INSA de Lyon
URGC – Hydrologie Urbaine

Graz University of Technology
Institut für Siedlungswasserwirtschaft und Landschaftswasserbau

Diploma thesis

Long Term Simulations of Combined Sewer Facilities

Author:
Valentin GAMERITH

Assessors:
Habil. Dr. Ing. Jean-Luc BERTRAND-KRAJEWSKI
Univ.-Prof. DDipl.-Ing. Dr.techn. Harald KAINZ

Supervisor:
Ass.-Prof. Dipl.-Ing. Dr.techn. Günter GRUBER

Date of submission: 06. June 2006

Valentin Gamerith
e-mail: valentin.gamerith@yahoo.com

For all questions concerning this diploma thesis feel free to contact the author by e-mail.

Declaration of Authorship

I hereby declare that the whole work of this diploma thesis is my own work, except where explicitly stated otherwise in the text or in the bibliography. This thesis has not been submitted in whole or in part for the award of any other academic degree.

Graz, 06.June 2006

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Signature

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Abstract

Abstract	The main objective of this work was to evaluate the effects of long term simulations with different simulation models on the design of CSO structures and storage tanks and the comparison of the obtained results to traditional design rules as applied in France, Austria and Germany. The study was based on data from the “Le Marais” catchment in Paris, France. Three rainfall time series of 17 years were simulated (one French and two Austrian series) with different models - a hydrological, a hydrodynamical and a build-up wash-off model. Various storage tank volumes were simulated and annual pollutant load interception efficiencies were determined. The results show that traditional design approaches (e.g. single design storm) do not reflect the comportment obtained with a more detailed modelling approach. As a great annual variability of the results can be observed, the conclusion that long rainfall time series should be used for simulation as well as monitoring should be carried out over a long period can be drawn. Depending on to the used model the results underlie an important variation. It was confirmed that – for the studied case – a more complex pollutant model leads to lesser interception efficiencies for the storage tank.
Résumé	L’objectif principal de cette étude était d’évaluer l’effet de simulations en long terme sur le dimensionnement de déversoirs d’orages et bassins de stockage. Les résultats obtenus par des modèles de simulation ont été comparés entre eux et aux standards Autrichiens et Allemands. L’étude a été basée sur les données du bassin versant du Marais, Paris. Trois séries de pluie de 17 ans, dont une Française et deux Autrichiennes, ont été simulées par trois modèles différents : Un modèle hydrologique, un modèle hydrodynamique et un modèle d’accumulation-érosion. Un bassin de stockage a été introduit, en variant le volume disponible. Les masses de polluants annuelles ont été calculées et des efficacités d’interception déterminées. Les résultats montrent que les approches traditionnelles du dimensionnement (p.e. pluie de projet) ne reflètent pas le comportement obtenu par une simulation détaillée. Vu qu’une importante variabilité annuelle peut être observée sur les résultats, l’utilisation des séries de pluie de long terme semble indispensable pour un dimensionnement correct. En outre elle laisse conclure que des observations et mesures doivent être effectués sur une période étendu. Selon le modèle utilisé les efficacités d’interception des polluants varient. Pour le cas étudié il a été confirmé que le modèle détaillé donne des taux d’interceptions plus faibles que les autres.
Zusammen-fassung	Ziel der Arbeit war es, die Auswirkung von Langzeitsimulationen auf die Bemessung von Mischwasserüberläufen und Mischwasserüberlaufbecken zu untersuchen. Die Ergebnisse dreier unterschiedlicher Simulationsmodelle wurden untereinander und mit bestehenden Regelwerken verglichen. Basis für die Arbeit waren Daten aus dem Einzugsgebiet "Le Marais" in Paris. Drei Regenserien (eine Serie aus Frankreich, zwei aus Österreich) mit einer Dauer von jeweils 17 Jahren wurden mit drei unterschiedlichen Simulationsmodellen - einem hydrologischen, einem hydrodynamischen und einem Akkumulations-/Erosionsmodell - simuliert. Für ein Mischwasserüberlaufbecken mit variablem Volumen wurden Jahresschmutzfrachten und der Weiterleitungsgrad berechnet. Die Resultate zeigen, dass traditionelle

	Bemessungsvorgaben (z.B. Bemessungsregen) nicht das Verhalten einer detaillierten Simulation widerspiegeln. Eine starke Variabilität der einzelnen Jahresserien musste festgestellt werden. Dies führt zu dem Schluss, dass die Modellierung und Validierung von Mischwasserbewirtschaftungsanlagen mit mehrjährigen Regenserien durchgeführt werden sollten. Abhängig von dem verwendeten Simulationsmodell variieren auch die Weiterleitungswirkungsgrade der Schmutzfrachten beträchtlich. Die Langzeitsimulation am untersuchten Einzugsgebiet bestätigte, dass das komplexe Akkumulations-/Erosionsmodell zu geringeren Weiterleitungswirkungsgraden führt als die anderen beiden Modelle.

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1. Introduction

1.1. General context

Under certain conditions unitary sewer systems spill waste water to the receiving waters during storm weather to delimit the discharge to the waste water treatment plant. The overflow is composed from a mixture of sanitary sewage, industrial waste water and storm water. Depending on the overflow structure – known as combined sewer overflow (CSO) – the spilled water can be partially treated or be spilled untreated. The spilled pollutants are known to have a major impact on the quality of the receiving water, notably the ecosystem and the aquatic milieu. Especially in developed countries rules have been put in place trying to delimit theses discharges and to survey their effect. The costs for the demanded measures are important, the interest in a detailed understanding of the processes therefore evident.
To evaluate the impacts, knowledge of the quantity and the quality of the spilled discharge is necessary. Modelling with more or less complex simulation software became a widely used and appreciated tool, especially since the calculation power increased rapidly over the last decades.

Most of the models used today link meteorological data to a hydraulic simulation. Some models are based on simplified hydrological equations; others include a detailed hydraulic runoff simulation in the sewer network. Pollutant calculations, if available, are for most common models based on a mean concentration approach.
While the level of prediction for pure hydraulic simulations seems to be quite reliable, quality modelling is still an important issue. Most of the equations used in quality modelling date from the late 1980s and only few newer insights acquired over the last years are taken into account. Apparently detailed quality modelling is not applied in most of the European countries, be it for the incertitude of the models, the lack of pollutant measurements or the important simulation time that is still needed for complex models. Nevertheless is seems proved that the pure hydraulic approach does not reflect the phenomena of pollutant flows encountered in sewer systems.
The meteorological phenomena on the other hand are sometimes less considered than the actual modelling. In many European countries the design for overflow structures is still based on single design storms with specific parameters (e.g. return period). Long term rainfall time series, even if available, are rarely used.

Based on these observations, the objectives for this work were defined. It was set up in the context of the Amadeus program, a bilateral research program mounted by Egide[1] between France and Austria, in this case a collaboration of the URGC (Unité de Recherche Génie Civil), INSA de Lyon and the IUT (Institut für Umwelt Technik), Universität Innsbruck.

The main aim of this work was to evaluate the effects of long term simulations on the design of CSO structures and storage tanks with different simulation models, including pollutant flow modelling and the comparison of the obtained results to traditional design rules as applied in France, Austria and Germany.

Six initial objectives were defined in the Amadeus project (Dossier PAI n° 06609WM). This work is focused on the objectives 3 to 5 as work had already been carried out on the other objectives by Sara de Toffol (IUT) and Mohammad Mourad (URGC).
Most of the work in this study was based on the Ph.D. thesis of M.Mourad[2].

[1] Centre français pour l’accueil et les échanges internationaux
[2] Modélisation de la qualité des rejets urbains de temps de pluie : sensibilité aux données expérimentales et adéquation aux besoins opérationnels

1.2. Objectives

The following objectives, defined in the scope of the Amadeus project are treated in this study. The numeration according to the project paper was kept for better coherence.

Objective 2: to evaluate how long term simulations may change the traditional paradigm, i.e. move from a single value design approach (typically with a single design storm event) towards a statistical approach which reflects more realistically the real phenomena and their natural variability linked to the variability of rainfall events.

Simulations had been carried out by URGC with long term rainfall time series for two French catchment areas. They confirm a great annual variability and lead to the conclusion that basing the design of e.g. storage tanks on a single design rainfall event is not appropriate to have a meaningful estimation of the real efficiency of the tank. Similar simulations have been carried out by M. Mourad with a new catchment and better calibrated models that led to the same conclusions.
Since only 3 years of rainfall had been simulated, the same models will be used in this work simulating various rainfall time series with a duration of 17 years to confirm the above results.

Objective 3: to evaluate how long term simulations may affect the estimation of pollutant loads discharged by CSOs into receiving waters compared to traditional or standard design rules.

A first part of the work was done by M. Mourad who analysed various types of pollutant models (a-hydraulic model, b-site mean concentration model (SMC),c-event mean concentration model (EMC), d-pollutograph simulation built up wash off model). It was showed that the first three models (a to c) led to similar results while significantly different results were obtained for the type d model.

To answer to this objective, a final calibration of the models will be carried out. In addition a hydrological model (KAREN) will be introduced since the draft of the new Austrian standard “ÖWAV Regelblatt 19” recommends to use hydrological models for CSO and storage tank design. The results from the different models will then be compared to each other as well as to the Austrian and German guidelines

Objective 5: Propose new tools and design rules which contribute to the revision of national technical recommendations.

While no propositions on new design rules will be included in this report, a comparison of the Austrian and German guidelines for CSO and storage tank design will be carried out. In addition an overview of applied guidelines, used rainfall data and simulation models in several European countries will be given.

1.3. *Organisation of the report*

To treat the objectives defined above, this report is organized in the following fashion:

In a first chapter, the “Le Marais” catchment (Paris, France) that this study was based on is described.

The second chapter presents the three different simulation models used in this work: KAREN, a hydrological model developed at IUT, CANOE, a hydrodynamic model from INSA/SORGEAH and a Build-up wash-off model (referred to as Matlab-model or BW-model) written by M. Mourad.

Next the available rainfall time series and the choice of the three applied time series will be discussed (chapter 3).

Chapter 4 details on the modelling and simulation with the presented models. An overview of the tests that were carried out and the choice of the simulation parameters are given. The calibration of the pollutant model as well as the introduction of a CSO structure is described.

The 5th chapter deals with the illustration of the obtained results and the comparison of the three models and the Austrian and German standards.

A last part is consecrated to a questionnaire on rainfall data and CSO/storage tank design that was answered by several experts from different European countries.

In a final point the conclusions and perspective are presented.

2. Description of the "Le Marais" catchment

The "Le Marais" catchment (see Figure 2-1) is a residential area in Paris, France, covering parts of the 3rd and the 4th district. It has a densely urbanised surface of 42 hectares with an imperviousness coefficient equal to 95% and a runoff coefficient of 0.78.
The catchment has an approximately rectangular shape (800*600m) and it is clearly delimited from the surrounding catchments. It is densely populated (295 inhabitants/ha) with many small shops and little industrial activity. The population is uniformly distributed. The sewer network is combined, without loops, and entirely man-entry. It has 3 main trunks – denominated "St. Gilles", "Vielle du temple"and "Rivoli" – with a slope of less then 0.1% and around 50 elementary sewers with an average slope of 0.8%. The sewers sections are characterized by a large profile, leading to low runoff velocities. An overview of the profiles can be found in ANNEX B, page 54.
The outlet ("*exutoire*") is situated in the south west of the catchment.

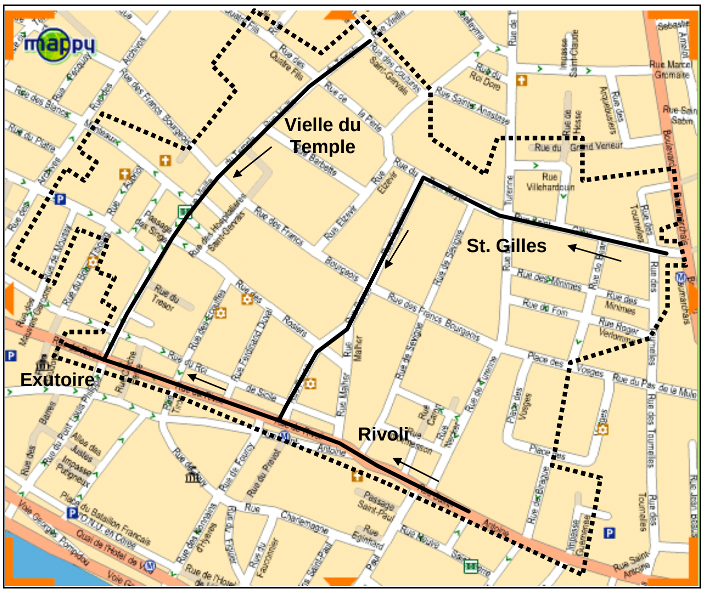


Figure 2-1 – Map of the Le Marais catchment

The Le Marais catchment is one of the best studied sites in France between 1994 and 2000 (Gromaire, 1998; Ahyerre, 1999; Garnaud, 1999; Gonzalez, 2001; Oms, 2003; Mourad 2005). 40 measured rainfall events including data on pollutant loads were available for this study. In addition, the exhaustive knowledge of the runoff properties allowed a good calibration of the models.

2.1. Discharge and pollutant flow

All measurements concerning the discharge and the pollutant flows were carried out at the catchment outlet.
The discharge is measured by an ultrasonic flow measuring method with an Ultraflux flow-meter: the runoff velocity is measured by ultrasound, the runoff depth by pressure measurement. Equation (Equ. 2-1) relates the two parameters to obtain the discharge.

$$Q = Vm \times S(H) \quad \textbf{Equ. 2-1}$$

With
Q… discharge [m^3/s]
Vm… mean velocity [m/s]
S(H)… area of flow for depth H [m^2]

2.1.1. Dry weather flow

The dry weather flow for the Le Marais catchment underlies an important variation between different seasons (Mourad, 2005). Generally a lower runoff can be observed during winter. For this study an average dry weather flow hydrograph composed from the monthly measurements was applied (Figure 2-2). Between 08:00 and 12:00h a distinctive peak can be observed, the minimum is reached between 03:00 and 06:00h. The average dry weather flow is calculated to 0.06 m^3/s.

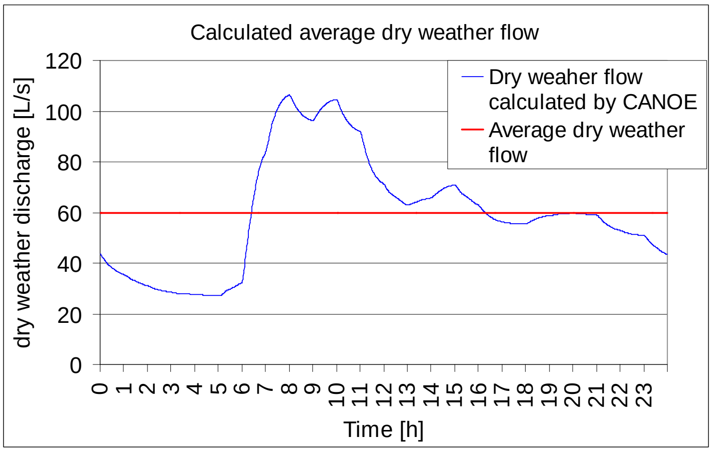


Figure 2-2 – Dry weather flow

2.1.2. Pollutant flow

Two automatic samplers are installed at the catchment outlet to determine the pollutant flows. The first one, equipped with 24 flasks of 2.9 L (Bühler PP92), is used to obtain the pollutographs while the second one holds a single flask of 70 L that allows obtaining an average sample with a big volume. When the discharge surpasses the maximum dry weather runoff the samplers are launched. Samples are taken with a frequency proportionally to the runoff volume to create measurement samples proportional to the discharged flow. The total suspended solids (TSS) are determined by vacuum membrane filtration followed by a drying at 105°C and weighing.

