 *Adaptation and application of an immission-based guideline for the Berlin River Spree*

After preliminary studies with different guidelines (Riechel 2009b) the Lammersen-approach (1997) was applied to the CSO affected stretch of the River Spree in more detail. The protocol defines DO standards for cyprinid ecosystems like the Spree (corresponding to the regulated lowland river type) and copes with the dynamic effect of CSO via concentration-duration-relationships. The approach is based on a large series of scientific studies and aims at protecting fish and invertebrates from any adverse effects ranging from impairment of swimming behaviour to death. It does not define quality standards for long term impacts like eutrophication or accumulation of sediment but allows a detailed assessment concerning short term impacts like low DO and elevated NH_3 concentrations.

In contrast to UPM (FWR 1998) and BWK M7 (Borchardt et al. 2007) which categorize only three durations of events, the Lammersen-approach uses quasi-continuous thresholds for eight different durations ranging from 10 minutes to 24 hours. It defines thresholds not in dependency on the frequency of occurrence but allows a general return period of 7 years for short and long lasting events. An inter-event time of seven years is recommended by Mehlhart and Steltmann (1994) to allow the full regeneration of a population.

Unlike other guidelines, Lammersen takes into consideration that DO stress rises with increasing temperature and therefore specifies three different sets of thresholds for water temperatures of 10, 15 and 20 °C. For the Berlin application, the three concentration-duration-relationships proposed by Lammersen have been interpolated to obtain a specific set of thresholds for each temperature. To further adapt the quality standards to the specific needs of the Berlin River Spree, thresholds have likewise been extrapolated to temperatures above 20°C. This extrapolation was implemented in agreement with local fish experts, taking into account that water temperature in the Berlin River Spree can rise to 25°C or higher and thresholds defined for 20°C would not meet the requirements of sensitive fish. Figure 4 shows the adapted set of quality standards used for impact assessment in the Berlin River Spree. Water quality has to be considered as suboptimal, when e.g. for a temperature of 20°C, DO falls below 3 mg L^{-1} for more than 2 hours.

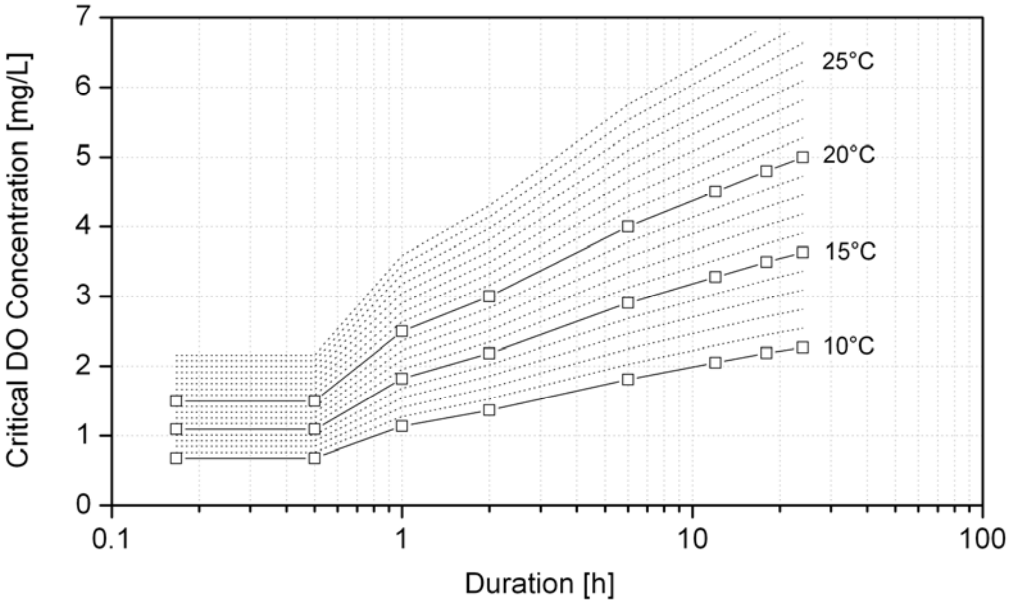


Figure 4: Concentration-duration-thresholds for different temperatures and a return period of seven years adapted from Lammersen (1997). Solid lines with eight boxes each represent thresholds provided by Lammersen for T = 10, 15 and 20°C. For better readability, values between the boxes have been linearly interpolated. Dotted lines give examples for the inter- and extrapolated thresholds for any other temperature above 10°C.

Often, not only one but various critical concentration-duration-relationships are fulfilled at the same time, i.e. a longer period of suboptimal conditions can include several short, intense DO depletions. To be able to distinguish severity of CSO impacts and allow comparison between scenarios, exposure-threshold classes of the approach by Lammersen (1997) were combined to distinguishable temporal events. A time period is classified as an event with suboptimal conditions, when for a given temperature at least one of the eight concentration-duration-criteria represented in Figure 4 is met. Figure 5 exemplifies the application of the concentration-duration-thresholds for 20°C (see upper solid line in Figure 4) to the DO concentration measured in the Berlin River Spree after a storm event in July 2005. The length of the dashed horizontal lines in Figure 5 visualizes the duration for which the eight thresholds were violated (some of them two times or more). Note that two events are separated by a recovery period of six hours following the recommendations of FWR (1998). In total 16 threshold violations were counted combining to a total time period with suboptimal conditions of 5 d, 7 h and 30 min.

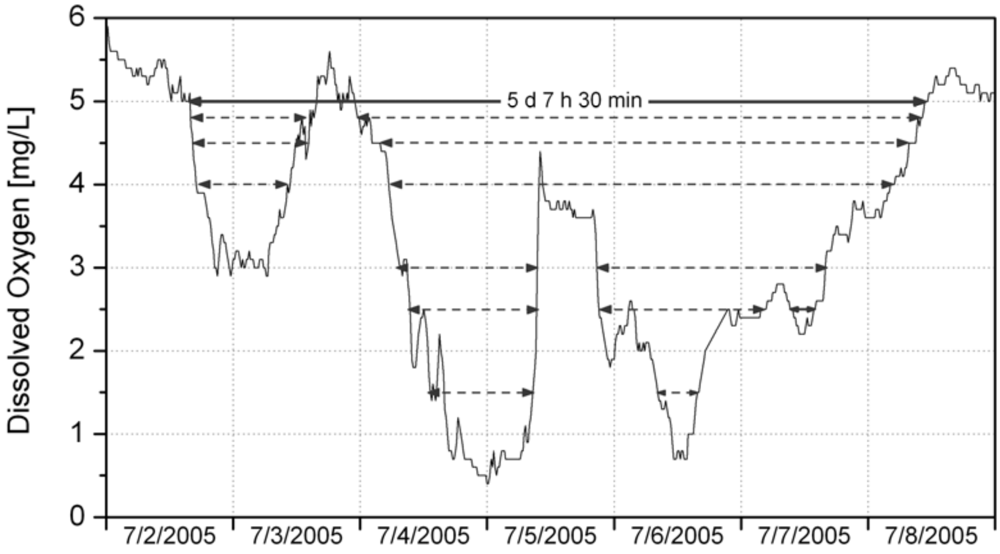
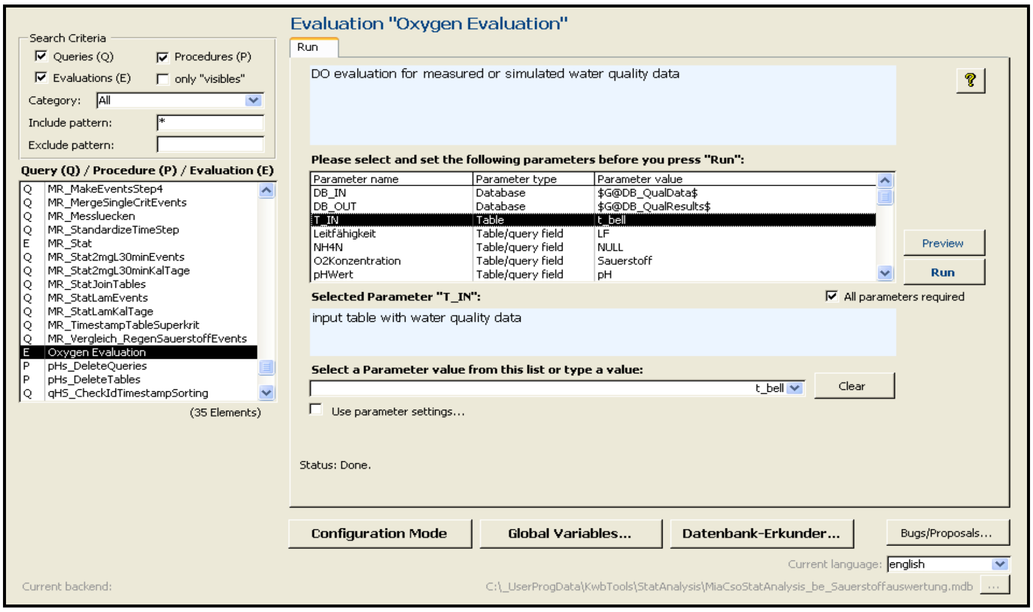


Figure 5: DO concentration in the River Spree following a major storm event in July 2005. Dashed lines indicate the concentration-duration-thresholds defined by Lammersen (1997) for T = 20°C which have been violated during the shown event. All threshold violations can be combined to a time period with suboptimal conditions lasting 5 d, 7 h and 30 min.