As for the dry weather flow, a seasonal variation of the TSS can be observed. The mean value of TSS concentration for dry weather conditions is calculated to 181 mg/L, corresponding to 75 g/day/inhabitant.

Concerning the TSS concentration for storm weather, a mean concentration of 226 mg/L is obtained from the 40 measured storm events. According to Gromaire (1998), the repartition of the TSS concentration during a storm event is characterized by the phenomenon that for most of the events the concentration peak slightly advances or accompanies the runoff peak. This comportment is more distinctive for runoff peaks superior to 1 m^3/s.

The particles in suspension observed at the catchment outlet are relatively small with a representative diameter d_{50} of 38.6 µm. Their median settling velocity V_{50} is at 0.0325 $cm*s^{-1}$. According to the equation of Stockes the average density of the particles results to 1.4.

3. Software and models

Three different simulation models were used in this work:

The first one, CANOE, is a hydrodynamic model that was developed at the laboratory of urban drainage at INSA de Lyon. This model was chosen since it is known to give reliable results and the possibility to directly interact with the programming team should any problems occur.

KAREN, the second model was developed at IUT Innsbruck. It is a simplified hydrological model that uses a linear time area method.

A complex build-up wash-off model was also designed at INSA de Lyon by M. Mourad. It simulates the production and transfer of pollutant loads (TSS). This model (referred to as Matlab-model or BW-model) includes functions for accumulation, surface erosion and erosion/deposit in the sewer system.

3.1. CANOE

CANOE is a hydrodynamic modelling software that simulates the transformation of rainfall to surface runoff and the actual runoff in the sewer system, using the full Barré de St. Venant equation.

3.1.1. Transformation rainfall – runoff

In CANOE the transformation of rainfall to runoff is calculated in two steps. In a first step the production is calculated, the second step simulates the transfer.

3.1.1.1. Production

The production function defines the part of the rainfall that reaches the end of the subcatchment. Potential losses (as evaporation, retention through vegetation, infiltration) are subtracted from the initial rainfall leading to a net rainfall. The momentous intensity of the rainfall multiplied by the subcatchment surface leads to the runoff volume.

Three choices are offered by CANOE for the production simulation:

- Using a constant runoff coefficient for every rainfall event.
- Taking into account initial and constant losses in proportion to the rainfall intensity.
- Using the infiltration model from Horton that represents the comportment of permeable soil under regular rainfall.

The first approach was chosen, being the most simple and most classic one. It is adapted to homogenous and highly urbanised surfaces as is the case for the modelled catchment “Le Marais”.

3.1.1.2. Transfer

A transfer function transforms the net rainfall volume to discharge at the subcatchment outlet. CANOE uses a linear reservoir model (Desbordes, 1974 and 1975; O'Loughling *and al.*, 1996). It aims to transforming the discharge hydrograph during its passage of the sub catchment.

It combines the continuity equation:

$$\frac{dV_S}{dt} = Q_e(t) - Q_s(t) \qquad \textbf{Equ. 3-1}$$

with a storage function linking the stored volume to the outlet discharge:

$V_s(t) = K_{RL}.Q_s(t)$	**Equ. 3-2**

Wherein K_{RL} model parameter called lag time [s]
$Q_e(t)$ net rainfall volume [m^3/s]
$Q_s(t)$ outlet discharge [m^3/s]
$V_s(t)$ stored volume in the subcatchment [m^3]

This model can be represented by a single reservoir where the function of storage and outlet discharge varies linear with the water depth.

The outlet discharge Q_s at the time step *i* can be calculated with the following equation (after integration):

$Q_{s,i} = e^{-\frac{\Delta t}{K_{RL}}} \cdot Q_{s,i-1} + \left(1 - e^{-\frac{\Delta t}{K_{RL}}}\right) \cdot Q_{e,i}$	**Equ. 3-3**

This type of transfer model is widely used in urban hydrology.

3.1.2. Runoff in the sewer system

CANOE simulates the runoff in the sewer system by using the full Barré de Saint-Venant equation. The following equations are used for the calculation:

Continuous equation, conservation of the fluid mass:

$\frac{1}{B} \cdot \frac{\partial Q}{\partial x} + \frac{\partial Y_T}{\partial t} = 0$	**Equ. 3-4**

Dynamic equation equilibrium between moving (slope, inertia) forces and resistance forces (friction):

$\frac{\partial U}{\partial t} + \frac{\alpha_{BSV}}{2} \cdot \frac{\partial U^2}{\partial x} + g \cdot \frac{\partial Y_T}{\partial x} + g \cdot K_{BSV} \cdot U \cdot \lvert U \rvert = 0$	**Equ. 3-5**

with *x* abscise [m]
t time [s]
$Y_T(x,t)$ level of water surface [m]
$U(x,t)$ mean velocity [m/s]
$Q(x,t)$ discharge [m^3/s]
$B(x,t)$ width of water surface [m]
g gravity constant [m/s^2]
α_{BSV} coefficient of velocity repartition [-]
K_{BSV} coefficient of hydraulic losses [s^2/m^2]

Against the discharge the equation can be written in the form:

$\frac{\partial Q}{\partial t} - \frac{Q \cdot B}{S} \cdot \frac{\partial Y_T}{\partial t} + \alpha \frac{Q}{S} \cdot \frac{\partial Q}{\partial x} - \alpha \frac{Q^2}{S^2} \cdot \frac{\partial S}{\partial x} + g \cdot S \cdot \frac{\partial Y_T}{\partial x} + g \cdot S \cdot \frac{Q \cdot \lvert Q \rvert}{Deb^2} = 0$	**Equ. 3-6**

with $S(x,Y)$ section [m^2]
$Deb(x,Y)$ discharge [m^3/s]

The equations are solved by an implicit scheme using a finite differences method that allows a discretisation of the time step and the space step of six steps. (Scheme of Preissmann, 1961). Both parameters time step and space step are variable.

This discretisation leads to a linear matrix system that is resolved by a method developed by INSA/SOGREAH, 1999.

3.2. KAREN

KAREN is a simplified hydrological model developed at IUT Innsbruck that allows calculating CSO efficiency according to the Austrian guideline “ÖWAV Regelblatt 19” – draft version for up to 5 catchments.

It simulates production and transfer, using a linear time-area method. Catchments are described by their surface [ha] and the flowing time to the CSO structure [min]. Initial losses [mm] and permanent losses (as evaporation) in [mm/d] can be introduced. The initial losses are counted to fill a volume in the basin that is, after a rain event, emptied according to the permanent losses.

Concentrations for the dry weather flow and storm weather as well as properties of the receiving water can be chosen for immission based calculations that are included in the Regelblatt 19. This option was not used in this study.

For each catchment a CSO structure can be modelled by indicating the restricted effluent, a storage volume, a sedimentation coefficient and the mode of connection (direct or indirect).

3.3. MATLAB-model

The MATLAB-Model was used to simulate a complex build-up wash-off mechanism. As result the TSS concentration during each event, for every time step and sewer section is obtained.
Additional MATLAB functions were implemented to simulate CSO and storage tank structures.

3.3.1. Build up - wash off simulation with the Matlab-model

For the build up – wash off model (BW-model) a classic modelling approach, close to the schema used by Hyrdoworks is used. The modelling scheme is composed of several models describing the following phenomena that influence the production and the transfer of suspended solids on the surface and in the sewer system:

- Suspended solids in the sanitary sewage
- Accumulation on the surface
- Erosion and transfer on the surface
- Erosion and sedimentation in the sewer system
- Transfer of suspended solids in the sewer system

3.3.1.1. Suspended solids in the sanitary sewage

Modelling the transfer of suspended solids in the sewer system demands the knowledge of their distribution in the dry weather flow for each subcatchment. However, the only information available for the Le Marais catchment is the total pollutant flow at the catchment outlet. This flow does not correspond exactly to the sum of the pollutant flows at the subcatchment outlets since it is influenced by the phenomena of erosion and accumulation in the sewer system. In absence of more detailed data the two pollutographs were considered similar.
Generally the TSS flow of a subcatchment can be assumed to be proportional to its inhabitants. So, as for the dry time discharge, the TSS flow for each subcatchment can be obtained by fractioning the total flow relatively to the inhabitants.

To introduce the TSS for dry weather a mathematical relation between TSS flow and discharge at the outlet of each subcatchment (the discharge for each subcatchment is simulated with CANOE) was set up by M. Mourad.

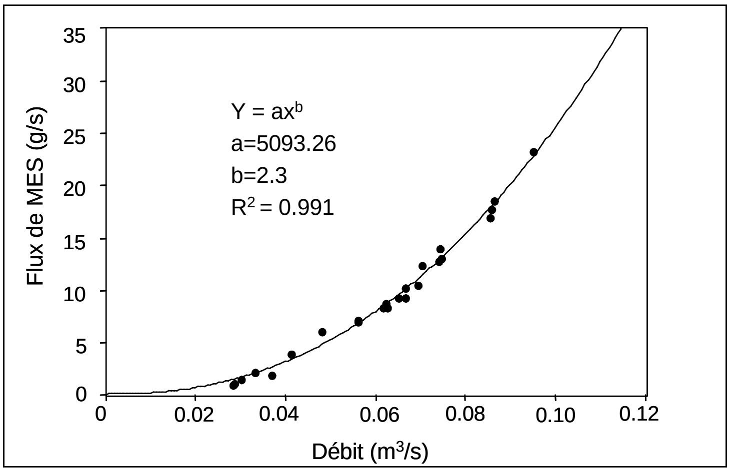


Figure 3-1 – Correlation of dry weather discharge and pollutant flow

With:
flux the MES... TSS flow [g/s]
Débit... discharge at catchment outlet [m^3/s]

3.3.1.2. Surface accumulation:

The chosen model for the surface accumulation is one of the most widely used: An asymptotic accumulation model with the two parameters accumulation rate and dispersion factor. It is described by Equation (Equ. 3-7):

$$Ma(t) = \frac{ACCU}{DISP} \cdot Cimp \cdot AS \cdot \left(1 - e^{-DISP \cdot t}\right) + MR \cdot e^{-DISP.t} \qquad \textbf{Equ. 3-7}$$

With

ACCU	accumulation [kg/ha/h] (*calibration parameter*)
AS	surface of subcatchment [ha]
Cimp	imperviousness coefficient
DISP	dispersion [h^{-1}] (*calibration parameter*)
Ma	accumulated surface mass in subcatchment [kg]
MR	residing mass at the end of the previous event [kg] (*calibration parameter*)
t	time[h]

3.3.1.3. Surface erosion:

The used surface erosion model was proposed in SWMM. It is described by the following equation:

$$Me(t, t+\Delta t) = Ma(t) \cdot \left(1 - e^{-\alpha_1 \left(\frac{Q}{\alpha_2 \cdot AS \cdot Cimp}\right)^{\alpha_3} \cdot \Delta t}\right) \qquad \textbf{Equ. 3-8}$$

With

α_1, α_2, α_3	*calibration parameters* for the surface erosion model
Δt	time step [s]
Ma	accumulated surface mass in the subcatchment [kg]
Me	entrained mass [kg] between *t* and $t+\Delta t$

3.3.1.4. Erosion / deposit in the sewer system CIRIA (1996)

The model of Ackers (1991) was chosen for the simulation. It is based on a transport capacity of the runoff (maximum concentration). If the calculated TSS concentration is superior to the transport

capacity the surpassing mass is deposed. Otherwise, deposed particles are eroded until the limit of the transport capacity is reached. The erosion and sedimentation are instantaneous; this means that the equilibrium is always imposed.
A maximum transport capacity limit was chosen with 2 g/L (Mourad 2005).

$C_v^* = j_A \cdot \left(\frac{W_e \cdot R}{A_A}\right)^{\alpha_A} \cdot \left(\frac{d_{50}}{R}\right)^{\beta_A} \cdot \lambda_c^{\gamma_A} \cdot \left(\frac{\lvert U \rvert}{\sqrt{g \cdot (s-1) \cdot R}} - K'_A \cdot \lambda_c^{\delta_A} \cdot \left(\frac{d_{50}}{R}\right)^{\varepsilon_A}\right)^{m_A}$	**Equ. 3-9**

With

λ_c	friction factor [-]
A_A, α_A, β_A, γ_A, δ_A, ε_A, m_A, j_A, K_A'	coefficients depending on the particle size D_{gr} (CIRIA, 1996)
Cv^*	transport capacity [-] adimensional
d_{50}	median particle diameter [m]
g	gravity constant [m/s^2]
i	index from 1 to n
Q	discharge from subcatchment [m^3/s]
R	hydraulic radius [m]
s	particle density
U	mean runoff velocity [m/s]
W_e	effective deposit width [m]

3.3.1.5. Transfer of suspended solids in the sewer system

The particle transfer in the sewer system is calculated by simple advection. The physique dispersion is neglected, a choice that can be put in question but is also used in quality simulation software like Infoworks.

$\frac{\partial (C \cdot S)}{\partial t} + U \frac{\partial (U \cdot C \cdot S)}{\partial x} = 0$	**Equ. 3-10**

With

C	concentration in the interval ∂x at the instant t [mg/L]
S	section [m^2]
t	time [s]
U	mean velocity [m/s]
x	abscise [m]

This equation is resolved by an explicit scheme (finite differences). A mass balance is established for each sewer section taking into account the TSS mass arriving from the previous section and the TSS mass inserted from the subcatchment (including the sanitary sewage concentration). The outgoing flow depends on the TSS concentration in the sewer section. Two hypotheses are made:

The propagation of the particles in suspension is realized with the mean runoff velocity
A total mixture of the TSS is assumed in the sewer sections for each timestep

4. Rainfall time series

For this project, several different rainfall time series were available. Retrieved form various resources, a close examination of the supplied data was carried out. In a next step, the different file formats were converted to the format used respectively by CANOE, the MATLAB-model and KAREN.

4.1. Available time series

4.1.1. Rainfall time series Le Marais

The rainfall series from the Le Marais catchment was used in the prior work by M. Mourad. CANOE and the Matlab-model were calibrated with this data and all following simulations were based on it. It served as reverence for the other time series.

File: FOINF.MDB

Size: 1.46 Mb

Period: 16.05.1996 – 14.06.1999 (3 years)

Format: CANOE database

Time step: 1 minute

Dry time: 2 hours between two consecutive events.

4.1.2. Rainfall time series Seine Saint Denis

A series recorded at 7 rain gauges in the catchment area Seine Saint Denis (near Paris, France). Two consecutive rain events are separated by a dry time of 2 hours. No rainfall depth inferior to 2mm are recorded.

File: HY05_SSD.TXT

Period: 01.01.1976 – 31.12.1992 (17 years)

Size: 15 816 kb

Time step: 5 minutes

Dry time: 2 hours

Format: 4 117 26/12/1977 1300 24
[rain gauge] [event number] [date] [starting hour] [intensity]
Rain gauge: ranging from 1 to 6, 9 corresponds to the 7th rain gauge.
Event number: continuous numeration for each rain gauge
Date: [dd/mm/yyy]
Starting hour: minutes counted from 00:00:00h of the current day
Intensity: maximum intensity in 1/10 mm/h

The first tests with CANOE show that neglecting rainfall depth lesser then 2 mm has an impact on the runoff volume. Even if low intensities may not affect the number of sewer overflow events they will impact on the calculation of interception ratios and the efficiency factors as used in the Austrian and German guidelines. Therefore the data set of Seine Saint Denis is not used in the simulations.

4.1.3. Rainfall time series Grand Lyon

The time series from Grand Lyon contain the measurements from 28 different rain gauges distributed in the Grand Lyon district (France). The raw data was treated with a program developed by the URGC - laboratory of Urban Hydrology. Two consecutive events are separated by 2 hours of dry time. However, if rainfall is measured on one rain gauge in the Grand Lyon area, this is counted as the beginning of an event for every rain gauge, even if no rainfall is measured there.

Files: plu[yyyy].can

Period: 01.01.1988 – 31.12.2004 (17 years)

Format: CANOE import format

Time step: 6 minutes

Dry time: 2 hours

4.1.4. Austrian rainfall time series

7 Austrian rainfall time series were provided by the IUT Innsbruck (see Table 4-1). They all share the same format. Each file contains the description of the rain gauge as header, followed by a continued time series, each line corresponding to a time step of 5 minutes. This means that no separation is made between consecutive events. Gaps in the measurement are indicated by the word “Lücke”.

Region	Rain gauge	Period	File	Size
Tirol	Kufstein	01.01.1948 –31.12.2002 54 years	n197001.ixx	170 Mb
	Innsbruck	01.01.1981 – 31.12.1999 19 years	n7000103.ixx	58.6 Mb
	St. Martin	01.01.1981 –31.12. 2003 23 years	n7000116.ixx	73.7 Mb
Upper Austria	Wels	1978 – 2002 25.04.1978-1.1.1985, 7:00:00 1.1.1985, 00:00:00- 1.1.1991, 00:00:00 1.1.1991, 00:00:00- 1.1.1997, 00:00:00 1.1.1997, 00:00:00- 31.12.2002, 00:00:00 total: 15 years	n7885.ixx n8590.ixx n9196.ixx n9702.ixx	20.4 Mb 18.3 Mb 18.3 Mb 18.5 Mb
Vorarlberg	Dornbirn	01.01.1991 – 31.12.2000 10 years	rauch_Do.zip	2.38 Mb
	Fußach	01.01.1992 – 31.12.2000 9 years	rauch_fu.zip	2.22 Mb
	Tschagguns	01.01.1991 – 31.12.2000 10 years	rauch_Ts.zip	. 2.46 Mb

Table 4-1 – Austrian rainfall time series

Format: 08.11.1981 06:45:00 0.0
08.11.1981 06:50:00 0.0
08.11.1981 06:55:00 Lücke
08.11.1981 07:00:00 Lücke
[date][hour][intensity]
date: [dd.mm.yyyy], continued
hour: [hh:mm:ss] continued, time step of 5 minutes
intensity: rain intensity for one time step [mm]
e.g.: an intensity of 0.1mm is equivalent to 1.2 mm/h

$$0.1mm \cdot \frac{60}{5} = 1.2 \frac{mm}{h}$$

Time step: 5 minutes

4.2. Critical view on the received data

The results of any simulation are highly dependant on the quality and the properties of the input data. In this study, different rainfall series are applied to one single catchment. The catchment itself is described by some parameters that influence the choice of the rainfall data to apply:

The time that separates two consecutive events is chosen with 2 hours, knowing that after 2 hours of dry time the initial conditions can be supposed to be restored.

The catchment is characterized by a high imperviousness coefficient. In the modelling, losses were included in a constant runoff coefficient (see 3.1.1) and no initial losses were taken into account. This means that also low rainfall intensities do affect the runoff volume.

The rainfall data from Le Marais that was used in the prior work includes all measurements with a total depth higher then 0.2mm. The discretisation time step is 1 minute. Also very short events (3 minutes) were simulated. Therefore it was decided to use all of the events in the supplied data from Austria and Grand Lyon, even if only 1 time step is encountered (corresponding to 5 or 6 minutes). It has to be said that this choice can be questioned since one tip of a rain gauge doesn't essentially need to be a rainfall event or lead to surface runoff. However, the aim of this work was to compare different rainfall time series and modelling strategies, so the data had to be as coherent as possible.

4.2.1. Seine Saint Denis rainfall time series

In the Seine Saint Denis rain data set only events with a total rainfall depth higher than 2mm are taken into account. As stated above and shown in paragraph 5.2.2.2, also lower intensities have an influence on the runoff volume.
Therefore it was decided not to use the Seine Saint Denis series.

4.2.2. Grand Lyon rainfall time series

Even though a program already existed to convert the raw data to the CANOE format, some modifications had to be made in order to adapt the data.
The parameters that were used for the transformation program can be found in Annexe A, page 51. They were chosen in a way so that the rainfall data corresponded to the "Le Marais" format.

As stated above, an event is triggered every time rainfall is registered on one single rain gauge. This event counts for every rain gauge in the Grand Lyon area, leading to events with no rainfall at all or gaps at the beginning and at the end for a single rain gauge. In addition, even though the dry time between two consecutive events was chosen with 120 minutes it happens that on one gauge the dry time during an event exceeds 2 hours.

Furthermore, not all of the 28 available rain gauges could be used due to gaps in the measurement. All gauges with large gaps were sorted out. This led to a final set of 7 rain gauges wherein the rain gauge “Gerland” was the most convincing.

4.2.3. Austrian rainfall time series

The rainfall series form Innsbruck, Wels, Dornbirn and partly Kufstein do not include measurements during winter period from November to April (see Figure 4-1).

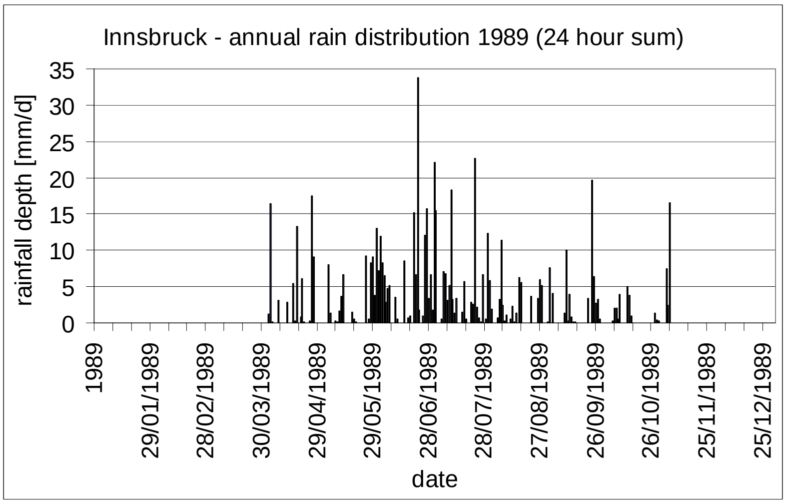


Figure 4-1 – Example of measurement gaps in the Austrian rainfall time series

This leads to a strong underestimation of the total annual intensity. According to the Austrian Meteorological Service[3] the average annual rainfall depth for Innsbruck during the years 1980-1999 is at 857 mm. The analysis of the available rainfall time series leads to only 586 mm.
For the Kufstein series, the winter period is not recorded between 1948 and 1989. From 1990 to 2002 all events are measured. Comparing the average annual rainfall depth, the period 1948-1989 leads to 812 mm while the series without gaps from 1990 to 2002 results in 1375 mm. (see Annexe A, page 47 for details). For the rainfall time series of Wels and Dornbirn the same effect exists.

The rain data sets from the Tirol – St. Martin and from the Vorarlberg rain gauges Fußach and Tschgguns are complete.

4.3. Choice of the data used for the simulation

As stated above not all data could be used for the simulation.
Since a major aim of this work was to test how long term simulation might influence the design of CSOs and storage tanks, it was decided to use the longest possible period of rainfall data. On the other hand the comparison of the results was an important issue. To be able to compare the results conveniently all applied time series were chosen with the same period.

This led to the decision to use 3 long term rain series of 17 years with the data from Grand Lyon – Gerland, Tirol - St. Martin and a composed series from Vorarlberg (Fußach and Tschagguns).

[3] http://www.zamg.ac.at/

4.3.1. Gerland rain gauge - Grand Lyon, France:

The Grand Lyon time series includes measurements from 28 rain gauges. In a first selection process, all rain gauges with dry times higher then 50 days between 2 events were sorted out. This value was chosen after a comparison of all the recorded rain gauges. It was presumed that a high value of dry days between two events that does not show for other rain gauges can be supposed to be a gap in the measurement.
From the 7 rain gauges that passed this filter variation (Gerland, Charly, Loyasse, Mions, Corbas, Polimieux, Montanay), the annual rainfall and the number of events per year were compared to the respective annual average of the 7 gauges.

The standard deviation *s* (Equ. 4-1) was calculated for the two parameters.

$$s = \sqrt{\sum (x - \bar{x})^2} \qquad \textbf{Equ. 4-1}$$

Finally the rain gauge "Gerland" was chosen because it showed the lowest deviation and no significant extreme values. For more details see Annexe A, page 48.

The chosen time series is characterised by an average annual rainfall of 616 mm, varying between a minimum annual rainfall of 436 mm and a maximum of 763 mm. On the average 161 events are encountered every year, ranging form the lowest of 127 to the highest of 200 events. The period of 17 years spans from beginning of 1988 to end of 2004.

4.3.2. St. Martin rain gauge, Tirol, Austria

The St. Martin time series consists of 23 years of measurement. In 2000 an important gap in the measurement is encountered between 16.08.2000 and 09.12.2000 (see Annexe A, page 51). Since it was decided to take a continued time series of 17 years, three time series were examined and compared (starting respectively from 1981, 1982 and 1983). The aim was to find the time series closest to the complete time series of 22 years - not including the year 2000.

The values for average annual rainfall intensity, average events and average annual rainfall time were compared. In this comparison the time series from 1983 to 1999 is the closest to the 22 year time series except for the number of events. It has to be said that the year 1999 is characterized by especially heavy rainfall, with deviations of annual rainfall depth of 400mm, 260 hours of rainfall and 70 events to the 22-year average. However, also the years 2001 and 2002 are characterized by over average values.

		22 year average	1981-1997		1982-1998		1983-1999	
			average	deviation	average	deviation	average	deviation
Rainfall depth	[mm/a]	1253	1216	-37	1212	-40	1239	-14
Nr. Events	[-/a]	220	223	4	222	2	227	7
Rainfall duration	[h/a]	782	753	28	747	35	769	12

Table 4-2 – Choice of the St. Martin rainfall time series

Finally the decision fell to the series 1983-1999 since it is close to the 22 year average and the simulation of an exceptional heavy year was also of interest. This series is described by an average annual rainfall of 1239mm, showing a minimum of 1004mm in 1989 and the maximum of 1653mm in 1999. With an average of 227 events per year the fewest events were measured in 1985 with 174 events, the most in 1999 with 289 events.

4.3.3. Combined data from Fußach and Tschagguns rain gauges, Vorarlberg, Austria

In total 19 years of rainfall data were available for the two rain gauges. Even though the rain gauges are separated by 64 kilometres, Fußach being a village near Lake Constance (*Bodensee*) and Tschagguns in the Alps, the characteristics of the rainfall are quite similar.

All 9 years of the Fußach series were chosen and 8 years of the Tschagguns series were added. The years of 1999 and 2000 were left out for Tschagguns. This implies that the years 1993-1998 are simulated more or less twice.

Even though it is not a recommendable fashion to combine rain series in that way this was done to gain an additional a rainfall time series, especially since the other data could not be used as described earlier.

4.3.4. Overview of the chosen rainfall time series

The chosen rainfall time series will in the following be referred to as "Gerland", "St. Martin" and "Vorarlberg". Table 4-3 gives an overview of the chosen series.

		Gerland	St.Martin	Vorarlberg
Period		1988-2004	1983-1999	1992-2000 / 1991-1998
Rainfall depth	[mm/a]	616	1239	1323
Nr. of events	[-] total	2731	3858	4130

Table 4-3 – Overview of the chosen rainfall time series

4.4. Format conversion

The available raw data had to be converted to the different formats demanded by the used software. In a first step all raw data was transformed to the format used by CANOE. With this converted data the data verification and the choice of the rain series was carried out. After choosing the rainfall series to be simulated they were converted to the KAREN and Matlab-model format.

The format conversion was carried out by a Visual BASIC macro written for this purpose. (See Annexe A, page 51 for more details)

4.4.1. Transformation to the format used by CANOE

To be able to use the rainfall time series with the model CANOE they had to be transformed to the corresponding import format and then be imported to a database used by CANOE (called "rain data library"). The transformation was carried out corresponding to the instructions found in the CANOE manual; however, some remarks have to be made:

The manual demands that the name of each rain event is put between double quotes. For a correct importation only the name of the first event has to be put between quotes.

The example file found in the annexes of the CANOE manual suggests that only integer values can be imported by CANOE. However, also values with one decimal are taken into account.

CANOE can only store up to 1440 time steps for each simulated event. When using a time step of 1 minute this corresponds to 1 day. Therefore all events longer then 24 hours (including the additional 100 minutes for simulating the runoff after the end of an event) had to be spilt into two ore more events for the simulation.

For the Austrian time series a macro was written to filter the actual rainfall events from the continued measurements. A dry time of 2 hours between two successive events was chosen. In addition a file is created that indicates all measurement gaps stated in the original file, giving starting date and the corresponding event before the gap. In a next step all rain events longer than 1340 minutes were split into 2 or more events.

The Grand Lyon time series also had to be treated to correspond to the demanded properties. A macro was used to extract the different rain gauges, delete all zero values at the beginning and the end of an event and to split events with dry times longer then 120 minutes. As for the Austrian time series all rain events longer then 1340 minutes were split.

4.4.2. Transformation to the format used by KAREN

The transformation to the KAREN format was based on the converted rainfall time series in the CANOE format. This implies that all events longer then 1340 minutes are split into two or more events.

KAREN uses the old MOUSE format for the rainfall time series. Each event has to be stored in the following format:

```
3 19880103  1442   0   3  6  1.2
 1.111 1.111 1.111
```

Where in the first line: “3” is system value, followed by the date (yyyymmdd), the starting time [hhmm], the number of time steps, the duration of the time step and the total intensity of the rainfall event [mm]. From the second line to line “n” the intensities [µm/s] for each time step are stored with a maximum of 10 intensities in each line.
The conversion of mm/h to µm/s follows the equation Equ. 4-2.

$$1\,{}^{mm}\!/_{h} \cdot \frac{1000}{3600} = 1\,{}^{\mu m}\!/_{s} \qquad \textbf{Equ. 4-2}$$

For each of the 3 used rainfall time series a file that contains the complete 17 year series and a file for each year were created.

4.4.3. Transformation to the format used by the MATLAB-Model

The format used by the MATLAB model is close to the format used by CANOE. However, for each rainfall event a single file has to be created. In addition the discretisation time step had to be set to one minute and the dry time between two consecutive events had to be included.

For details on the different formats see Annexe A, page 52.

5. Modelling and simulation

The two models CANOE and KAREN were used to simulate the hydraulic runoff. The pollutant load calculations for these models are based on a site mean concentration (SMC). This signifies that the runoff volume is multiplied by a constant concentration for every event to obtain the pollutant loads. On the other hand the Matlab-model (or BW-model) simulates pollutant loads for every event with a complex build-up wash-off approach. It uses the data from the hydraulic simulation (CANOE) as basis.

5.1. *Assumptions and hypotheses*

The following hypotheses were set up for the model:

- All losses were covered by a constant runoff coefficient.

- For the transport function of the suspended solids in the sewer system always the same initial conditions were applied. The dry time between two events was not considered for the initial mass.

- The Strickler value was chosen constant for all sewer sections

- For the dry time runoff contribution of each subcatchment no measurements were available. Only the measured dry time hydrograph at the catchment outlet was available. To obtain the dry time discharge for each subcatchment the runoff was divided by the total inhabitants and multiplied by the inhabitants of the respective subcatchment. Even though this procedure does not respect the transformation of the hydrograph during the runoff in the sewer system the obtained simulation results were close to the measured discharge. (Inside the incertitude of measurement of 12% see Gromaire in Bertrand-Krajewski and *al.*, 2000b.)