In addition to these suboptimal conditions, that imply any kind of adverse effects, a threshold of 2 mg L^{-1} for 30 minutes was used as a second quality standard for critical conditions. Below this value major fish kills can occur in the Spree (pers. comm.: Wolter 2011).

For the automatisation of impact assessment a MS-Access-based “Impact Assessment Tool” was developed at KWB. The tool allows the user to successively run a fixed set of SQL-queries (SQL = Structured Query Language) that implement the quality standards for both approaches described above. The user can run the queries from a user interface depicted in Figure 6 without touching the SQL-code itself.



Evaluation "Oxygen Evaluation"

Run

☑ Queries (Q) ☑ Procedures (P)
☑ Evaluations (E) ☐ only "visibles"
Category: All
Include pattern: *
Exclude pattern:

Query (Q) / Procedure (P) / Evaluation (E)

Q	MR_MakeEventsStep4
Q	MR_MergeSingleCritEvents
Q	MR_Messluecken
Q	MR_StandardizeTimeStep
E	MR_Stat
Q	MR_Stat2mgL30minEvents
Q	MR_Stat2mgL30minKalTage
Q	MR_StatJoinTables
Q	MR_StatLamEvents
Q	MR_StatLamKalTage
Q	MR_TimestampTableSuperkrit
Q	MR_Vergleich_RegenSauerstoffEvents
E	Oxygen Evaluation
P	pHs_DeleteQueries
P	pHs_DeleteTables
Q	qHS_CheckIdTimestampSorting

(35 Elements)

DO evaluation for measured or simulated water quality data

Please select and set the following parameters before you press "Run":

Parameter name	Parameter type	Parameter value
DB_IN	Database	$G@DB_QualData$
DB_OUT	Database	$G@DB_QualResults$
T_IN	Table	t_bell
Leitfähigkeit	Table/query field	LF
NH4N	Table/query field	NULL
O2Konzentration	Table/query field	Sauerstoff
pHWert	Table/query field	pH

Selected Parameter "T_IN": ☑ All parameters required

input table with water quality data

Select a Parameter value from this list or type a value: t_bell

☐ Use parameter settings...

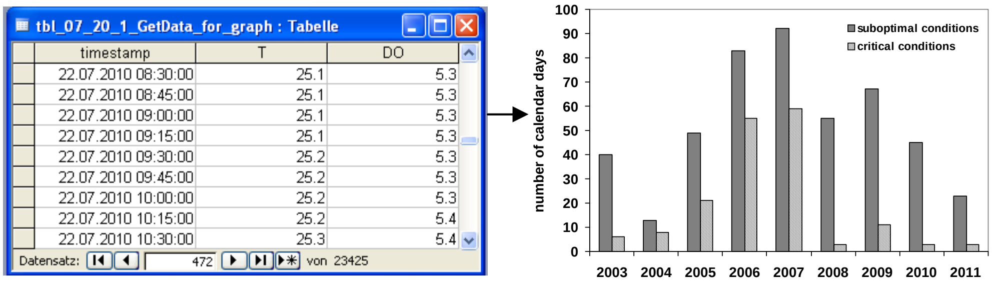
Status: Done.

Current language: english

Current backend: C:_UserProgData\KwbTools\StatAnalysis\MiaCsoStatAnalysis_be_Sauerstoffauswertung.mdb

Figure 6: User interface of the Impact Assessment Tool

The tool automatically applies the two approaches described above to any given measured or simulated time series of DO and temperature and produces an output table and graph quantifying the annual number of events with suboptimal and critical conditions respectively the duration in calendar days per year. It is recommended to not only count the number of events but also take into account the duration, given that single events with suboptimal conditions can last up to several weeks at some river sections. Figure 7 shows an example for the tool's expected input and the obtained output.


tbl_07_20_1_GetData_for_graph : Tabelle

timestamp	T	DO
22.07.2010 08:30:00	25.1	5.3
22.07.2010 08:45:00	25.1	5.3
22.07.2010 09:00:00	25.1	5.3
22.07.2010 09:15:00	25.1	5.3
22.07.2010 09:30:00	25.2	5.3
22.07.2010 09:45:00	25.2	5.3
22.07.2010 10:00:00	25.2	5.3
22.07.2010 10:15:00	25.2	5.4
22.07.2010 10:30:00	25.3	5.4

Datensatz: 472 von 23425

Figure 7: Input (left) and output (right) of the Impact Assessment Tool. The input is a MS-Access-table containing (at least) DO and temperature time-series. The output is a graph showing the annual number of calendar days with suboptimal or critical conditions. Here the tool was applied to measured data for a heavily CSO impacted river stretch from 2003 to 2011. The year 2007 peaked with 92 days with suboptimal conditions and 59 days with critical DO conditions.

Using the two approaches on existing measurements for a 12-year-time-period (2000 to 2011) identified an average of 32/0.2 days per year (suboptimal / critical conditions) upstream of CSO outlets, 53/20 days in the city centre and 26/0.6 days at a monitoring station 5 km downstream of the last CSO outlet. Thus, suboptimal conditions for fish and invertebrates are registered at all studied monitoring stations and quality standards defined by Lammersen are not met at any part of the urban River Spree. Nonetheless critical conditions, for which fish kills have to be expected, predominantly occur in the highly CSO-influenced river section in the city centre located between two weirs.

The presented method can also be applied to model results for different CSO management and climate change scenarios. Next to the quantification of suboptimal or critical DO conditions the presented tool can also be a valuable instrument for model calibration and validation (see chapter 2.4.3).

2.2 Sewer Modelling

2.2.1 *Required complexity and model inputs*

Sewer models are important tools to understand the hydraulic response of a combined sewer system during storm events and predict hydraulic and pollutant loadings to receiving waters. In the past decades a large variety of sewer models for both hydraulics and water quality have been developed. Nonetheless their level of complexity differs significantly. In the following, different groups of hydraulic and water quality models for sewer applications are briefly described.

Regarding hydraulics the simplest model type is a *water budget model*, e.g. SWBM (Luijten 2000) that estimates runoff flow to the sewer system without actually simulating flow or water levels in the sewer itself. These models provide a water balance on a watershed scale but are not suitable for predicting CSO occurrence.

For simulating water levels and predicting the frequency and duration of CSO events a more sophisticated approach is necessary. Simple sewer systems can be simulated with a *model based on the kinematic wave approximation of the hydrodynamic equations*, e.g. SWAT (TWRI 2009). These models allow a good simulation of variable flow and even flood waves, as long as no significant backwater effects occur (Matzinger 2009).

For simulating backwaters or looped sewer systems a *complete dynamic model based on the full hydrodynamic equations* is required, e.g. Hystem-Extran (itwh 2010), SWMM (EPA 2004), InfoWorks CS (WSL 2004), MIKE URBAN (DHI 2010). These numerically complex models offer an unsteady flow simulation, taking into consideration sewer geometry, friction, abrupt changes in inflow, up- and downstream propagation of waves, as well as backwater effects (Dyck and Peschke 1995).

If the focus of CSO impact assessment is not only hydraulics but also water quality, both a hydraulic and a water quality component are required. The simplest type of a sewer water quality model is a *land use loading model* that provides pollutant loadings as a function of the distribution of land uses in the watershed, e.g. SWAT (TWRI 2009), RQSM (Crobeddu and Bennis 2011). These models are not suitable for acute impact assessment but may be applied to modelling of long term CSO impacts like eutrophication or accumulation of sediments.

Moreover, *statistical models* based on derived frequency distributions for event mean concentrations (EMC) - each for a specific pollutant, land use or season - can be used for sewer simulation. However, statistical relationships developed from a given data set can hardly be transferred to other spatial patterns and processes. Hence, such models are not capable to fully capture such highly dynamic processes as the accumulation and erosion of sediments in sewers.

State-of-the-art sewer models considering both hydraulics and water quality are the so called *build-up / wash-off models*, e.g. SWMM (EPA 2004), InfoWorks CS (WSL 2004), MIKE URBAN (DHI 2010), simulating the basic processes that control the quality of runoff. They represent the build up of solids in the time period between storm events and simulate the wash off (erosion and transport) in dependency of the rainfall intensity. Some models also represent the decay of constituents, e.g. SWMM (EPA 2004), MIKE URBAN (DHI 2010), growth, death and sedimentation of pathogens, e.g. SWMM (EPA 2004), MIKE URBAN (DHI 2010), or street cleaning, e.g. SWMM (EPA 2004).