5.2. *Simulation with CANOE*

The structural model of the catchment “Le Marais” already existed in CANOE as it was used for simulations in the Ph.d. thesis of M.Mourad. No further adjustments were made to this model. Three main trunks of the catchment were modelled; the side arms were included in the subcatchments. In total the model contains 41 sewer sections and 20 subcatchments.

An overview of the structural model can be found in the Annexe B, page 54.

5.2.1. Construction of the “rain data libraries”

To organize the rainfall events from one time series or rain gauge CANOE uses so called “rain data libraries” (“*bibliotheques de pluie*”). They were constructed by importing the ASCII files created beforehand (see 4.4.1) using a tool provided by CANOE.

CANOE allows using continued time series (“*chroniques*”) for long term simulations. However the CANOE database for the output results can only store a certain amount of data. This means that not the whole time series of 17 years could be simulated at once. It was therefore decided to simulate each year separately.
Special care in the construction of the *chroniques* had to be taken for rainfall events on the 31st of December. If the event extends to 1st of January the starting time for the next year’s simulation has to be set ulterior to the end of the rainfall event. Otherwise CANOE simulates the event again for the next year.

5.2.2. Testing the model

The model was calibrated for the Le Marais rainfall time series. Since the properties of the other series differ in some points, a few tests have been carried out before starting long term simulations concerning the parameters of the simulation, the simulation duration and the mode of saving the results. For the tests data from the rainfall time series "Fußach" was used.

5.2.2.1. Parameters of the simulation

Since the rainfall time series from Austria and Grand Lyon use a different time step than the series from Le Marais (respectively 5 and 6 minutes instead of 1), tests were carried out changing the simulation time step and the time step of discretisation of the rainfall.

For the simulation, time steps of 10, 20 and 30 seconds were tested. No influence on the result was observed. Therefore a time step of 30 seconds was chosen, the same as used in prior simulations.

The time step for discretisation was tested with one and 5 minutes (using the Fußach rain data which uses a time step of 5 minutes). Even though no difference in the results could be observed a discertisation of 1 minute was chosen. This was based on the fact that the model calibration was carried out using a rain set with a time step of 1 minute.

Concerning the duration of dry time simulation after an event no further tests were carried out. The choice of 100 minutes after an event to return to dry time conditions was presented convincingly by M. Mourad (2005).

5.2.2.2. Influence of feeble rainfall depth

Since the rainfall time series of Seine Saint Denis do not contain total event rainfall depth lesser then 2mm, a test set of 9 rainfall events (1 month) was constructed to examine the influence of feeble depth on the runoff.
The test clearly shows that for the Le Marais catchment and the chosen parameters also feeble depth lead to runoff in the sewer system. Therefore it was decided not to use any data of Seine Saint Denis.

In addition a phenomenon was observed when simulating a continuous set of events. Just at the beginning of a rainfall event, a peak can be observed in the discharge for any sewer section as shown in Figure 5-1.

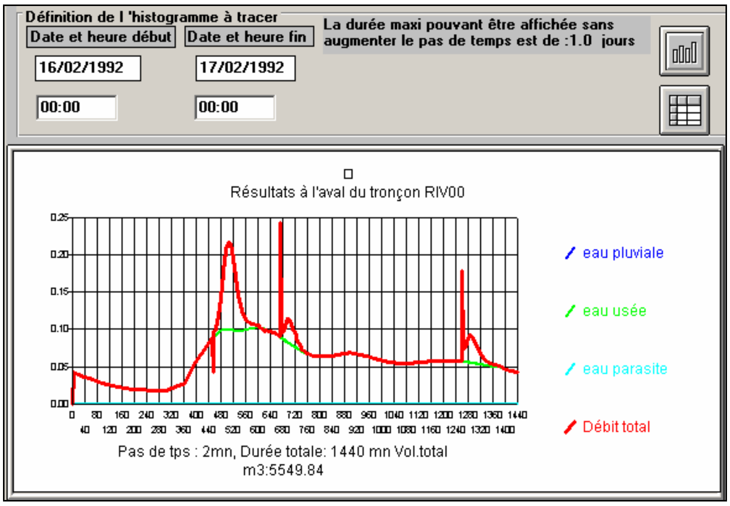


Figure 5-1 – Peaks in the calculated runoff before rain events

When visualizing a single event this problem does not show. Also the output data used in the following by the Matlab-model is not influenced. The problem persists for different simulation parameters. The following parameters were tested:

Using a basic runoff as initial condition, calculated for 10 hours before the first event starts.
- Starting from a “dry” condition.
- Varying the time step for discretisation of the rain data using 1 or 5 minutes.
- Varying the simulation time step between 10 and 30 seconds.

According to the CANOE programming team the error is due to the difference in the time steps of the visualized runoff graph and the simulation. In any case it does not influence the results that were exploited.

5.2.2.3. Observations on the components

In the sewer system, for any storm event, a superposition of sanitary sewage and stormwater takes place. When using the equation of Barré St. Venant, CANOE calculates the total discharge (stormwater and sanitary sewage) for every time step in each sewer section.
The program allows visualizing the runoff graphs (e.g. discharge) after a simulation. It is possible to visualize the single components stormwater, sanitary sewage and infiltration to sewage. However, CANOE resamples the components from the total calculated discharge. This can lead to incorrect discharge values for the single components as shown in Figure 5-2. (with E. PL (“*eaux pluviales*”) – stormwater runoff; E. U (“*eaux usées*“) – sanitary sewage) where the stormwater runoff reaches negative values.

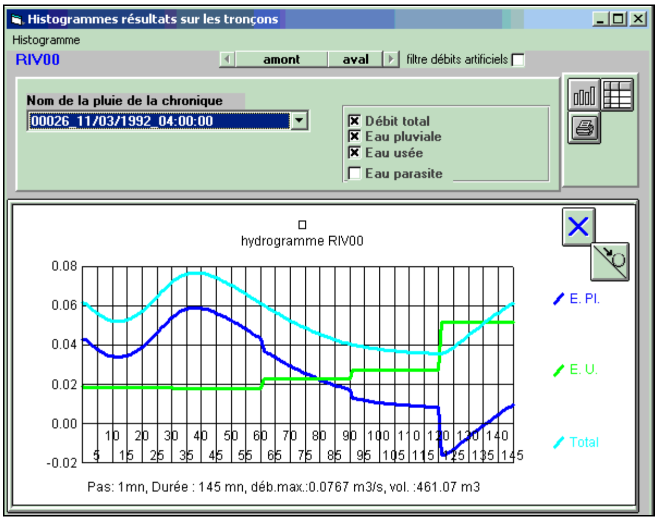


Figure 5-2 – Resampling of runoff components

Since only the total runoff volume was used for the further simulations this effect does not influence the results.

5.2.2.4. Storing the results for further treatment

In order to be able to introduce the CANOE results to the Matlab-model a special tool was implemented in CANOE by the programming team. Annexe B, page 55 gives details on how to activate this module. However, some constraints are encountered in the possibility of storing data:

The main database storing the results is limited to a certain size. E.g. for a long term simulation of the Fußach rainfall time series, the maximum size was reached after about 1800 event. This corresponds roughly to 6 ½ years.

- The maximum duration of a single storm event is also limited. Once this duration is reached, no data for the storm event will be stored. In total 1440 time steps - including simulation after an event - can be stored for one storm event, corresponding to 24 hours in case of a time step of 1 minute.

- In the output files only single events are stored, even if a continued simulation is chosen. When no events are encountered CANOE uses a pre-calculated value for the dry weather discharge.

For each event two files are stored, one including results for the subcatchments (file: rbv[nr].bvm) the other one the results for the sewer sections (file: rtr[nr].trm). For each time step and sewer section the values for discharge, velocity, runoff level and the hydraulic radius are stored.

5.2.3. Continued simulation versus simulation event after event

In the prior work by M. Mourad a simulation “event after event” was chosen since the duration of a continued simulation was important. The newer version of CANOE allows using continued simulations where the dry weather runoff is simulated once for all and applied in dry weather periods.

The advantages of a continued simulation are that no simulation time is needed to stabilize the simulation before an event since the pre-calculated dry time conditions are used as initial condition. In addition an important advantage exists for the events that have to be split - as noted above all events longer than 24 hours. If an event is followed by another one before the initial conditions are reached the continuous simulation takes into account the actual runoff in the sewer system. Contrary, the simulation “event after event” always starts from the initial conditions.

Therefore the continued simulation was chosen for this study.

5.2.4. Calibration of the model

The model had been calibrated in the prior work by M. Mourad with the 40 available measured storm events from the Le Marais catchment. The calibration for the CANOE model was carried out on the global runoff coefficient of the subcatchments and the Strickler coefficient in the sewer system. While the runoff coefficient was semi-automatically calibrated by CANOE the Strickler value had to be calibrated manually by trial and error.

As the same simulation parameters were used in this study the calibrated parameters were not changed.

5.2.5. Long term simulations

After testing the model the long term simulations were launched. Since it was not possible to simulate the whole series at once as stated above it was decided to simulate the rainfall time series year after year. The choice of simulating each year separately proved to be a good decisions since some errors occurred in the first simulations. They could be easily resolved be re-simulating the series in question.

One after another the three 17 year rainfall time series “Gerland”, “St. Martin” and “Vorarlberg” were simulated. The simulation of one year took about 4 hours of simulation time.

The parameters used for the simulation can be found in Annexe B, page 55.

5.2.6. Problems encountered during the simulation

After checking the results of the simulation some problems were encountered. For some events, the results for the sewer sections contained one time step more than the initial time step and than the results for the subcatchments. Furthermore one year from the St. Martin time series had to be simulated anew as the results did not match the input data.

One test series was composed (5 rainfall events, St. Martin 25.01.93 – 30.01.93) and simulated with the CANOE version 2.03a where no error could be observed. The same series, using the same parameters was simulated on the newer CANOE version 2.03h. In this case some results included one time step too much. When comparing the results it could be observed that in the newer version one time step was added to the results of the sewer section calculations for some events. The problem was signalled to the CANOE programming team. It was resolved by writing a macro that deleted all additional time steps from the sewer section results.

5.3. Modelling and simulation with the Matlab-model

Several steps were necessary for the modelling with the Matlab-model. First the results from the CANOE simulation had to be loaded to a Matlab table. The data from this table is then used for the detailed build-up wash-off simulation and for the calculation of the CSO and storage tank parameters. Before starting the simulation the model had to be calibrated with the measured pollutographs from the catchment.

5.3.1. Introducing the base data to the Matlab-model

To be able to introduce the data it was necessary to create a file that links the transformed rain data files to the corresponding results obtained with CANOE. Annexe B, page 55 shows an example of this file. The introduction procedure creates a table from the CANOE output files and the associated files for the rainfall events. Since the importation routine takes a lot of memory space it was necessary to import the data in packages of 500 events. In the end the matrixes were combined so that the total matrixes for the 17 year rainfall series were obtained.

5.3.2. Initial mass of deposits in the sewer sections

According to Oms (2003) the depositions in the sewer network of the Le Marais catchments are localized in the upstream sections of the three main branches. After a storm event the organic layer, principal source of pollutants, is rapidly reconstituted. In an equilibrium state this layer is estimated to 1580, 435 and 252 kg respectively for the branches Saint-Gilles, Vielle du Temple and Rivoli (see Figure 5-3). This mass is considered to be available for each rainfall event.

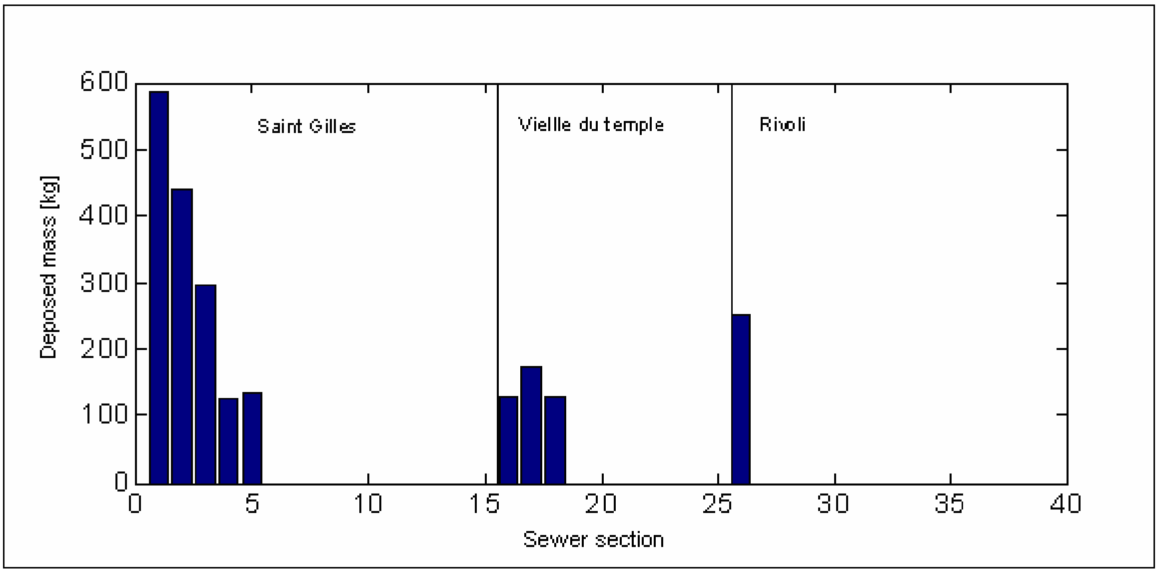


Figure 5-3 – Initial mass for each storm event in the main sewer branches

5.3.3. Calibrating the Matlab-model

For the calibration of the Matlab-model 40 measured pollutographs were available. Three parameters of the surface accumulation model and two of the surface erosion model were used for the calibration. (see chapter 3.3.1 for more details).
The calibration method was to minimize the objective function FO (Equ. 5-1) by comparing the measured to the calculated pollutographs, using a random set of the calibration parameters within predefined limits.

$$FO = \frac{1}{n} \cdot \sum_{i=1}^{n} \sqrt{\frac{\sum_{j=1}^{n_i} \left(Cm_j - Cc_j\right)^2}{n_i}}$$ **Equ. 5-1**

with

n_i number of measurements for of for the i^{th} pollutograph

n number of pollutographs used for the calibration (40 in our case)

Cm_j and Cc_j respectively the mean concentrations of the measured and calculated pollutograph for the j^{th} measurement step

In a first run, 20000 random sets of variables were used for calculating FO. The results were then sorted and new limits for the calibration parameters were applied according to the best 500 calibrations. A second run with 10000 sets from the new parameter limits led to the final calibration parameters (Table 5-1)

	Surface accumulation			Surface erosion	
Calibration parameter	MRPUS	ACCU	DISP	$\alpha 1$	$\alpha 3$
First calibration - limits	0 - 100	0 - 10	0 - 1	0 - 10	0 – 2
Best values after first calibration	39.925	2.4879	0.0190	0.1016	0.7521
Second calibration - limits	0 - 50	4 -10	0 - 1	0 - 1	0.5 - 1.5
Final parameters	36.081	5.8627	0.0579	0.0472	1.1003

Table 5-1 – Calibrated parameters for the BW-model

For most events the calculated pollutographs show a good correlation with the measured data. In general it can be observed that the calculated pollutographs follow the variation of concentration. However, for some measurements the calibration does not give satisfying results.