The model MIKE URBAN (DHI 2010) also simulates water temperature variations within the sewer. It might be useful for catchments where changes in temperature can have a negative effect on aquatic organisms, which is only the case for very small streams (see chapter 2.1.1).

Xenobiotics are hardly represented in any of the state-of-the-art sewer models. Anyway, some self-tailored model approaches have been applied to describe the fate and transport of selected xenobiotic trace pollutants (e.g. Lindblom et al. 2006).

Loadings of nutrients and suspended solids can be modelled with most build-up / wash-off models. However, for studying long term impacts of CSO like eutrophication or accumulation of sediments land use loading models like SWAT (TWRI 2009) may be more convenient since they can handle continuous long-term simulations (up to 100 years) on a daily time-step.

Table 3 summarizes which models might be appropriate for which kind of CSO impact. Some long term CSO impacts like aesthetic or structural deficits can only be modelled indirectly via hydraulics or transport of suspended solids and do not appear in the list. For a more detailed overview on model representation and application the works of Zoppou (1999) and Freni et al. (2003) are recommended.

Table 3: Suggested sewer model approach for different CSO impacts.

Impact in receiving water	Required sewer model representation		Applicable Sewer Models
	Hydraulics	Water quality	
Hydraulic stress	✓		Hystem-Extran (plus hydraulic submodels of all models listed below)
DO, NH_3, turbidity, TSS	✓	✓	InfoWorks CS, SWMM, MIKE URBAN, KOSIM
Pathogens	✓	✓	SWMM, MIKE URBAN
Temperature	✓	✓	MIKE URBAN
Nutrient loads, accumulation of sediments	✓	✓	InfoWorks CS, SWMM, MIKE URBAN, (SWAT [1])

[1] SWAT does not solve the full hydrodynamic equations and is only applicable to simple and steep sewer systems without loops or backwater effects.

For assessing any of the CSO impacts described in chapter 2.1.1 with any of the sewer models described in chapter 2.2.1, a large variety of input data is typically needed to run the model. The amount of required data depends on the complexity of the model as well as the spatial and temporal resolution. In Figure 8 the main driving-forces for sewer models are summarized and illustrated.

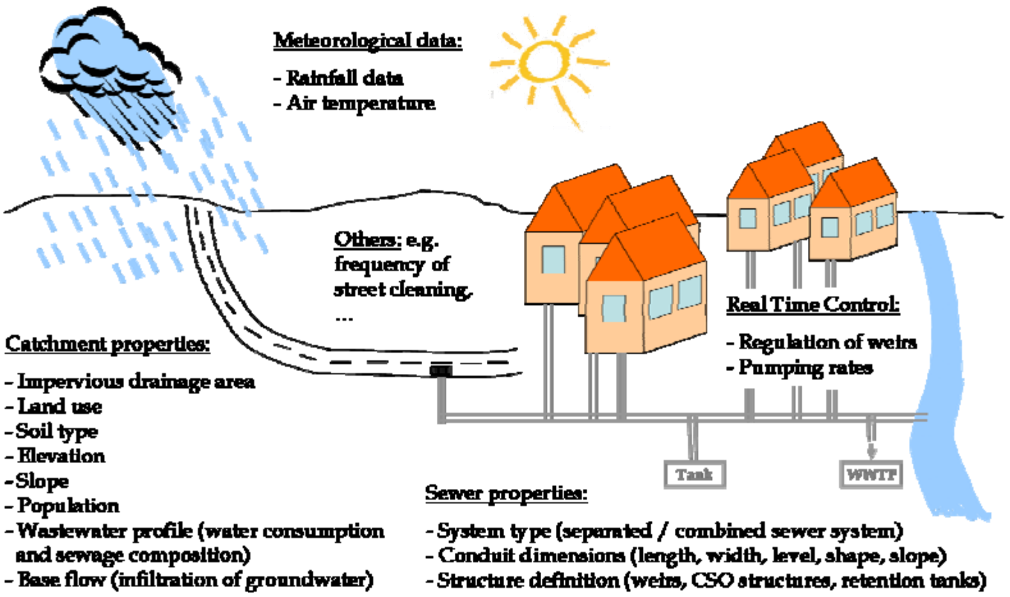


Figure 8: Useful input data for CSO Modelling.

It is important to note that the list of required input data might turn out more or less extensive, always depending on the kind of impact that is looked at and the kind of model that is being applied. Nonetheless, the fundamental driving-force for CSO simulation is the rainfall.

Regarding rainfall data very different kinds of datasets might be used, e.g. (i) rainfall series taken with rain gauges according to Hellmann, (ii) radar data or (iii) rainfall series obtained via mobile networks. The temporal resolution of a rainfall series used for CSO modelling shall be preferably 5 to 15 minutes. A time step larger than 15 minutes does not allow capturing the dynamic nature of most storm events. The required spatial resolution basically depends on the size of the modelled catchment. For large catchments the use of more than one rain gauge is convenient, especially for the representation of convective storm events with a very heterogeneous spatial distribution. Depending on the requirements of the model, different rainfall series can be used separately or be aggregated via Thiessen polygons or other aggregation techniques.

2.2.2 *Example: CSO modelling in the Berlin city centre*

The sewer system of Berlin is highly complex and plain, thus requiring hydro-dynamic representation available in all models listed in Table 3 except SWAT (TWRI 2009). A hydro-dynamic application in the software package InfoWorks CS (WSL 2004) was already applied for the Berlin sewer system (Pawlowsky-Reusing et al. 2007) and is calibrated based on measurements taken with online probes in a major overflow sewer.

The model InfoWorks CS (WSL 2004) – originally developed by Wallingford Software Ltd and nowadays distributed by Innovyze - solves the full St. Venant equations and simulates the transport of dissolved and solid fractions of biological oxygen demand (BOD), chemical oxygen demand (COD), NH_4, total Kjedahl nitrogen (TKN), TSS, total phosphorus (TP) and ortho-phosphate (PO_4). Flow and pollutant loadings originating from sewage are usually simulated via hydrographs and pollutographs which allocate to each land use a typical daily distribution of water flow and concentration. Degradation processes are not considered assuming that the travel time in sewers is too short for significant decay of constituents.

Since the main CSO impact observed in the Berlin River Spree is the lack of oxygen, sewer modelling for the Berlin city centre mainly focuses on organic pollution indicators like BOD and COD. According to a preliminary eight-month simulation for the year 2010, the modelled stretch of the River Spree received a total CSO volume of 2.9 Mio m^3, 551 t of COD, 99 t of BOD and 1073 t of TSS. Figure 9 shows cumulative volume and COD concentration for the 67 CSO outlets along the Berlin River Spree and its side channels following a 34.8 mm rain event in July 2010. With a peak flow of 59 m^3/s (88 m^3/s including 41 outlets outside the studied river section, see chapter 2.1.3.1) it was the largest CSO event modelled in 2010 contributing 75% to the peak discharge of the river.

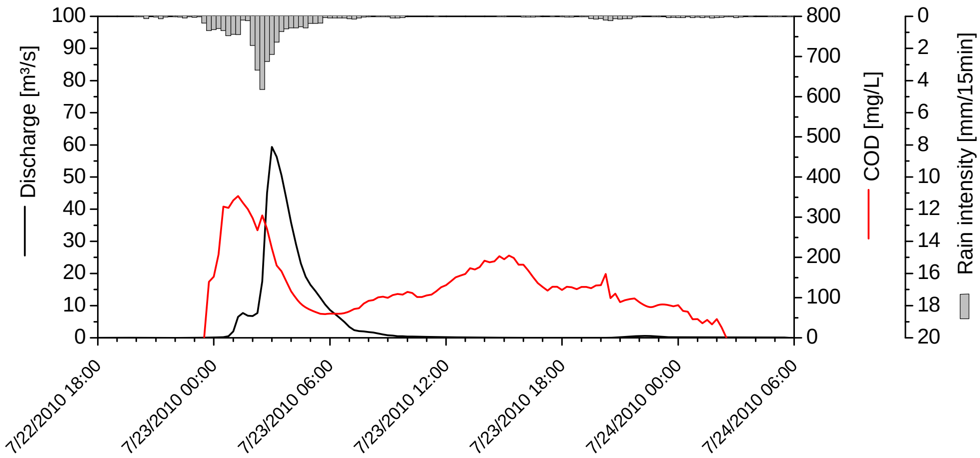


Figure 9: Cummulated simulation results for 67 CSO outlets towards the River Spree for an exemplary 34.8 mm rain event in July 2010 with InfoWorks CS (WSL 2004). Cumulative flow and volume-averaged chemical oxygen demand (COD) is shown for all 67 simulated outlets.

For the link with the water quality model, each of the 67 CSO outlets is used as a separate boundary condition at the point of entry. Chapter 2.4 contains a more detailed description of the coupling of the different model tools.

2.3 Surface Water Modelling

2.3.1 *Required complexity and model inputs*

There is a large number of available substance flow and water quality models of varying complexity for river, lake and estuary representation. In general, the necessary model complexity and data requirements depend on:

- the type of receiving water,
- the impact/goal variable to be simulated and
- the processes in the surface water, which have a significant impact on goal variables.

All considered models combine (i) a hydraulic submodel, which simulates advective and/or diffusive transport with (ii) a water quality submodel, which simulates processes in the surface water system. Table 4 lists the required submodel complexity, boundary conditions as well as exemplary model applications for all the CSO impacts and concerned surface water types outlined in Table 1. For a more complete overview of surface water quality models and model approaches, existing reviews on river (Matzinger 2009), lake (Reichert and Mieleitner 2008) and estuary models (Zhao et al. 2011) are suggested.

Hydraulic submodel: Most of the CSO impacts, which are suggested to be simulated (section 2.2) are of acute nature and therefore require hydrodynamic representation. The only exception in Table 4 is the long term effect eutrophication (split into "nutrient loads" and "eutrophication" given varying definitions in guidelines in section 2.1.1), for which simplified stationary flow conditions (e.g., Neitsch et al. 2001) or mixed reactor(s) for lakes (Vollenweider 1969) may be sufficient. However, for complex lake systems, hydrodynamic approach is suggested also for eutrophication (e.g. Matzinger et al. 2007).

For most applications in CSO impact assessment, 1-dimensional model representation is reasonable, given (i) that it is often not critical where impacts occur across a river section, (ii) the high momentum of CSO which often lead to fast mixing and (iii) the high model effort and data requirements for validation and calibration if more than one spatial dimension is simulated. An approach with 2 or 3 spatial dimensions is only suggested for pathogens, where the expected concentrations at a specific bathing spot are important.

Water quality submodel: If water quality impacts are also an issue, a water-quality component needs to be added. The complexity of the water quality approach depends very much on the required state variables and processes (Table 4).

Again, the simplest approach can be used for *nutrient loads*, where either no processes are simulated or a daily, monthly or annual removal per flow-km is considered. For simple sewer and surface water situations, nutrient loads could also be simulated by one single substance flow model, which takes into account CSO sources and stationary transport in the receiving river (e.g., SWAT (Neitsch et al. 2001; TWRI 2009) or Moneris (Venohr et al. 2011). All the other impacts require dynamic water quality simulation.

For acute impacts from *temperature (T)*, *ammonia (NH_3)*, *turbidity* and *xenobiotics*, models can focus on concerned processes without requiring a full ecosystem approach. As a result, flexible model tools (e.g., Aquasim (Reichert 1994) or Mike11/Ecolab (DHI 2008)) may be used instead of complex ecosystem models.

Similarly, impacts from *pathogens* are typically modelled via fecal indicator bacteria with relatively simple approaches, which consider a first order removal (e.g., CE-QUAL-W2, Cole and Wells 2008). However, publications indicate that fecal indicator bacteria may survive in sediments and be released to the water column during resuspension events (Fries et al. 2008; Jamieson et al. 2005). Moreover, studies show that removal may be closely related to populations of protozoa that feed on bacteria (Krejci et al. 2004). Both findings suggest a more complex model approach, but no applications were found in a literature review.

Finally, an ecosystem approach including nutrient cycles, algal growth, degradation of organic matter, sediment processes and exchange with the atmosphere are required for a full assessment of *eutrophication*. The same is valid for *DO*, which is affected by almost every process in surface waters, most importantly by phytoplankton growth and respiration as well as by degradation of organic carbon after CSO (Matzinger 2009).

Table 4: Required surface water model representation, depending on impact and surface water type

Problem in receiving surface water (see Table 1)	Charac-teristics of surface water system	Boundary conditions	Hydraulic submodel			Water quality submodel		Possible model applications
			Stationary flow/mixed reactor	**1-D Hydro-dynamics**	**2-D or 3-D Hydro-dynamics**	**State variables** [1]	**Processes**	
Hydraulic stress	Small or large stream	- stream geometry - discharge at upper boundaries - water level at lower boundary		✓		×	×	most river models, e.g., EPD-RIV1 (Martin and Wool 2002), MIKE11 (DHI 2008), Aquasim (Reichert 1994), Hydrax (Kirchesch and Schöl 1999), etc.
Ammonia toxicity	Small stream or regulated lowland river	- same as ″Hydraulic Stress″ - water quality state variables		✓		NH_4, pH, T, (DO)	- mixing of river and CSO - nitrification (if long residence times)	most river models: without nitrification, e.g., REBEKA (Fankhauser et al. 2004), with nitrification, e.g., EPD-RIV1 (Martin and Wool 2002)
Oxygen deficits	Regulated lowland river	- same as ″Hydraulic Stress″ - meteo data - water quality state variables (- initial state of sediment/benthic variables)		✓		T, NH_4, NO_3, TN, PO_4, TP, Org_{dis}, Org_{part}, DO, Phyt, (Zoo, Mac)	- atmospheric exchange - nitrification - biodegradation - phytoplankton (+ macrophyte) growth, respiration and death - sediment processes (- zooplankton growth and death)	ecosystem-approach models, e.g., WASP (Wool et al. 2001), QSim (Kirchesch and Schöl 1999), RWQM1 (Reichert et al. 2001)
Turbidity	Small or large stream	- same as ″Hydraulic Stress″ - water quality state variables - initial state of sediment		✓		TSS	- sedimentation - resuspension	stochastic models, e.g., Rebeka (Fankhauser et al. 2004) deterministic models, e.g., WASP (Wool et al. 2001), MIKE11 (DHI 2008), Telemac (Villaret 2010)
Temperature	Small stream	- same as ″Hydraulic Stress″ - meteo data - water quality state variables		✓		T	- heat balance	most river models, e.g., EPD-RIV1 (Martin and Wool 2002), Aquasim (Meier et al. 2003; Moosmann et al. 2005)
Pathogens	Streams	- 1D, 2D or 3D geometry - same as ″Hydraulic Stress″ (- initial state of sediment) - water quality state variables		✓	(✓)	fec, T, (TSS), (Zoo)	- sedimentation (- resuspension) - mortality (- feeding loss)	typically adapted models: e.g., adapted substance-flow model SWAT (Bougeard et al. 2010; Kim et al. 2010)
	Lakes	- 2D or 3D geometry - discharge of inflows - meteo data (wind!) (- initial state of sediment) - water quality state variables			✓			CE-Qual-W2 (Cole and Wells 2008), several adapted models: e.g., Mike21 (Tomicic et al. 2001), Slim-EC (de Brauwere et al. 2011),
	Sea				✓			
Nutrient loads	Streams	- stream geometry - average inflow - water quality state variables	✓			TN, TP	(- nutrient retention)	substance-flow models, e.g., SWAT (Neitsch et al. 2001), Moneris (Behrendt et al. 2000)
	Lakes (or estuaries)	- lake geometry - average residence time - water quality state variables	✓					mixed reactor models, e.g., Aquasim (Reichert 1994) or analytical solving
Eutrophication	Streams	- same as ″Oxygen deficits″		✓		same as ″Oxygen deficits″	same as ″Oxygen deficits″	ecosystem-approach models, e.g., WASP (Wool et al. 2001), QSim (Kirchesch and Schöl 1999), RWQM1 (Reichert et al. 2001)
	Lakes	- lake/estuary geometry - meteo data (wind!) - water quality state variables	(✓)	✓				ecosystem-approach models, e.g., BELAMO (Omlin et al. 2001), Caedym (Hipsey et al. 2006), CE-Qual-W2 (Cole and Wells 2008)
	Sea		(✓)	✓				

[1] Org_{dis}/Org_{part},= dissolved/particulate organic matter, Phyt = phytoplankton, Zoo = zooplankton, Mac = macrophytes, fec = fecal indicators, TN = total nitrogen

2.3.2 *Example: Water quality modelling for the Berlin section of the River Spree*

Given the impact assessment in section 2.1.3, DO depressions are clearly the most serious CSO impact in the Berlin River Spree. Accordingly, the hydrodynamic sewer model InfoWorks CS (WSL 2004) is applied for the simulation of CSO emissions, including critical organic pollution indicators BOD and COD (section 2.2.2). Finally, for the simulation of DO dynamics in the river, a complex ecosystem-based river water quality model is required according to Table 4.