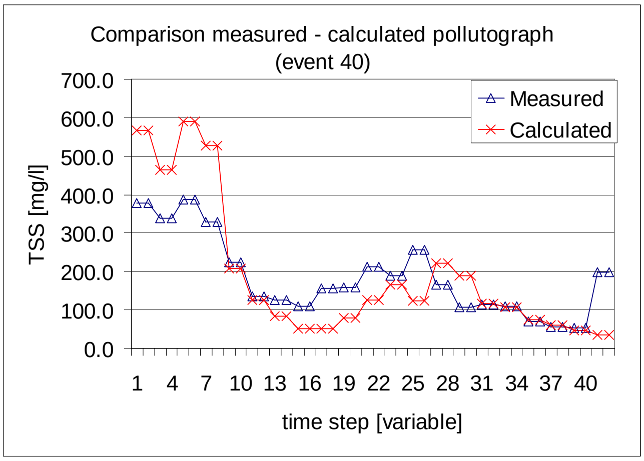


Figure 5-4 – Comparison of measured and calculated pollutograph (event 40)

When comparing the calibrated pollutograph calculation to the actual runoff during a rainfall event in the last sewer section, a strong link between the runoff and the calculated pollution is evident (Figure 5-5).

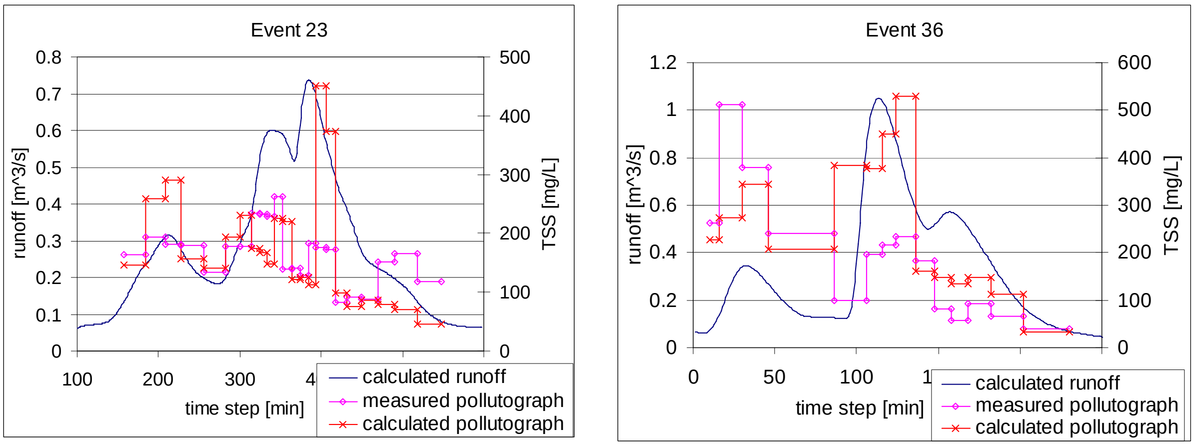


Figure 5-5 – Comparison of calculated runoff, calculated and measured pollutograph for 2 events

On the average a slight underestimation of the total runoff TSS can be observed for the calculations. The average deviation is at 6.8 mg/L for the 40 events. A table with a comparison of all measured and calculated calibration events can be found in the Annexe B, page 56.

5.3.4. Build up – wash off simulation with the Matlab-model

Details on the used equations for the BW-model can be found in chapter 3.3.1.

For the simulation, in a first step the transport capacity for every event was calculated. The maximum transport capacity was limited with 2 g/L. For each event the transport capacity in all sewer sections for every time step is stored in a Matlab table.
Since an important amount of simulation time is needed (with the available machine the calculation of 100 events took about 24 hours) not all three rainfall time series could be simulated. It was chosen to use the two series “Gerland” and “St. Martin”.

Once the transport capacity is calculated the complete simulation can be effected, including the models for surface accumulation, surface erosion, erosion / sedimentation in the sewer system and for transfer. The input data for this simulation are the calculated transport capacity, the hydraulic data taken from the CANOE simulation and the calibrated parameters for the surface accumulation and erosion model. As results, the pollutographs (TSS) for each event and sewer section are obtained.

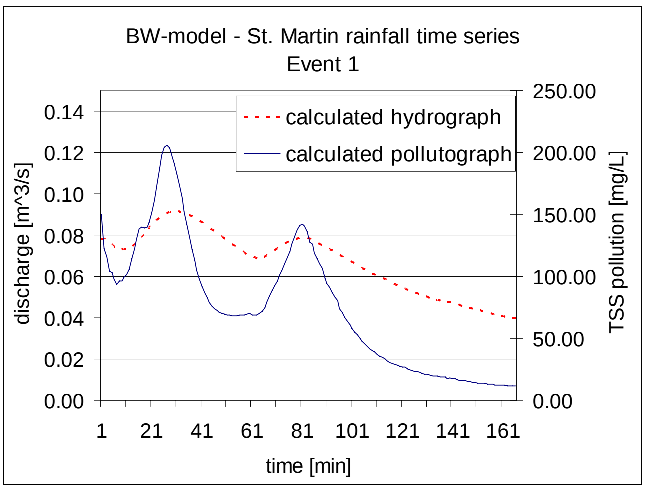


Figure 5-6 – Example of the results obtained by the Matlab-model

For the further calculations concerning CSO and storage tank design only the values for the last sewer section (at the catchment outlet) had to be retained. Figure 5-6 shows an example of the results obtained at the catchment outlet with the model for the first event in the St. Martin rainfall time series.

5.3.5. Modelling of a CSO and a storage tank

5.3.5.1. *Modelling of a CSO with no storage tank volume*

The admissible flow to the WWTP Q_{WWTP} was chosen with three times the average dry weather discharge Q_{dt} to 180 L/s. This choice was arbitrary but it satisfies the design that can be observed in general practice.

Since the CANOE results contain the runoff hydrograph for each event and time step, the modelling of the CSO was relatively simple. For every time step where the discharge is superior to Q_{WWTP} the surpassing discharge is spilled. Therefore the total overflow volume can be calculated by the sum of the surpassing discharge (Equ. 5-3).

$Q_{OF} = Q_{outlet} - Q_{WWTP} \mid Q_{OF} \geq 0$	**Equ. 5-2**
$V_{OF} = \sum_i (Q_{OF,i} \cdot 60) \mid Q_{OF} \geq 0$	**Equ. 5-3**

With

Q_{OF}… Overflow discharge [m^3/s]

Q_{outlet}… Discharge at the catchment outlet (last sewer section) [m^3/s]

Q_{WWTP}… admissible flow to the WWTP [m^3/s]

V_{OF}… Overflow volume [m^3]

i… time step [min] from 1 to total time steps of the current event

For the pollutant load calculation two different approaches were used. In the first one, the site mean concentration model (SMC), the runoff discharge is multiplied by a constant TSS concentration C_{SMC} of 226 mg/L. The pollutant load is therefore directly proportional to the runoff volume. The total runoff pollution mass pm_{tot} and the overflow pollution mass pm_{OF} are calculated respectively by the Equations Equ. 5-4 and Equ. 5-5.

$pm_{tot,SMC} = \sum_i (Q_{outlet,i} \cdot C_{SMC} \cdot 60)$	**Equ. 5-4**
$pm_{OF,SMC} = V_{OF} \cdot C_{SMC}$	**Equ. 5-5**

The BW-model on the other hand calculates the pollutant loads by Equ. 5-6 and Equ. 5-7 for each time step *i* according to the actual TSS concentration $C_{BWM,i}$ that is obtained from the Matlab simulation.

$pm_{tot,BWM} = \sum_i (Q_{outlet,i} \cdot C_{BWM,i} \cdot 60)$	**Equ. 5-6**
$pm_{OF,BWM} = \sum_i Q_{OF,i} \cdot C_{BWM,i} \cdot 60$	**Equ. 5-7**

In order to compare the three models, the values to retain were chosen in accordance with the values given by KAREN.

5.3.5.2. Introduction of a storage tank

The same design for the storage tank as used in the thesis of M. Mourad was chosen. It has to be remarked that the model varies in some details from the one used in KAREN.

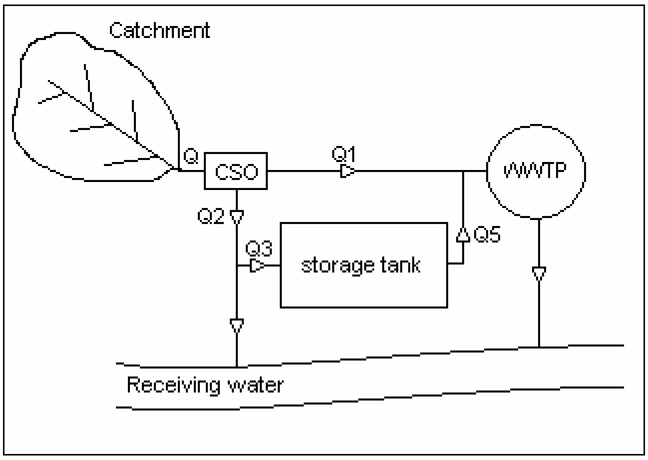


Figure 5-7 – Scheme of the storage tank function

The function scheme of the storage tank is shown in figure Figure 5-7.
During storm weather the discharge Q is directed directly to the WWTP, provided that it is inferior to the admissible flow to the Waste water treatment plant Q_{WWTP}. Once this limit is reached ($Q_1= Q_{WWTP}$) the exceeding discharge is directed to the storage tank ($Q_2=Q_3=Q - Q_1$) as long as the tank is not completely filled. As soon as the tank is filled, the exceeding discharge is spilled into the receiving water ($Q_3=0$). The same equations as in 5.3.5.1 are applied.
Only when the storm event is over the outlet of the storage tank is activated. It is drained at a constant discharge of $Q_5= Q_{WWTP} - Q_{dt}$ .Should a new storm event start before the tank is totally emptied, the remaining volume is guarded in the tank.

Two observations have to be made concerning this model:

Contrary to the model used in KAREN, the drainage of the tank does not start before the end of an event (including the 100 minutes simulated after each event) and stops as soon as the next event starts. This means that even if Q_1 is inferior to Q_{WWTP} during this period, the tank is not emptied.

Assuming a constant dry weather flow Q_{dt} is not valid for single events. However, as only yearly series were examined the average seems to be a valid choice.

For the simulations the specific volume of the tank was varied between 0 and 1000 m^3/ha (active catchment surface). If a volume of 0 m^3/ha is chosen the system functions as a CSO without any storage volume. The value of 1000 m^3/ha is just a theoretical value for which no more overflow events are registered for any of the three rainfall time series.
To compare the obtained results from the different models an interception factor was introduced (Equ. 5-8). In addition all results needed for the comparison to the Austrian and German guidelines (e.g. overflow and runoff volume) were retained.

$Interception = 100 - \frac{pm_{OF}}{pm_{tot}} \cdot 100$	**Equ. 5-8**

With
pm_{OF} … Overflow pollution mass [kg]
pm_{tot}… total runoff pollution mass [kg]

5.4. Modelling and simulation with KAREN

KAREN is a simplified rainfall-runoff model programmed at the IUT Innsbruck. It allows simulating the transformation or rainfall to runoff using a linear time-area method. Up to 5 separate catchments with a combined sewer overflow at their outlet can be introduced.

The aim was to fit the model as closely as possible to the real conditions using the same hypotheses as for the CANOE simulation. For this purpose 2 variants were modelled in KAREN. The first one (Variant A) consists of one single catchment, the second one (Variant B) of three catchments, one for each main sewer section of the CANOE model.

5.4.1. Parameters for the simulation

Several parameters have to be assigned for the simulation with KAREN:
The catchment area is characterized by its surface [ha], runoff time [min], initial loss [mm] and permanent loss [mm]. For emission calculation the dry weather flow [L/s], dry and storm weather concentration [mg/L] can be assigned.
The CSO is characterized by a storage volume [m^3] and the restricted effluent [L/s]. A sedimentation coefficient can also be introduced for the storage volume. As the chosen model for the storage tank (see 5.3.5.2) does not lead to sedimentation effects this option was not used.
The last parameter is the flowing time from the catchment outlet to the WWTP or the next CSO in minutes.

5.4.1.1. Surface and runoff time

The surface was calculated for the two variants according to the scheme of the sewer system and the attached subcatchments (Figure 5-8). The two subcatchments that are linked to the nodes N28-40 and N16-34 are counted for branch 3.

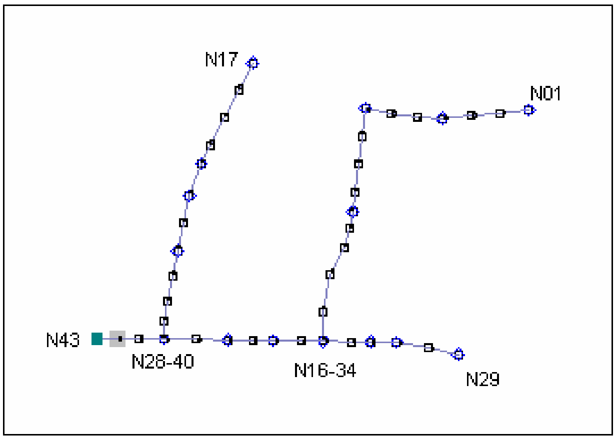


Figure 5-8 – Scheme of the 3 main sewer branches

Branch	Node	Length [m]	Active Surface [ha]	Mean velocity [m/s]	Runoff Time [min]
1	N01 to N16-34	691	12.5	0.24	50
2	N17 to N28-40	501	11.5	0.26	50
3a	N29 to N16-34	232		0.20	
3b	N16-34 to N28-40	273		0.30	
3c	N28-40 to N43	114		0.44	
3 complete	N29-N43	618	9.7	0.29	36
Total		1811	32.7	0.26	56

Table 5-2 – Surface and runoff time for the KAREN model

According to Table 5-2 the total active surface of 32.7 ha was assigned to the single catchment for variant A. In variant B three catchments with the corresponding active surfaces of 12.5, 11.5 and 9.7 ha were modelled.

To calculate the runoff time the mean runoff velocity in the different sewer sections was used. A macro was written to extract the velocity values calculated by CANOE and to calculate the mean velocity for each sewer branch. All the events of the Grand Lyon – Gerland time series were used. A comparison to the obtained mean velocities for the St. Martin rainfall time series showed only minimal deviations.
For variant A the runoff time was calculated with the overall mean velocity (0.26 m/s) and the longest runoff section (branch 2 + 3b + 3c) of 888.12m, leading to a runoff time of 56 minutes.
In variant B the runoff time was calculated for each of the three modelled subcatchments. For each subcatchment the length from the corresponding starting node to the catchment outlet (N43) was used to calculate the runoff time. The runoff time for the branches 1 and 2 was calculated to 50 minutes each, for branch 3 with 36 minutes.

5.4.1.2. Initial and permanent loss

As all initial losses were neglected in the CANOE simulation both values were set to zero for the comparison of the two models. In the design according to the Austrian guideline Regelblatt 19 a variant with 2mm initial loss and 1mm for the permanent losses was examined.

5.4.1.3. Average dry weather flow

The average dry weather flow for the Le Marais catchment is at Q_{dt}=60 L/s. In Variant B the dry weather flow was introduced in total to the 3rd catchment. As the dry weather flow is an average value, dividing it to the 3 catchments does not change the results.

5.4.1.4. Dry and storm weather concentration

The dry and storm weather concentration is used to calculate the yearly pollutant mass that is spilled by the CSO [kg/a].
For the Le Marais catchment, concentration measurements for total suspended solids were available. The mean values are indicated with 181 mg/L for dry weather flow and 226 mg/L during storm weather. Since no specific concentration for storm water was available, the concentration of 226 mg/L was applied to both dry and storm weather concentration. (In accordance with IUT Innsbruck)

5.4.1.5. Storage volume

In a first step, the storage volume was set to zero for the comparison of the results from KAREN and CANOE.
For the design of the CSO structure and storage tank according to the “ÖWAV Regelblatt 19” the storage volume was varied to obtain the demanded CSO efficiency.