Here, the hydraulic model Hydrax with the coupled complex water quality model QSim (Kirchesch and Schöl 1999) were chosen since they represent phytoplankton dynamics and were already established for the Berlin River Spree for temperature simulations. QSim was developed by the German Federal Institute of Hydrology (BfG) in 1979 with the aim to assess the environmental impacts of hydro-engineering measures on rivers and channels. Since then it has been further developed and is probably the most widely applied river water quality model in Germany. The hydraulic model Hydrax solves the full St. Venant equations. Moreover a great number of special features, such as macrophyte cover or spur dykes, which affect river hydraulics, can be activated. QSim covers a great number of biological parameters, including both planktonic forms that move with the water (green algae, diatoms, cyanobacteria and rotifiers) and sessile species (benthic algae, macrophytes and filter feeders) (Schöl et al. 1999; Schöl et al. 2002).

In QSim the 67 CSO outlets simulated with Infoworks CS (section 2.2.2) are defined as 67 single boundary conditions to account for the spatial distribution of CSO outlets along a the Berlin River Spree. Although the sewer model simulates the most critical parameters for DO depressions it does not cover all the state variables of QSim. Accordingly assumptions have to be made on parameters such as phytoplankton (which is probably close to zero in the sewer) or DO (which is assumed to be 0 mg L^{-1} in CSO, but which may be wrong given the turbulent flow of CSO).

A simulation for the rain event shown in Figure 9 demonstrates the temporal and spatial representation of DO depressions (Figure 10). Figure 10 shows clearly that there are more than one DO depressions, which are advectively transported downstream. As a result, the coupled model can be used to assess CSO impacts at strategic hotspots within the river section.

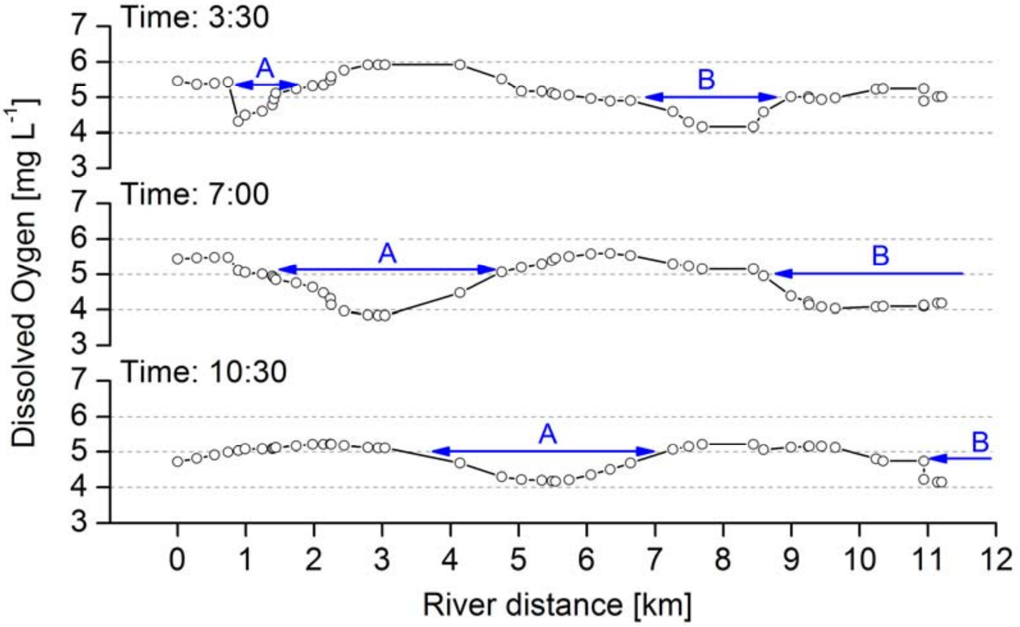


Figure 10: Simulated effect of CSO emission on 07/23/2010 on the River Spree by the river water quality model QSim, based on CSO simulated in InfoWorks CS (WSL 2004) (see Figure 9). Letters identify peaks from different CSO outlets, which are transported downstream.

2.4 Model coupling

2.4.1 Running coupled models

Coupled models can either be run in series or in parallel. The latter is necessary if there is a significant feedback from the surface water quality model to the sewer model. For instance, the volume and timing of CSO may be affected by the water level of the surface water, which in turn depends on the amount of CSO. However in most cases, serial running of the sewer and the surface water model will be possible; the impact assessment tool can always be run as a last (serial) step.

Both for parallel and serial approaches, state variables needed by a model in the chain must be made available by the previous model. In some cases this may not be the case for all state variables. For instance, surface water quality models may require more state variables than supplied by the sewer models (e.g., some biological state variables). In this case, these state variables must be supplied by the user. In other cases state variables may have to be translated, e.g., if the sewer model supplies biological oxygen demand and the surface water model requires total organic carbon.

In addition to the state variables that are exchanged by the models, models require boundary conditions (see Figure 8 for sewer models and Table 4 for surface water models). It is important to keep in mind that these boundary conditions may depend on each other. For instance, rainfall boundary conditions of the sewer model and boundary conditions of the surface water are usually interlinked, since the surface water boundary conditions (upper boundary, tributaries, climate, etc.) are influenced by the same climatic conditions. This is particularly important for scenario analysis, where rain data for the sewer model cannot be changed without changing the boundaries of the surface water model. As a result, long-term statistics can only be done for years where dependent boundary conditions are available for all models. So, if there are 70 years of rain data but only 3 years of water quality measurements at the upper boundary of the surface water model, only 3 years can be used for scenario analysis.

2.4.2 *Model validation and calibration*

In most cases, sewer and surface water quality models need to be calibrated, since models always represent a simplification of reality. As a first step, a local sensitivity analysis may be used to rank parameters according to their effect on state variables (such as DO). For calibration, parameter combinations should be chosen, which have a high ranking and are clearly identifiable in their effects from each other (Reichert and Vanrolleghem 2001). The actual calibration can be done manually (particularly if there is prior knowledge on parameter combinations) or automatically via numeric algorithms (e.g., Rode et al. 2007).

Results from calibrated or non-calibrated models (e.g., to see if calibration is necessary) must be validated with measured data. Most authors suggest a combination between visual validation (e.g., regarding model behaviour) and objective comparison via statistical, relative or difference indicators, e.g., the Nash-Sutcliffe-efficiency (Krause et al. 2005; Legates and McCabe 1999).

In the case of the model tool in Figure 1, it is suggested to calibrate/validate the two models separately. For the surface water model, measurements in the absence of CSO can be used. As a second step, the coupled models should be calibrated/validated in combination for the effects in the river. As a third calibration/validation step, the results of the impact assessment tool need to be compared between simulation and measurements. Since the impact assessment is usually based on thresholds, its application to simulation results can be very different from reality, even if Nash-Sutcliffe-efficiency is good for representation of the goal variable in the surface water. This third calibration step is very important, since the result of the impact assessment tool will be used for scenario evaluation (Figure 1).

2.4.3 *Example: Model tool application for Berlin*

Technically, serial coupling of the two models was successful in a preliminary test by Schumacher et al. (2007). In a first step, preliminary coupled simulations for 2010 were validated with measurements (Figure 10) to test performance and necessity for calibration. Results were already satisfactory for goal state variable DO with Nash-Sutcliffe-efficiencies E2 between 0.72 and 0.80 at different monitoring stations. However, satisfactory E2 values are also possible if not all the DO depressions are met. As a consequence, it is important to check simulation results with the impact assessment tool. Figure 11 compares the results of the impact assessment tool for DO measurements with DO simulations at four monitoring stations along the River Spree (see section 2.1.3 for definitions of suboptimal and critical conditions). Simulation leads to a reasonable order of magnitude regarding the total duration of suboptimal conditions in 2010 (upper panel in Figure 11). However, the coupled model never reaches critical conditions with DO < 2 mg L^{-1}, which did occur in reality (lower panel in Figure 11). As a result, calibration of the coupled model is necessary to represent very low DO conditions, although direct validation of DO was satisfactory.

As a result, the coupled model tool need to be calibrated based on measurements of the year 2010 along the procedure suggested in the section 2.4.2. Both models will be calibrated separately in a first step (in the case of the river water quality for periods without CSO). In a second step the output of the coupled model will be calibrated. In a third step, validation of the calibrated model will be done for measurements of the year 2011.