5.4.1.6. Restricted effluent

As restricted effluent the admissible flow to the WWTP Q_{WWTP} = 180 L/s was chosen. For Variant B the value for the first two catchments was set to 9000 L/s. Therefore only the CSO in the 3rd catchment is active in the simulation.

6. Results, model comparison and storage tank design

This chapter details on the obtained results from the simulations with CANOE, KAREN and the Matlab-model. A comparison of the hydraulic CSO parameters obtained with CANOE and KAREN is carried out. The comparison of the two models to the Matlab-model concerns the calculated pollutant loads in the runoff and the overflow volume.
To be able to comment on the influence of using long term rainfall time series, the annual variability of the obtained results is examined.
In addition the storage tank design according to the Austrian and German guidelines “Regelblatt 19” and “ATV A 128” can be found in this chapter.

The three rainfall time series “Gerland”, “St.Martin” and “Vorarlberg” were simulated with CANOE and KAREN. For the Matlab-model only the first two series could be simulated due to the important simulation time.

6.1. Comparison of CANOE and KAREN

The comparison of the two models was based on the hydraulic results for the CSO. The parameters overflow volume, overflow duration and number of overflows for the total 17 year time series and for each year were examined.

Two variants (variant A and variant B, see 5.4.1) were modelled with KAREN. In a first step it had to be decided which variant would be used for the further simulations. Table 6-1 shows the results for the three 17 year rainfall time series for the two variants and the CANOE simulation.

	Results - 17 year rainfall time series				Precentile difference to CANOE results		
	Variant A	Variant B	CANOE		Variant A	Variant B	
GL	78	79	78	[-/a]	-0.3	1.0	No. Overflows
	98.1E+3	98.7E+3	100.0E+3	[m^3/a]	-1.9	-1.3	Overflow volume
	172.3	160.2	153.6	[h/a]	12.2	4.3	Overflow duration
SM	101	108	115	[-/a]	-12.5	-6.4	No. Overflows
	133.9E+3	134.8E+3	134.0E+3	[m^3/a]	-0.1	0.6	Overflow volume
	271.2	282.2	292.3	[h/a]	-7.2	-3.5	Overflow duration
VB	111	118	124	[-/a]	-10.1	-4.5	No. Overflows
	129.6E+3	130.7E+3	127.1E+3	[m^3/a]	2.0	2.9	Overflow volume
	279.8	290.5	295.3	[h/a]	-5.3	-1.6	Overflow duration

Table 6-1 – Comparison of KAREN (variant A and B) to CANOE

As can be seen the obtained results from KAREN are close to those from CANOE. The variation of the overflow volume stays inferior to 3% for each variant. Depending on the rainfall time series, the results for the number of overflow events and the overflow duration vary slightly. While for the Gerland time series KAREN tends to a slight overestimation compared to CANOE it is the inverse for the St. Martin and the Vorarlberg time series.

According to the smaller observed deviations it was chosen to use variant B for further simulations.

6.1.1. Comparison for annual series

As the properties of the rainfall time series (e.g. annual rain height) vary strongly from year to year, the yearly variation of the parameters was examined in detail to see if the good coherence between the models for the 17 year series is also valid for single years.

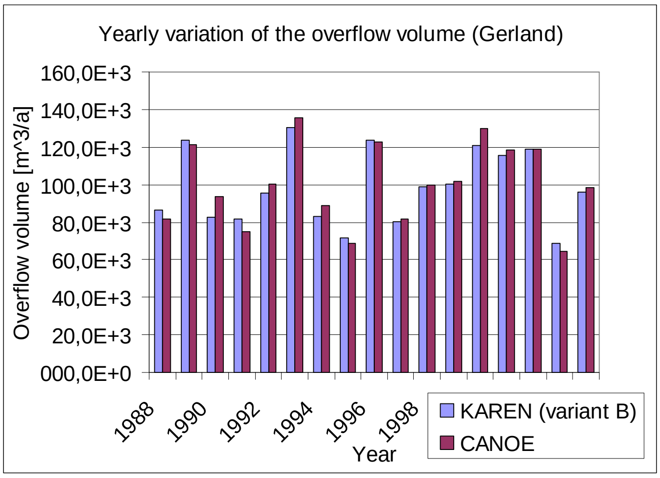


Figure 6-1 – Yearly variation of the overflow volume (Gerland, variant B)

In Figure 6-1 it can be observed that the overflow volume underlies important variations from year to year. The overflow volume for the strongest year is with 135000 m^3/a about the double of the feeblest (65000 m^3/a).
The same is valid for the other two parameters overflow duration and number of overflows. The results of the two models are quite coherent for each year, the biggest deviation between the two models can be observed for the Gerland rainfall time series in 1990 (with an underestimation of 11% from KAREN compared to CANOE). Again variant B proves better results as the maximum deviation for variant A is at 14%.
Detailed figures for all rainfall time series and variants can be found in Annexe B, page 59.

6.2. Comparison Matlab-model – Hydraulic approach (CANOE, KAREN)

As explained in paragraph 5.3.5.1, the pollutant loads calculated with CANOE and KAREN are directly proportional to the corresponding runoff volumes. The value for the TSS was presumed to be constant during each storm event at 226 mg/L. On the other side the Matlab-model returns a pollution concentration value (TSS in mg/L) for each time step. For the CSO and respective storage tank design this signifies that the exact (calculated) value for the TSS concentration is known at each minute of an overflow event.

Generally it can be observed that the peak of pollutant loads calculated by the Matlab-model correlates more or less with the runoff peak during a storm event (Figure 6-2). Since the CSO will be active mainly for runoff peaks it can be supposed that the overflow pollution according to the BW-model will be superior to the one calculated with a mean concentration. 20 random events for the St. Martin rainfall time series were compared; in most of the cases the calculated pollutograph follows the runoff hydrograph. See Annexe B, page 58 for the graphs of the 20 examined random events.

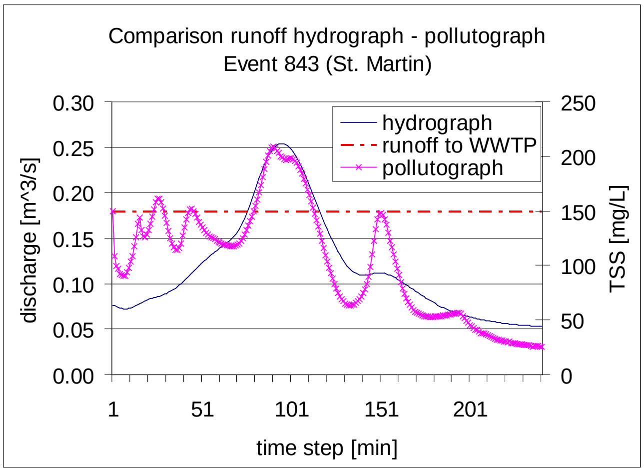


Figure 6-2 – Comparison of runoff hydrograph and pollutograph for a random event

6.2.1. Total runoff and overflow pollutant load

In a first step the correlation between the total runoff [m^3/a] and the runoff pollution load [kg/a] for the yearly rainfall series was examined. As can be seen in Figure 6-3, the results from the Matlab simulation are largely inferior to those obtained with CANOE. The differences reach up to 35% for the Gerland time series and up to 45% for the St. Martin series.

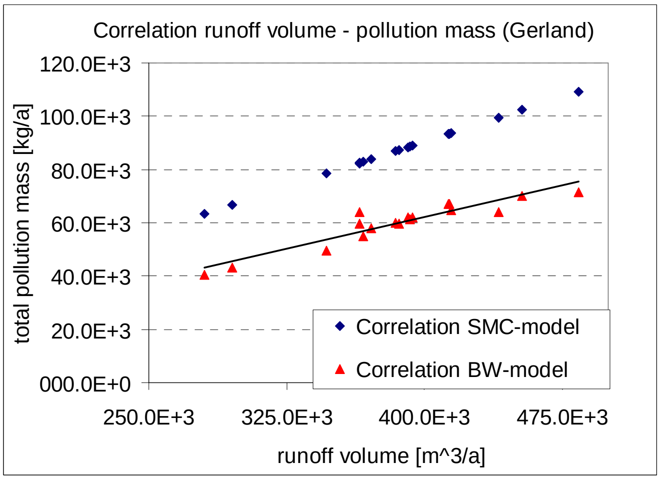


Figure 6-3 – Correlation of total runoff volume and pollutant mass

This difference can be explained to a certain part by the more sophisticated approach of the Matlab model. Surface erosion is only simulated while surface rainfall runoff is registered in the subcatchment. Once there is no more surface runoff, the simulation uses only the pollutant loads for the dry weather flow (see also paragraph 3.3.1.1). The mean concentration approach does not take into account this difference. Knowing that CANOE ends the simulation of one event 100 minutes after the last registered rainfall, a part of the runoff at the end of the event will contain only the dry weather concentration that is inferior to the mean storm weather concentration. In addition the calculated mean concentration for the calibrated events is slightly inferior to the measured mean concentration (see also 5.3.3)

After introducing the storage tank with varying specific volumes a second correlation – the overflow volume against the overflow pollution mass – was examined for the two approaches (Figure 6-4).

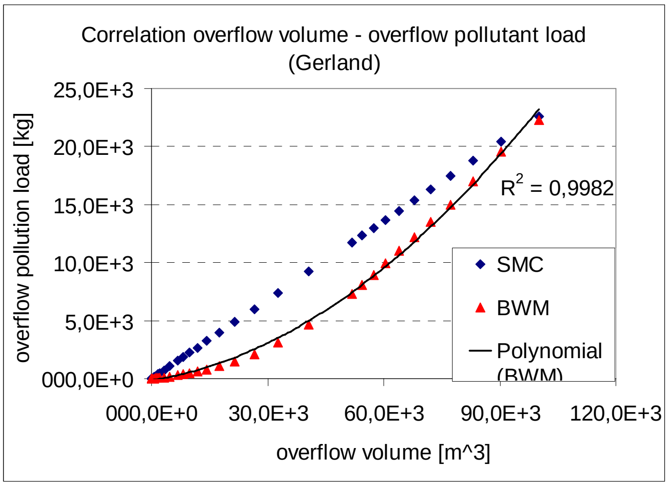


Figure 6-4 – Correlation of overflow volume and overflow pollution mass

While the total runoff pollution is clearly inferior when calculated with the BW-model, for high overflow volumes (corresponding to small storage tank volumes) the overflow pollution is nearly the same. This confirms the observations that pollutant peaks correlates to the runoff peaks.
Graphs for the St. Martin rainfall time series can be found in Annexe B, page 60.

6.2.2. Interception of pollutant loads

To be able to compare the efficiency of the storage tank for the three models, the pollutant interception ratio (see Equ. 5-8, page 27) in function of the specific tank volume was calculated.

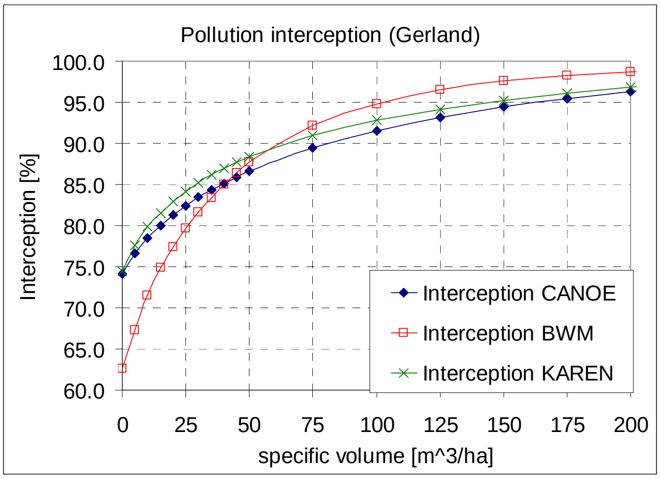


Figure 6-5 – Pollution interception calculated with the 3 used models

Figure 6-5 confirms the results obtained by M. Mourad (2005). For the Le Marais catchment the detailed BWM approach leads to lower interception ratios for small storage tank volumes. For an interception of 80% of the TSS pollutant loads the models CANOE and KAREN calculate the storage tank volume to about 15 m^3/ha while according to the Matlab-model 30 m^3/ha would be needed (Gerland rainfall time series).

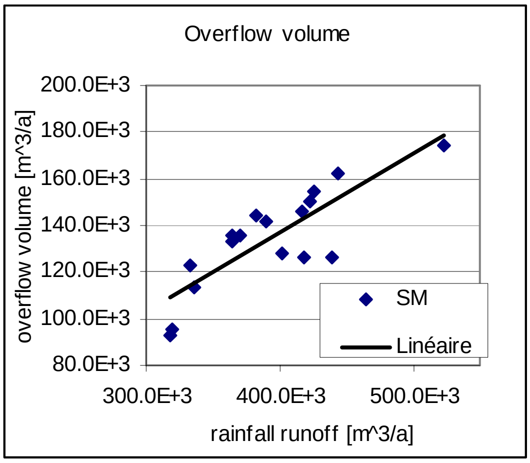
Augmenting the storage tank volume has a stronger effect on the interception ratio calculated with the BWM than on the SMC approach. Assuming that for larger settling tank volumes more peaks in the runoff are intercepted relatively to smaller volumes this comportment is consistent to the observations on the pollutant peaks.

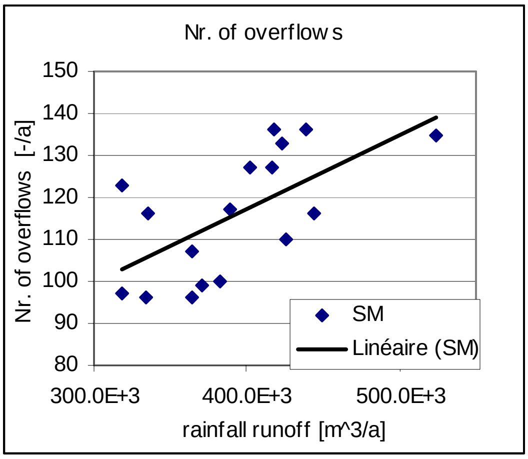
While the interception values for the St. Martin rainfall time series are slightly higher then those for Gerland, the same general comportment can be observed.
The complete tables for the calculated interception ratios in function of the storage tank volume for the rainfall time series St. Martin and Gerland can be found in Annexe B, page 61.

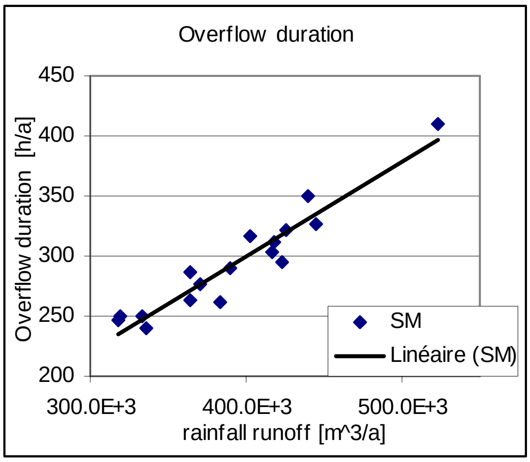
6.3. Annual variability of the results

An important aspect is the examination of the annual variability of the obtained results. It has already been shown that the overflow volume varies greatly for different yearly time series. (see Figure 6-1). The same is valid for the overflow duration and the number of overflows.

Now we shall compare the yearly rainfall runoff to the associated CSO parameters overflow volume, duration and number of overflows for the St. Martin rainfall time series:







While the correlation between total rainfall runoff (m^3/a) and the overflow duration seem quite satisfying, the correlation of rainfall runoff to overflow volume (m^3/a) has some significant extreme values. The correlation for the number of overflows is by far the worst.