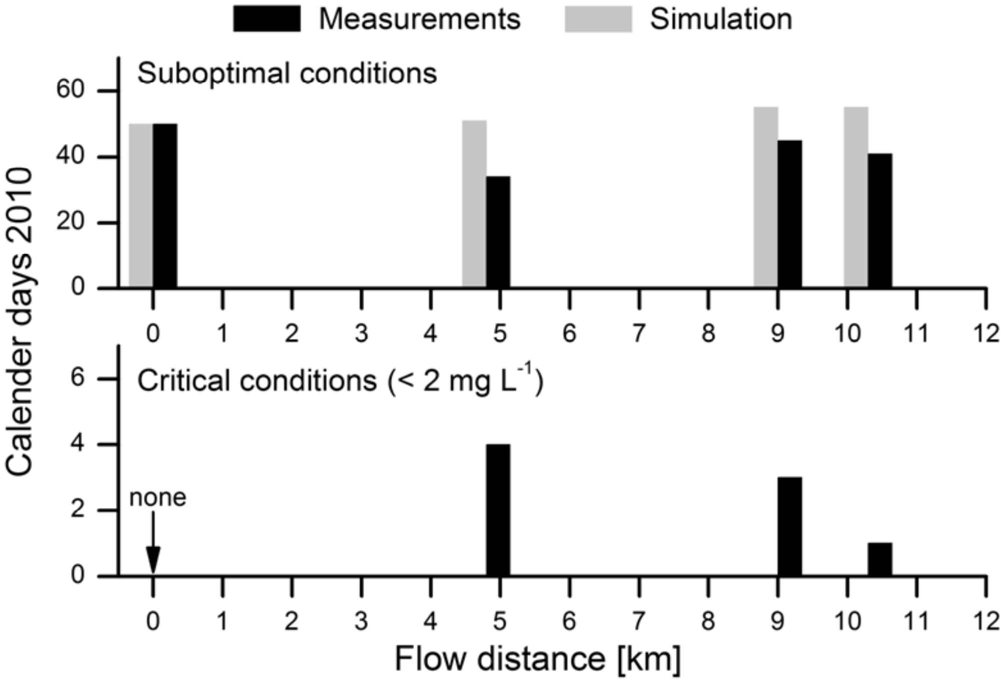


Figure 11: Results of coupled model tool for Berlin example: Number of calendar days with suboptimal and critical DO conditions for measurements and simulations. Upper panel shows occurrence of suboptimal conditions, lower panel shows occurrence of critical conditions (see section 2.1.3 for details).

3 CSO management and climate change scenarios

The following section describes possible solutions for reduction of CSO and a way to find the optimal solution for a specific context. The section describes how future changes like climate change can be taken into account and how specific solutions and changes can be described in the models used to analyze the different solutions.

3.1 Climate Change scenarios

Regarding future climate change, three possible effects should be considered (see Prepared WA2 Report "Overview of climate change effects which may impact the urban water cycle").

3.1.1 Temperature

Expected increase of temperature of surface waters may change the impact of CSO (i) by general acceleration of biological and chemical processes, e.g., growth and respiration of algae, decay of organic matter (and thus DO consumption and NH_3 production) and (ii) by decreasing the DO dilution capacity in the water. Both (i) and (ii) may lead to an aggravation of CSO impacts in receiving rivers.

Apart from the receiving water, rising atmospheric temperature may also have an effect on water quality in the sewer system. However, these effects are difficult to describe and hence predict and will not be taken into account.

3.1.2 Rain fall pattern

The number and intensity of CSO depends on the number of high intense, high volume rainfall events. Traditionally, analyses and design of CSO are based on the use of historical rain series. In the context of PREPARED it should be considered whether the expected climate changes will also influence the rainfall pattern and it therefore could be necessary to adjust the historical rain series for climate change. However, uncertainty of regional climate models to predict the local phenomenon of future rainfall intensity is very large. As a result the decision, whether planning of storm water measures needs to take into account a potential future increase/decrease in intense rainfall events should be based on local information obtained from the local/regional meteorological office and their interpretation of the results of regional climate models.

3.1.3 Sea level rise

It is generally agreed that in the future there will be an increase of sea level. In the context of CSO this can affect the impact on receiving waters and the hydraulics of the CSO structures.

If the outlet from the CSO structure is connected, by gravity, directly to the sea, a sea level rise will reduce the hydraulic capacity of the CSO structure, which might lead to increased risk of flooding in the sewer system upstream of the CSO structure.

If the outlet of the CSO is located in a river affected by sea level rise this will also compromise the hydraulic capacity of the CSO structure again leading to increased risk of flooding in the upstream system. Furthermore the sea level rise will result in a lower velocity in the affected river which means increased sedimentation and reduced re-aeration. This means that the impact of CSO will be more severe in terms of water quality, especially DO depletion, in the river.

3.2 Selection of realistic solutions

The first thing to do when looking for realistic solutions to overflow problems is obviously to determine what the damaging effects on the receiving waters are. This information should be kept in mind when looking for possible solutions. In general there are three ways to reduce overflow of harmful substances to the receiving waters.

i) Add storage volume at or upstream of the CSO,
ii) Remove inflow to the upstream system,
iii) Treat the overflowing water.

The last option obviously only works if the harmful substance is not the water itself. These three types of solutions can be combined to establish the overall most economical solution and will be explained in more detail in the following subchapters.

3.2.1 Adding storage volume upstream a CSO

Adding storage volume upstream the CSO, will work in most situations, since it will reduce the frequency and volume of overflow including any harmful substance. There are several ways of adding storage volume to a system and the following should always be explored.

First, detailed analyses of the function of the system with a hydraulic model might reveal situations where the implementation of static weirs or water brakes can activate unused storage volume in pipes and other structures. This always under the precondition that no additional flooding events are created by the measures. These are cheap and fast measures to implement.

Second, in continuation of the above analyses it should be considered whether installation of controllable devices, such as movable weirs and gates and variable-frequency driven (VFD) pumps, could activate more storage in the system. Such controllable devices can be either locally controlled, keeping water back until a certain threshold is reached, or globally controlled taking into account the state of the relevant part of the entire system.

A globally real time controlled (RTC) system can benefit from the fact that it might not rain over the entire city simultaneously, hence water from an area with heavy rainfall can be stored in parts of the system where it does not rain or the rainfall is light, provided that there are controllable gates/weirs and transport capacity to such areas. In the same way, water from upstream areas with no or little rain could be held back in pipes and reservoirs to increase transport and storage capacity in downstream areas with more heavy rainfall.

Another advantage of a controllable system, and especially the globally controlled system, is that it will include a number of level and flow sensors which provide the operators with information on how the system reacts to various loadings. Moreover, it shows the status of the system at all times, allowing the operators to gain a very good knowledge of the functioning of the system as well as getting information on any failures in the system that then can be rectified quickly. A RTC system can also include a flow forecast procedure that could be based on radar measurement of rainfall. This would allow the system to optimize the use of the existing capacity even better.

In many systems implementation of RTC can be a very cost effective way to increase the storage capacity and by that reduce CSO.

When these options have been analysed the more traditional ways of adding storage volume can be explored and compared with the other types of solutions.

A more detailed description of the above methods and of various other ways of adding storage capacity can be found in "Deliverable 5.4.1, A knowledge base of existing techniques and technologies for sanitation system adaptation" (Ashley et al. 2011).

3.2.2 Remove inflow to the upstream combined sewer system

The inflow to the upstream combined sewer system can be reduced by separation of rain and storm water, infiltration, green roofs, etc. A more detailed description of these types of solutions can be found in Ashley et al. (2011).

As rainwater runoff from different surfaces can be rather polluted some of these solutions might require treatment before the rain water runoff can be released to a recipient. This could change the economy of a particular solution completely.

As an example, infiltration of rainwater runoff from streets might be a possible solution in some areas, but since the runoff water is not clean enough, environmental authorities might require some treatment before infiltration of the runoff water. That would then require a new pipe system to be laid and some sort of treatment facility to be constructed which might need regular maintenance. This will then add to both costs of construction (CAPEX) and costs of operation (OPEX) of such a solution.

3.2.3 Treatment of overflow water

Providing that the detrimental effects of CSO on the receiving waters are not related to hydraulic stress but to the pollutants that are contained in the overflow water, it could also be considered to treat the overflow water. A detailed description of such techniques and technologies for reduction of the detrimental effect of CSO can be found in Ashley et al. (2011).

The most commonly used treatment techniques are primary treatment techniques like settling and storage tanks and various types of screens and sieves. What they all have in common is that they remove floating matter and suspended solids but do not significantly remove any dissolved pollutants.

Another form of treatment often seen is the reduction of pathogens where overflows are discharging to areas used for recreation (swimming and other water sports). The techniques used are UV-radiation and addition of chloride, ozone, hydrogen peroxide or a per acid like peracetic acid.

Dissolved pollutants like nutrients, ammonia and various organic compounds are often the ones causing severe damages. In order to remove those, a secondary treatment or adsorption system is needed. Such systems could be based on chemically enhanced sedimentation, membrane filtration or activated carbon or zeolite filters. The choice of technique depends on the required efficiency and the type of pollutants to be removed.

3.2.4 Selection criteria

This section describes how to reduce the long list of possible measures to reduce the effects of CSO to a list of realistic solutions for the specific problem to be solved.