This leads to the conclusion that using a parameter as yearly rainfall runoff (directly proportional to the rainfall depth) is not appropriate to predict the CSO comportment. Synthetic events that are calibrated for one parameter might not be adept to deduce other CSO parameters.

Apparently also the interception ratio will underlie an important annual variability. Figure 6-6 and Figure 6-7 show the interception ratios (SMC and BWM) for the 17 year average and for the 2 extreme series of 1993 and 1995.

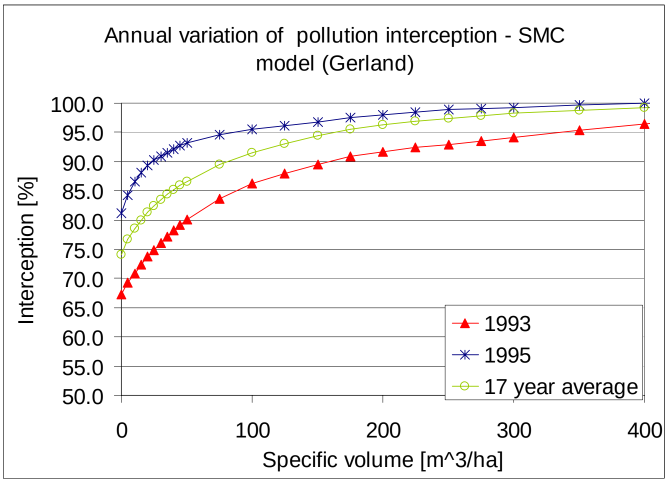


Figure 6-6 – Annual variability of interception (SMC model)

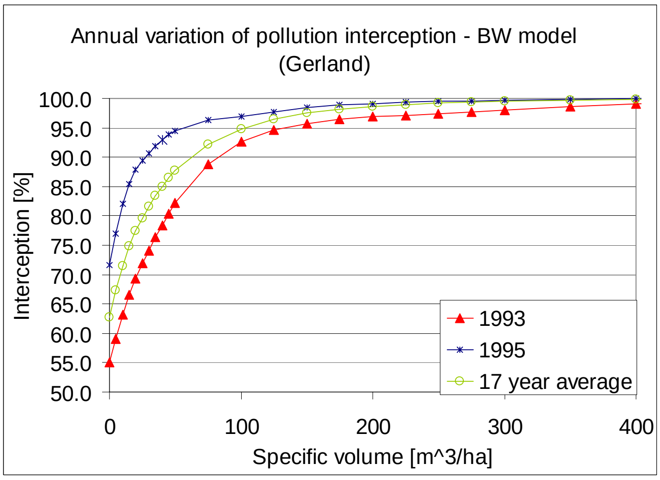


Figure 6-7 – Annual variability of interception (BW model)

The variability of the CSO pollutant load interception according to the BW-model lies between 55% and 71% with no introduced storage tank volume. An interception ratio of 80% would be reached for a specific volume of about 7 m^3/ha for the time series of 1995, while 45 m^3/ha would be needed for the 1993 series. The difference is even more important for the SMC approach where respectively 0 m^3/ha or 50 m^3/ha would lead to a pollution interception of 80% for 1995 and 1993.
This important difference shows that using only few rainfall events or even yearly rainfall time series for the design can lead to enormous variations in the design ratio.
It also implies that monitoring of CSOs needs to be carried out over a long period of time to be able to deduce a valid conclusion on their function.

6.4. CSO and storage tank design according to Austrian and German standards

In the context of the Amadeus project a comparison of the regulations and standards used in Austria, France and Germany was proposed.

In Austria, CSO structures have to be design according to the “Stand der Technik” that is defined in the guideline “ÖWAV Regelblatt 19”. The first edition (1987) is being revised at the moment. The second edition was therefore only available in its draft version (from 11.12.2003).

France on the other hand does not have any clear standards on CSO design, only recommendations exist (CERTU 2003).

In Germany, as in some other European countries, the guideline “Arbeitsblatt ATV A 128” is widely used. Even though it has not the status of a national standard it is the minimum design requirement in most of the federal states.

A direct comparison of the standards was difficult, since they use different approaches for the design. While the old Austrian standard “Regelblatt 19 – 1st edition” bases the design on a single design storm, the new draft version defines an efficiency factor that has to be reached, based on dissolved pollutants and suspended solids. The German ATV A-128 on the other hand is based on COD loads.

6.4.1. Regelblatt 19 – 1st edition – 1987

This guideline aims to directing 70-90% of the suspended solids during a storm event to the WWTP. (in terms of an annual mean load).

The design is based on a single design storm event (called “critical storm event”) that is defined by the catchment properties. The minimal runoff that should be chosen is $r_{krit} = 15\, l/s \cdot ha$.
Since in general practice this value has been applied for most designs it was decided to use it also in this study.

Two design values are deduced from r_{krit} : the “critical rainfall runoff” $Q_{r,krit} = r_{krit} \cdot A_{red}$, wherein A_{red} is the active area and the “critical runoff” $Q_{krit} = Q_{r,krit} + Q_t$ with the dry weather runoff Q_t .

For the le Marais catchment the following values are obtained:

Q_t	60	[L/s]
Q_{wwtp}	180	[L/s]

r_{krit}	15	[L/s*ha]
A_{red}	32.7	[ha]
$Q_{r,krit}$	490.5	[L/s]
Q_{krit}	550.5	[L/s]

Table 6-2 – CSO design values according to Regelblatt 19, 1st edition

A combined sewer overflow has to be designed so that the spilling starts when the runoff surpasses Q_{krit}. If Q_{krit} is superior to the runoff that can be treated at the WWTP (what is the case in most catchments), a storage tank has to be introduced.

When r_{krit} is chosen with 15 L/s the specific storage tank volume is fixed to $V_s = 15\, m^3 / ha_{red}$.

In our case this leads to a total volume of 490.5 m^3.

Vs	15	[m^3/ha,red]
V	490.5	[m^3]

Table 6-3 – Settling tank volume according to Regelblatt 19, 1st edition

6.4.2. Regelblatt 19 – 2nd edition – draft 2003

Contrary to the 1st edition the second one recommends using rainfall time series of at least 10 years with a time step of 10 minutes or smaller. The simulation should be effected with a hydrological simulation model. In addition an immision based study on the receiving water is proposed.
In this work only the emmision constraints are regarded.

To design according to the "Stand der Technik" an efficiency factor η (Equ. 6-1) has to be reached.

In addition the ratio restricted effluent to dry weather discharge (overflow dilution) has to be superior to 8.

$$\eta_r = \frac{VQ_r - VQ_e}{VQ_r} \cdot 100 \qquad \textbf{Equ. 6-1}$$

With:
VQ_r… Total yearly rainfall runoff volume [m^3/a]
VQ_e… Total yearly overflow volume [m^3/a]

This factor is influenced by the population density, the annual rainfall depth and – if relevant – attached separated sewer systems.

The population density is indirectly taken into account by the size of the waste water treatment plant (indicated by the population equivalent).

	Size of the WWTP (population equivalent)		
	<5000	5000-50000	>50000
η : NH_4-N, total N, total P, COD, BOD_5	55	60	65
η : TSS	70	75	80

Table 6-4 – Efficiency factor η due WWTP size

For stronger rainfall the Regelblatt 19 allows to reduce the efficiency factor by an indicated percentage.

Rainfall time series	Gerland	St Martin	Vorarlberg	
Annual rainfall depth	710	1212	1223	[mm/a]
Reduction	5	15	15	[%]
η : NH_4-N, total N, total P, COD, BOD_5	55	45	45	[-]
η : TSS	70	60	60	[-]

Table 6-5 – Reduction of η due to annual rainfall depth

For dissolved pollutants (like N, P…) it is supposed that the pollutant load corresponds to the runoff volume. The efficiency factor η equals the above stated η_r .

For CSOs the efficiency factor for total suspended solids η_{AFS} is the same as η_r . If a storage tank is introduced that allows sedimentation, the factor η_{AFS} is calculated by Equ. 6-2. Since the chosen model of the storage tank does not allow sedimentation this option is not used in this study.

$\eta_{AFS} = \eta_r + \dfrac{VQ_e \cdot \eta_{sed}}{VQ_r}$	**Equ. 6-2**

With:
VQ_r… Total yearly rainfall runoff volume [m^3/a]
VQ_e… Total yearly overflow volume [m^3/a]
η_{sed} … Efficiency coefficient of sedimentation according to storage tank size (see Table 6-6)

Specific volume [m^3/ha]	η_{sed} [%]
Storage tank	
0	0
5	20
10	35
>15	50

Table 6-6 – Efficiency coefficient of sedimentation according to storage tank size

Several simulations with KAREN have been carried out for the three rainfall time series, varying the specific storage tank volume. Table 6-7 shows the resulting specific volumes that satisfy the efficiency ration.

Specific volume [m^3/ha]	Gerland	St. Martin	Vorarlberg		
	70	60	60	η_{AFS} , demanded	
	233.9E+3	392.2E+3	392.0E+3	rainfall volume	[m^3/a]
0	98.7E+3	134.8E+3	130.7E+3	Overflow volume	[m^3/a]
	57	66	68	η_{AFS}	[-]
5	86.3E+3			Overflow volume	[m^3/a]
	63			η_{AFS}	[-]
15	71.3E+3			Overflow volume	[m^3/a]
	70			η_{AFS}	[-]

Table 6-7 – Calculated efficiency factors (without sedimentation)

According to the results for η_{AFS} no storage tank would be needed for the St. Martin and the Vorarlberg rainfall time series. However, the demanded dilution ratio of 8 for CSOs would not be respected in that case. The draft version of the guideline does not detail on a resembling case.

6.4.3. ATV A 128

The ATV A 128 – "Richtlinien für die Bemessung und Gestaltung von Regenentlastungsanlagen in Mischwasserkanälen" bases the design on the COD concentration. Since the available data for the Le Marais catchment was in TSS, the "standard" values according to the ATV 128 were used.

For the catchment a "required total storage volume" (*Gesamtspeichervolumen*) is calculated. Depending on the parameters it can be obtained through a simplified design procedure using diagrams or through a more complex method using simulation models and rainfall time series.
An indicative parameter is the rainfall runoff to the WWTP q_r [L/(s*ha$_{red}$)]. When this value surpasses 2 l/(s*ha) – as is the case in this study (see Table 6-8) – the detailed method has to be applied.

Q_{t24}	60	L/s	Mean dry weather flow
Q_m	180	L/s	Discharge to WWTP
A_u	32.7	ha	Active surface
Q_{r24}	120	L/s	Rainfall runoff to WWTP during overflow $Q_{r24}=Q_m-Q_{t24}$
q_r	3.64	L/(s*ha)	$q_r=Q_{r24}/A_u$

Table 6-8 – Rainfall runoff to the WWTP (ATV A-128)

The detailed method consists of using a simulation model (both hydrologic and hydrodynamic simulation can be used) to calculate the allowed overflow ratio (*"Entlastungsrate"*) "e_0" and the actual overflow ratio "*e*" for a chosen storage tank volume. The storage tank volume has to be varied until the actual overflow ratio equals the allowed ratio. The equations that are influenced by the variation of the storage tank volume are listed below:

$Q_{re} = \frac{V_{qe}}{Te \cdot 3.6} + Q_{r24}$	[L/s]	Mean rainfall discharge during overflow event
With: V_{qe}…Overflow volume [m^3/a] T_e… Overflow duration [h/a]		
$m = \frac{Q_{re}}{Q_{t24}}$	[-]	Proportion rainfall to dry weather runoff
$c_e = \frac{m \cdot c_r + c_b}{m+1}$	[mg/L]	Overflow concentration
With: c_r… storm water concentration [mg/L] c_b… design concentration [mg/L]		
$e_0 = \frac{3700}{c_e - 70}$	[%]	Overflow ratio

Table 6-9 – Main equations for the calculation of the overflow ratio

Finally the specific volumes are calculated to 20m^3/ha for the Gerland rainfall time series and 5m^3/ha for St. Martin and Vorarlberg.

Gerland	St. Martin		
20	5	Specific Volume	[m^3/ha]
654	163.5	total Volume	[m^3]
371.3	275.0	Q_{re}	[L/s]
6.19	4.58	m	[-]
30.9	30.6	e_0	[-]
30.9	30.6	e	[-]

Table 6-10 – Calculated specific volumes ATV A-128

6.4.4. Result overview

The design according to the mentioned standards result in the specific storage tank volumes for each rain fall time series as listed in Table 6-11

	Gerland	St. Martin	Vorarlberg		
Regelblatt 19, 1st edition	15	15	15	specific volume	[m^3/ha]
Regelblatt 19, 2nd edition (draft)	15	0[1]	0[1]		
ATV A-128[2]	20	5	5		

Table 6-11 – Specific storage tank volumes according to Austrian and German guidelines

[1]… The Austrian standard Regelblatt 19 2nd edition includes a constraint for CSO design concerning the ratio of dry weather/storm weather flow in the overflow discharge. This ratio is not reached in our case.

[2]… The German ATV A-128 also demands a ratio of dry weather/storm weather discharge. With the chosen setting this ration can not be obtained.

The Regelblatt 19, 2nd edition allows a reduction of the efficiency factor η for strong rainfalls. In the studied case the stronger rainfall series lead already to a higher efficiency factor, so this reduction does not seem appropriate in this case. It has to be said however that a newer draft version of the Regelblatt 19 became available at the very end of this study. The possible reduction of the factor η in the newer version is not based on the average rainfall depth but on the parameter $r_{720,1}$ being the maximum rainfall volume in 12 hours with a return period of one year [mm/12h] as defined in the ATV Arbeitsblatt A-121.

For the ATV A-128 the total demanded storage volume for the catchment is calculated. If one single storage tank is introduced with the according volume, the demanded dilution ration can not be obtained.

7. Questionnaire on rainfall data and CSO design

A questionnaire was designed to get an overview of applied standards and guidelines for CSO and storage tank design in different European countries. Australia also took part.
Several international experts were contacted by Jean-Luc Bertrand-Krajewski and asked if they would participate in this survey. The echo was very positive so that finally we got specific information from 9 different countries.

The experts include researchers at universities as well as employees of private companies. Of course this overview can only include the personal knowledge of the experts, whereby it does not claim to be exhaustive. Table 7-1 gives an overview of the participating countries and the respective interviewed experts.

Country	Expert	Institution	City
Personal interview by phone			
Australia	Tim FLETCHER	Monash University - Department of Civil Engineering	Melbourne, Victoria
Belgium (Flanders)	Johan VAN ASSEL	Aquafin nv	Aartselaar
Denmark	Ole MARK	DHI - Institute for Water and Environment	Hørsholm
France	Jean-Luc BERTRAND-KRAJEWSKI	INSA de Lyon, URGC, laboratiore hydrologie urbaine	Lyon
Germany	Thomas EINFALT	einfalt & hydrotec GbR	Lübeck
Norway	Sveinung SAEGROV	NTNU - Dept. of Hydraulic & Environmental Engineering, IVT Faculty	Trondheim
Portugal	José MATOS	Universidade Técnica de Lisboa	Lisboa
	Luis Mesquita DAVID	Laboratório Nacional de Engenharia Civil	Lisboa
Spain	David SUNER	CLABSA	Barcelona
Answers by e-mail containing references			
USA	Eric STRECKER		
Luxemburg	Emmanuel HENRY	CRTE / CRP Henri Tudor Technoport Schlassgoart	

Table 7-1 – Participating countries

Since the practices in CSO design, the available rainfall data and the applied simulation models vary greatly from country to country a conclusive summery is nearly impossible. For two of the interrogated countries (Australia and Portugal) CSO design is of low interest as mainly separate sewer systems are in place.
The detailed information for each country as well as an example of the questionnaire can be found in Annexe C.