To determine which of the solutions described in chapter 3.2 are the realistic solutions, the following three criteria should be applied one by one:

i) Which effect(s) of the solution are required?

ii) Can the remaining solutions, after applying criteria 1, be implemented in the specific context?

iii) Are the costs of any of the remaining solutions, after applying criteria 1 and 2, prohibitive for implementing the solution?

The first selection criteria would be to determine which damaging effect it is that has to be reduced or eliminated followed by considering which of the remaining possible solutions can be implemented in the specific context. E.g. building a reservoir or treatment facilities, requires space that must be available. Separating a combined sewer system can be extremely difficult and expensive if it must be done in a densely built-on area. Removing inflow to the combined sewer system by infiltration of rain water might be impossible if most of the area is paved or the ground water table is close to the surface etc. Finally the costs of the remaining possible solutions have to be considered. Table 5 gives an overview of the effects and cost range of the various measures to reduce the impact of CSO.

Table 5: Effect and costs of various measures to reduce the impact of CSO

Type of measure	Effect of measure on CSO impact				Cost of measure
	Hydraulic stress	Particulate pollutant concentration	Dissolved pollutant concentration	Pathogens	
Increase storage by static weirs or RTC	Reduce	Reduce	No change	Reduce	Low to medium
Increase storage by reservoirs or pipe storage	Reduce	Reduce	No change	Reduce	High
Remove inflow	Reduce	Reduce	No change	No change or reduce	Medium to high
Primary treatment of CSO (Screens, drumfilters, etc.)	peaks might be dampened	Reduce	No change or reduced (wetlands)	No change or reduce	Medium to high
Secondary treatment of CSO (adsorption, Actiflo)	peaks might be dampened	Reduce	Reduce	No change or Reduce	Medium to high

3.2.5 *Example Berlin*

The main problem regarding CSO to the Berlin River Spree was determined to be dissolved oxygen depletion due to the discharge of degradable organic matter and to a lesser extend the discharge of ammonia, nutrients and bacteria.

Based on the initial analyses briefly described in the previous chapters it was decided that the main measure to reduce the amount of CSO to the River Spree should be an increase of the storage volume in the sewer system. Until the year 2020 the storage volume should be increased from 109,000 m^3 (reference volume for the time period 1989 to 2000) to 302,000 m^3. Model analyses showed that it is possible to create an additional 75,500 m^3 of storage by introduction of static weirs or by raising existing weirs. An additional 55,000 m^3 can be realized by sewerage management (Real time control). In total 130,000 m^3 or 67% out of the required 193,000 m^3 can be implemented fast and by fairly cheap methods just using existing structures in a better way. By 2010 many of these measures have already been realized and the storage volume has been increased to 213,000 m^3.

Further measures are expected to be needed in order to reach the water quality goals set by the Water Framework Directive (EU 2000). An assessment of the list of possible measures has been made and a list of realistic solutions has been compiled.

First a set of criteria was set up for the assessment. These were:

- Reduction of COD load,
- Reduction of ammonium load,
- Reduction of the TSS/DSM load,
- Reduction of the total phosphorous load,
- Reduction of the bacteriological load,
- Feasibility, e.g. space availability,
- Investment costs,
- Operational costs.

The result of applying these criteria on the list of possible solutions was the following list of realistic solutions.

- Green roofs,
- Use of Rainwater in gardens,
- Separation of sewer systems,
- Activation of storage capacity in the sewer through the usage of existing discharge sewers to the receiving waters as retention canals (instead of direct discharge into the receiving waters),
- Construction of a weir with a pumping station for emptying the sewer,
- Primary and secondary treatment of overflow water.

The next step will be to carry out further analyses to determine the effects of the various realistic solutions under current and future possible conditions and then to find the optimal combination of solutions.

3.3 Scenario definition

3.3.1 Sewer management scenarios

For each of the realistic solutions a scenario is defined to determine the effect of that particular solution under the assumption that it is implemented to the full extend for the area of interest. For example if the measure in consideration is green roofs then every roof in the area is given a green roof and it is calculated what the maximum achievable effect of using green roofs is. The same is done for all the other realistic measures. For reservoirs the maximum volume that there is room for or if space is not an issue the volume needed to reduce the overflow volume to zero is assumed. For treatment measures, all overflows in the area are treated. In this way a sensitivity analysis of the effect of each individual measure can be conducted.

With the results of these calculations it is now known what the maximum effect of each measure is. That is then the basis for defining scenarios with combination of measures, taking the cost (see section 3.4) of implementation and operation into consideration. This will be an iterative process, defining scenarios, calculating effects and costs until the optimal combination of measures are found.

The starting point for defining scenarios with a combination of measures could be to implement as much as feasible of the cheapest measure, continue with the second cheapest measure etc. until the goal is reached. This would give the cheapest solution under the assumption that the future would continue to look as the present.

Other factors might need to be included in the scenario definition such as future changes in population density, increase/decrease of impermeable area, climate change, growth of economy, scientific developments, etc. (Ashley and Tait 2011). To include these factors in the definition of scenarios could give other combinations of solutions. The aim could then be to find the solution that is most robust to changes in the included parameters. The results of such scenario calculations can also be seen as an extended risk analysis if the scenarios are designed properly.

To take climate change effects into consideration the resulting optimal solution from above could be recalculated with new temperature, rainfall pattern and sea level data based on a prediction of how they would be at the end of the lifetime of the solution. With this information a new iteration of finding the optimal combination of measures could then be carried out. The optimal combination of measures taking climate changes into account can now be compared with the previous found combination of measures with no climate change effects taking into consideration.

Depending on the solution (combination of measures) and the context it could then be considered to implement a solution that will work for the present situation and then prepare for and extension of it, when (if) the climate change effects become a reality. That might not be feasible for all solutions but that could then be taken into account when choosing the solution (combination of measures).

3.4 Calculation of cost of scenarios

The calculation of costs should include the calculation of cost of damage if no solution is implemented and the cost of implementation of the various solutions, which either partly or fully eliminate the damage in question. Each solution therefore has an associated cost of implementation and an associated gain in terms of reducing the cost of a damage or a set of damages.

It should also be considered whether different scenarios have different gains in terms of solving other potential problems. I.e. if the initial problem is related to CSO an additional storage volume might solve that but so will the use of a combination of green roofs, infiltration and separation. Whereas the first solution does not reduce the risk of flooding the second will and by that also have an economic gain in terms of reduced frequency of flooding.

If the environmental authorities require that the frequency of overflows is reduced at certain localities, due to poor environmental quality of the receiving waters, the gain could also include an increased value in terms of recreational use apart from the increased water quality of the receiving water as a result of adhering to the requirements of the environmental authorities.

It can be difficult to describe some of these additional gains in monetary terms and it might require quite some interdisciplinary cooperation to find a way to do this.

The calculation of direct costs of each scenario should be based on local cost estimates for the specific measure in the specific context. In order to be able to compare costs the total cost for implementation, operation and maintenance and damages over a period which, as a minimum is as long as the lifetime of the measure that have the longest lifetime, must be calculated. These calculations can be done as net present values based on depreciation and annuity calculations.

3.5 Model implementation of sewer management strategies and climate change effects

In order to estimate the effects of the realistic solutions and the effect of climate changes the effect of the individual measures has to be described in a model. The effects of climate changes have to be included in both the Urban drainage model and the surface water model but since all of the measures to reduce the effects of CSO discharges are located upstream the outlets from CSO they have to be described in the urban drainage model. The effects that have to be modelled are both the hydraulic effect and the pollutant transport effects.

Most of the commercially available models can model the hydrology/hydraulic processes very well but it has proven to be much more difficult to model the pollutant transport. Most models can do very complex pollutant transport modelling with many processes included (see section 2.2), but experience shows that it is very difficult to calibrate a pollutant transport model. This is partly due to lack of data to determine all the parameters in the pollutant transport model. One problem is that it is difficult and resource demanding to make enough measurements of sufficient quality and very often this is not done or only partially done. Another problem is that some of the required model parameters require knowledge of the composition of the rain/wastewater that can only be obtained for very simple and small isolated systems. In most other situations arbitrary values have to be assigned to these parameters.

It is however essential for the quality of the model results that the model is calibrated as well as possible also with respect to pollutant transport. The model results are used as input to the receiving water model and obviously the calibration and the quality of these simulations are very depending of the input from the urban drainage model. The uncertainty of the combined results should be considered when using them to determine necessary measures to achieve the required goals.

As stated in section 3.1 there are in general three ways to reduce overflow of harmful substances to the receiving waters.

i) Add storage volume at or upstream of the CSO

ii) Remove inflow to the upstream system

iii) Treat the overflowing water

Most of these measures can easily be implemented in the urban drainage model. But the effects of some of the measures can be difficult to model due to lack of data.

3.5.1 *Addition of volume*

All urban drainage models include the possibility to include additional storage volume no matter whether it is a concrete reservoir, extra-large trunk sewer or any other structure. Storage volume obtained by introducing new weirs in large sewers or adjustment of existing weirs can also be described well. The use of RTC is also something most models today can simulate rather well. To a certain degree, most models can simulate sedimentation in reservoirs and pipes and by that simulate reduction of pollutant transport over a weir that is combined with a reservoir. They can also simulate the first flush effect where the first highly polluted water is retained in the reservoir and transported to the treatment plant and only the later less polluted water is flowing over the weir. The accuracy of the simulation of these effects is however not good unless the model is calibrated towards detailed measurements.

If sufficient measurements are available to determine an overall removal rate for various pollutants for a combination of weir and reservoirs the simulation could also be done by simply reducing the input concentrations of the various pollutants in rain and wastewater.

3.5.2 *Removal of inflow*

Separation and infiltration measures are simple to implement in a urban drainage model. The contributing area is just reduced with the area where infiltration or separation is implemented. The general pollutant transport is not influenced by this.

Implementation of green roofs in the hydrological model is a little more challenging. Green roofs will capture an initial volume and give a delay/dampening effect of peak runoff. A simple model description would be just an initial loss, the size of which depends on the thickness of the soil layer, the infiltration capacity and rate of the soil layer when the rain starts, the initial intensity of the rain and to some extend the slope of the roof. It is possible to find literature values for the green roof initial loss values based measurements. The model would then need to include an evapotranspiration/evaporation rate to calculate the regeneration of the infiltration capacity in dry weather periods.

Some more advanced urban drainage models have more complex runoff modules which to some extend can simulate the runoff from green roofs based on infiltration calculations, provided that a number of soil and surface parameters are known. These parameters are soil infiltration rate and capacity (including a modelling approach for their development during wet and dry weather) and the slope of the roof. It is possible to find literature values for the infiltration model and it is also possible the find dedicated green roof runoff models (often made by suppliers of green roofs), the validity of which has to be tested on the local application.

A green roof might also influence the pollutant content of the rainwater by retaining some of the pollutants in the rainwater (mostly heavy metals) and releasing other pollutants (i.e. nutrients) to the rainwater generated runoff from the green roof. Suggestions for how much of various pollutants are retained/released can be found in the literature and with the suppliers How to describe this in a model is discussed below.

3.5.3 Treatment of overflow water

The possibilities of implementation of treatment processes for overflow water in urban drainage models are generally very limited. Apart from sedimentation in reservoirs and a fixed removal rate for some components, models for specific treatment processes are not included in urban drainage models. Anyway, the supplier of treatment equipment might have model descriptions that could be used for post processing of result files from the urban drainage models. The post processing can also be done based on simple removal rate assumptions.

If sufficient measurements are available to determine an overall removal rate for various pollutants for the specific treatment process the modelling could also be done by simply reducing the input concentrations of the various pollutants in rain and wastewater.

3.5.4 Climate changes

Climate changes will affect both the urban drainage system and the surface waters and as such they will have to be implemented in both models

Temperature increase
Temperature increase can easily be implemented in surface water models, where temperature-dependence is typically considered for most processes. However, that is usually not the case when it comes to the urban drainage model. These models (InfoWorks, Hystem-Extran, SWMM) mostly consider transport of pollutants, without taking into account temperature-dependent degradation processes. However, for some of the models (MikeUrban) it is an option, hence temperature increases and by that increase in degradation velocity can be taken into account.

Rain fall pattern

If one chooses to test predicted future rainfall patterns in the presented planning instrument, it is suggested to simply multiply the intensities of the historical measured rain series with a factor, the size of which must be discussed with the local meteorological office. This factor could be a factor for each month, quarter or summer – winter. Such a factor could be based on the relation between results of climate models for a period in the past (i.e. 1961-1990) and a future period (i.e. 2071-2100) (Larsen et al. 2009). The future scenario(s) could be based on the various IPCC scenarios. It should then be considered whether the initial rain series that is multiplied with this factor is representative for the period that is modelled with the climate model. I.e. the last 10 years of rainfall measurements from Denmark show significantly higher rain volumes and intensities for single events than the measured events in the period 1961-1990. It might therefore be wrong to use these last 10 years of measurement multiplied with a climate factor that is calculated based on average rainfall properties as modelled for the period 1961-1990.

Sea level rise

Surface and urban drainage models include the possibility to include various boundary data, one of which would be the sea/receiving water level. Most models allow to enter sea/receiving water level as time series, allowing to take into account any daily, seasonally and yearly variations.

3.6 Example: Scenarios and their model implementation for the Berlin case study

The following subchapter presents a preliminary approach for scenario analysis which is based on a catalogue of measures and proposed scenarios by the Berlin stakeholders: the water utility Berliner Wasserbetriebe (BWB) and the water authority Berlin Senate Department for Health, Environment and Consumer Protection (SenGUV):

- The main focus of the scenario analysis should be to test whether the planning instrument is sensitive to CSO mitigation measures. This is an important precondition for the future use of the instrument in concrete planning of CSO management by SenGUV and BWB.
- Based on the results the planning instrument should be adapted further to improve representation of CSO impacts and usability for end users. As a result, scenarios should be run step-by-step and results discussed with stakeholders.
- Scenarios should focus on measure types and climate change phenomena that cover the entire combined sewer area. Detailed planning of local measures will be done by stakeholders at a later point, once the planning instrument has been demonstrated successfully and future CSO management beyond 2020 is discussed.
- For all the scenarios, assumptions regarding the type of measures or the climate change should be realistic for Berlin. They will be defined in exchange with Berlin stakeholders.

- At this point, boundary conditions for the sewer (rain series) and the river model (hydraulic and water quality data at upper boundaries) are available for 12 years (2000 to 2011). Given the current limitation of software solutions and required effort for detailed validation of results, one or two years will be chosen for the scenario analysis. The years will be chosen based on the number of CSO events and the extent of critical conditions in the river.

The following set of scenarios are planned to be calculated:

1. Status quo: Simulation based on sewer and river conditions during the studied time period,
2. Situation in the year 2020: Simulation including the additional storage to be activated until 2020 within a city-wide program. The measures include raising of CSO crests, new storage tanks and storage sewers and improved sewerage control. They will lead to an increase of the specific storage volume of the sewer system from 21 to 43 m^3 ha^{-1} of impervious area. Since these measures will be implemented for certain, all the further scenarios are based on this situation.

CSO management scenarios:

3. Situation 2020 with increased storage volume: Simulation with a further increase of storage volume, which will be realized at the interface between the two models.
4. Situation 2020 with reduced impervious surfaces: Simulation with a reduced inflow to the sewer system will be realized by reducing the run-off-coefficient in the sewer model.
5. Situation 2020 with decentralized treatment of rain runoff: Simulation of one selected treatment system (filters, screens, sieves, etc.) which is installed at the manholes. Treatment systems will be implemented in the sewer model by reduced accumulation on the surface of the catchment.
6. Situation 2020 with end of pipe treatment: Simulation of one selected treatment system (mechanical, chemical or biological treatment) which is installed at major outlets or overflow structures. Treatment systems will be implemented at the interface between the sewer and the surface water model by reducing CSO pollutant concentrations.

Climate and local change scenarios

7. Situation 2020 under expected climate change: According to simulations by Lotze-Campen et al. (2009) the annual mean temperature in the area of Berlin will rise by 1.1°C for the time period 2016 - 2025 (compared to the reference time period 1951-2006). For the time period 2 (2046 - 2055) the annual mean temperature will rise by 2.5°C (compared to the reference time period 1951-2006). Summer and

winter temperatures will not rise to the same extent. Winter temperatures (October to March) will rise by 3.1 °C whereas summer temperatures (April to September) only rise by 1.9 °C.

Regarding extreme rain events, no model results for Berlin are available. Still different authors tried to make assumptions based on analysis of long-term rain series for Germany. Grieser and Beck (2002) evaluated various 100 year-rainfall-series (1901 – 2000, predominantly in western Germany) and came to the conclusion that frequency, rain depth and intensity of stormwater events has increased both in summer and in winter (but in winter more than in summer). On the other hand Jonas et al. (2005) evaluated historical rainfall-series for the German Environmental Protection Agency (UBA) and came to the conclusion that for summer a decrease in extreme rain events has to be expected.

Since the summer period (April to October) is relevant for the simulation of DO depletion in the river, the following scenarios are defined:

a) higher temperature by 1.9 °C (predicted increase for summer),

b) higher temperature by 1.9 °C and more intense rainfall in summer (multiplication with a factor, e.g. 1.2),

c) higher temperature by 1.9 °C and less intense rainfall in summer (multiplication with a factor, e.g. 0.8).

The above scenarios will be substantiated further, calculated and evaluated within the EU Prepared demonstration task 1.3.2. The results of this analysis will be described in EU Prepared report D 1.3.2, due in February 2013.

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