7.1.1. Standards and guidelines

As stated above significant differences between the countries can be observed. While some countries have clearly defined design rules others tend to give more freedom to their engineers. Only in few countries mandatory standards including detailed design rules are in place. Austria and Germany for example posses of guidelines proposed by waste water associations that define minimum requirements for CSOs design that are – in most cases – mandatory to be reached.
In other countries like Portugal or Norway standards and laws only contain general information and recommendations on design.
Then again, in Denmark CSOs design is based on a “Best Practice” method – meaning that there are no rules or requirements but that CSO design should be carried out in the most satisfying way in accordance with the municipalities.

7.1.2. Rainfall data

Also the rainfall data used for the design is far from being unified in Europe. In some countries, e.g. Portugal, Belgium or Spain more or less sophisticated single design storms are used for CSO design. In Germany the applied rainfall data varies for the federal states, ranging from single design storms, synthetic series to real rainfall time series of 20 years. In France, Denmark and Australia the use of rainfall data depends mainly on the consciousness of the engineer. In Austria, Norway and Denmark the use of real rainfall time series is recommended, still mostly single design storms are used for CSO design.
In most of the countries long term rainfall time series are only used to evaluate existing sewer systems or in case of complex studies.

National meteorological institutes provide rainfall data and are responsible for the network of measurement stations. Furthermore, in many countries additional measurement stations are maintained by municipalities or universities. The recording timestep varies between some minutes and daily records.
While in general rainfall data has to be paid for it can be obtained for free for research purposes in some countries.

7.1.3. Simulation models

According to the available rainfall data and the practice in CSO design the used simulation models range from no modelling at all over hydrological models (Germany, Austria) to detailed hydrodynamic modelling (Belgium, Denmark, Norway). MOUSE is the most widespread model in the interrogated countries. In France CANOE is widely used.
In Australia (Melbourne) a hydrological model that includes pollution transport was designed for storm water modelling.

8. Conclusions and perspectives

A first point that has to be made for the following conclusions is that the obtained results are limited to the examined catchment. As it is defined by some special properties as a high population density, an important part of imperved surface and very large sewer sections the results might not be valid for other catchments.

The results confirm that a great annual variability can be observed for all models. Not only do the observed parameters overflow volume, overflow duration, number of overflows and interception ratio vary strongly for different annual series. It was also shown that for a characteristic rainfall parameter (in the examined case the annual rainfall height) the results are not necessarily correlated. This leads to the conclusion that a single design storm can not reflect the real comportment of the overflow structure and will put the predictions on its function high in question.
These results show the importance of using long rainfall time series to obtain a meaningful estimation of the long term function of a CSO structure. Nevertheless the examination should not be limited to average values obtained with the total series as strong years can have an important impact on ecological or hydraulic sensitive receiving waters.
In addition this implies that the monitoring of CSOs needs to be carried out over a long period of time to lead to representative results.

Also the different model approaches yield interesting results. For the studied catchment the simplified hydrological model KAREN and the hydrodynamic model CANOE showed a high correlation in their results. However, the sewer system is not complex and due to the large sewer sections no surcharge or flooding occurs. As a study of Schaardt and Neumann (2005) shows, using hydrological models may lead to an overestimation of design ratios for storage volumes.
Concerning the pollutant modelling the hydraulic models that calculate with a site mean concentration and the Matlab-model using a detailed approach with pollutographs, an important difference could be observed. For smaller storage tank volumes the BW approach leads to lesser interception ratios. To obtain an interception ratio of 80% the double of the storage tank volume compared to the SMC approach would be needed.
This shows that the repartition of the pollutants in the discharge has a strong effect on the design ratio. However, the results for the pollutant simulations have to be regarded with a certain distance. Generally we try to predict real behaviour by a model that was calibrated by measured data. As it was shown, the results underlie a great variability according to the yearly variation in the rainfall characteristics. The question has to be posed if 40 measured events for the pollutographs can represent the pollution for the thousands of rainfall events that are included in the rainfall time series. Nevertheless the results lead to the conclusion that including pollutant flows will affect the results and therefore the design of CSO structures.

The comparison of the Austrian and German standards led to some surprising results. Actually the standards don’t seem to be fully adapted to the specifications of the le Marais catchment. With the chosen setting the demanded dilution factor found in the ATV Guideline can not be satisfied.
The Austrian Regelblatt 19 allows a reduction of the efficiency ratio for rainfall series with high intensities that does not seem coherent for the studied case as no storage tank volume would be needed according to the calculations. Only the demanded dilution factor for CSOs implies that a tank has to be constructed but no indications on the size are found. However, a new draft version of the Austrian standard became available at the end of this study that replaces the rainfall height by another parameter to allow the reduction of the efficiency factor. A recalculation using this parameter is recommended.

It became also clear with the effected survey that the practice for CSO and storage tank design in European countries differs enormously. A general European approach seems not to be thinkable of in the near future.

One question that should be asked in general when CSOs are concerned is “What is the aim of the structure?”
While emission based approaches base the design on interception factors or dilution ratios they can’t fully answer to the questions of the impact on the receiving water. For example, all effected calculations would imply that for the St. Martin and the Vorarlberg rainfall time series a lower storage tank volume than for the Gerland time series is needed. On the other hand the two Austrian time series are characterized by far more overflow events, a far higher overflow volume and overflow duration and consequently far higher overflow pollution mass than the French series for the same volume. Evidently the impacts on the receiving water would be more important.
Therefore also an immision approach seems appropriate.

Of course this work offers some interesting perspectives and leaves place for further research.

The use of rainfall time series should be enforced in CSO and storage tank design as other design approaches don’t seem to give satisfying results. As the tendency in European countries shows that more and more long term series will be available in the years to come it can only be advised to also apply them.

As described above the studied catchment has some particular properties. Applying the rainfall time series to other catchments could be of interest especially to see if the Austrian and German guidelines lead to more satisfying results there.

To conclude it seems evident that detailed pollutant models will give different results from mean concentration approaches. However, the simulation time is still important and the quality of the models can be put in questions due to the high number of variables that have to be adjusted. A high interest would lie in a model evaluation with long term pollutant measurements.
Pollution measurements are relatively expensive and therefore not often carried out. However, with the development of continuous pollution measurement it can be hoped that detailed data of good quality will be available in near future.

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ANNEXES

ANNEXE A - Rainfall data

Measurement gaps - Annual rainfall depth (Austrian rainfall time series)

Kufstein rainfall time serie: Annual rainfall depth								
Years with measurement gaps during the winter period						Years with no gaps		
year	mm	year	mm	year	mm		year	mm
1948	951	1963	761	1978	809		1990	1165
1949	895	1964	731	1979	844		1991	1189
1950	739	1965	577	1980	969		1992	1308
1951	417	1966	1262	1981	863		1993	1454
1952	526	1967	715	1982	848		1994	1272
1953	683	1968	866	1983	951		1995	1459
1954	1051	1969	683	1984	806		1996	1339
1955	872	1970	991	1985	886		1997	1364
1956	826	1971	677	1986	715		1998	1346
1957	882	1972	659	1987	846		1999	1571
1958	857	1973	586	1988	737		2000	1477
1959	1035	1974	824	1989	905		2001	1474
1960	911	1975	778				2002	1458
1961	774	1976	843					
1962	723	1977	735					
Average 1948 -1989:					812	Average 1990-2002		1375

Innsbruck rainfall time series - annual rainfall depth			
year	mm	year	mm
1981	720	1991	604
1982	540	1992	473
1983	629	1993	610
1984	586	1994	446
1985	633	1995	551
1986	516	1996	680
1987	575	1997	491
1988	616	1998	580
1989	621	1999	693
1990	572	Average:	586

Comparison of the Grand Lyon rain gauges

Excel file: “gl_ComparisonDataChoice.xls”

	Gerland						Moins						Charly					
year	rainfall depth			Nr. Events			rainfall depth			Nr. Events			rainfall depth			Nr. Events		
	[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2	[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2	[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2
1988	580.8	15.5	240.3	175	3	9	856.0	-259.7	67426.9	172	0	0	589.5	6.8	46.7	171	-1	1
1989	640.5	-168.9	28528.9	127	12	141	395.8	75.8	5739.9	115	0	0	443.2	28.4	808.2	112	-3	10
1990	583.2	-25.8	666.1	148	-1	1	568.8	-11.5	131.7	143	-6	36	497.2	60.2	3622.9	150	1	1
1991	460.3	31.9	1017.9	122	-8	62	388.0	104.2	10865.6	102	-28	776	461.2	31.1	965.4	133	3	10
1992	648.8	13.5	182.3	161	-13	162	705.8	-43.5	1892.2	167	-7	45	648.0	14.3	205.4	164	-10	94
1993	701.8	35.2	1238.4	150	-3	7	815.8	-78.8	6210.9	131	-22	465	763.7	-26.6	709.8	160	7	55
1994	598.8	-13.5	181.6	173	10	109	657.8	-72.5	5252.8	166	3	12	554.8	30.5	931.7	151	-12	134
1995	540.7	76.9	5910.7	161	2	5	626.0	-8.5	71.4	150	-9	76	558.0	59.5	3545.9	150	-9	76
1996	727.2	-25.8	663.7	160	14	192	696.8	4.6	20.9	137	-9	84	649.8	51.6	2659.6	142	-4	17
1997	540.8	-62.4	3888.4	165	11	127	524.0	-45.5	2072.4	157	3	11	422.5	56.0	3133.3	144	-10	94
1998	589.2	-28.9	834.1	151	3	12	646.7	-86.4	7461.7	147	-1	0	423.3	137.0	18755.9	122	-26	654
1999	618.0	41.1	1686.9	171	-8	62	636.8	22.2	494.5	172	-7	47	571.0	88.1	7756.6	163	-16	251
2000	700.7	-74.3	5521.9	180	19	372	621.3	5.0	25.2	138	-23	516	491.0	135.4	18321.6	150	-11	115
2001	724.3	-72.3	5225.2	200	17	275	667.7	-15.6	244.0	186	3	7	564.3	87.7	7693.8	174	-9	89
2002	763.0	24.1	580.6	198	14	188	878.3	-91.2	8324.4	180	-4	18	778.5	8.6	73.9	189	5	22
2003	435.8	-21.8	474.6	130	9	89	404.5	9.5	91.2	127	6	41	482.0	-68.0	4617.5	126	5	29
2004	620.0	-22.0	486.1	159	9	89	452.2	145.8	21253.5	124	-26	654	522.3	75.6	5718.3	133	-17	275
			57327.6		93	1900			137579.2		-124	2788			79566.6		-104	1928
((xq-x)^2)^0.5			239.4			43.6			370.9			52.8			282.1			43.9
average	616.1			161			620.1			148			554.1			149		

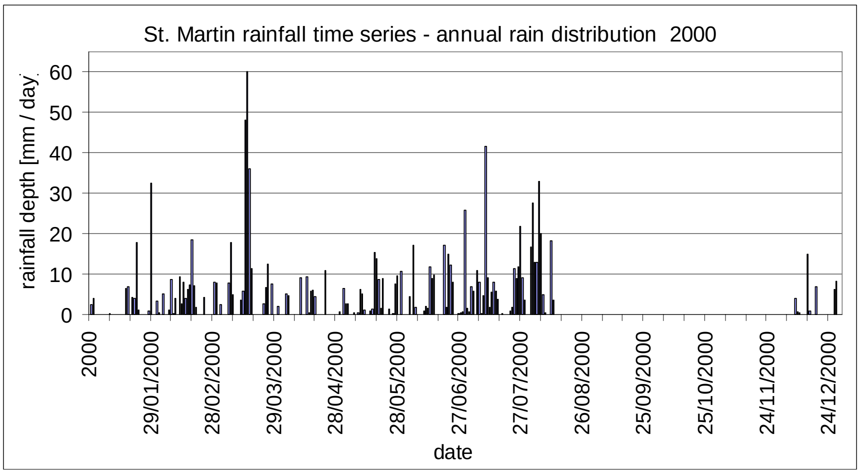
Montanay						Corbas						Loyasse					
rainfall depth			Nr. Events			rainfall depth			Nr. Events			rainfall depth			Nr. Events		
[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2	[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2	[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2
635.7	-39.3	1547.1	200	28	784	291.7	304.7	92821.8	92	-80	6400	549.8	46.5	2162.3	202	30	900
499.2	-27.6	760.2	108	-7	51	417.7	53.9	2908.3	110	-5	26	381.8	89.8	8057.2	119	4	15
485.2	72.2	5211.5	140	-9	81	548.3	9.0	81.4	137	-12	144	555.7	1.7	2.9	158	9	81
608.0	-115.8	13400.8	137	7	51	497.2	-4.9	24.3	131	1	1	495.2	-2.9	8.6	145	15	229
715.2	-52.8	2791.4	184	10	106	688.7	-26.3	693.5	186	12	151	687.3	-25.0	625.0	193	19	372
859.3	-122.3	14959.7	166	13	180	822.8	-85.8	7363.3	156	3	12	655.3	81.7	6673.3	157	4	20
645.7	-60.3	3637.3	181	18	340	583.7	1.7	2.9	155	-8	57	374.5	210.9	44460.7	141	-22	465
538.0	79.5	6327.8	150	-9	76	688.2	-70.6	4987.0	157	-2	3	620.5	-3.0	8.7	164	5	28
677.3	24.1	579.4	141	-5	26	772.0	-70.6	4983.7	141	-5	26	599.2	102.2	10452.6	143	-3	10
532.2	-53.7	2882.7	169	15	234	532.3	-53.9	2900.6	158	4	18	424.2	54.3	2949.5	145	-9	76
544.2	16.1	259.8	161	13	180	558.5	1.8	3.2	142	-6	31	575.8	-15.5	241.7	156	8	71
725.3	-66.3	4390.6	192	13	173	722.0	-62.9	3960.0	184	5	26	672.2	-13.1	171.5	192	13	173
662.5	-36.1	1306.3	158	-3	7	711.0	-84.6	7164.4	168	7	53	564.3	62.0	3846.9	169	8	69
688.2	-36.1	1304.6	175	-8	71	601.8	50.2	2521.5	180	-3	12	663.5	-11.5	131.2	195	12	134
816.2	-29.1	845.1	184	0	0	850.0	-62.9	3957.0	185	1	1	707.8	79.3	6282.4	185	1	1
401.7	12.4	153.3	127	6	41	471.5	-57.5	3300.8	113	-8	57	322.3	91.7	8411.5	130	9	89
741.2	-143.2	20510.3	171	21	459	516.0	82.0	6716.2	143	-7	43	653.8	-55.9	3122.7	159	9	89
		80868.0		106	2861			144389.7		-100	7063			97608.8		115	2820
		284.4			53.5			380.0			84.0			312.4			53.1
633.8			161			604.3			149			559.0			162		

Polimieux					
rainfall depth			Nr. Events		
[mm/a]	xq-x	(xq-x)^2	[-/a]	xq-x	(xq-x)^2
670.8	-74.5	5550.2	192	20	400
523.0	-51.4	2642.4	115	0	0
663.2	-105.8	11195.7	167	18	324
535.8	-43.6	1900.6	139	9	84
542.5	119.8	14360.0	161	-13	162
540.3	196.7	38687.2	148	-5	21
682.2	-96.8	9372.0	171	8	71
751.5	-134.0	17943.2	179	20	412
787.5	-86.1	7412.4	159	13	165
373.3	105.1	11055.0	138	-16	247
584.3	-24.0	578.3	154	6	41
668.2	-9.1	82.7	178	-1	1
633.7	-7.3	53.4	162	1	2
654.5	-2.5	6.0	174	-9	89
715.8	71.3	5078.2	169	-15	234
380.5	33.5	1125.4	91	-30	874
680.2	-82.2	6759.2	158	8	71
		133802.1		17	3197
		365.8			56.5
611.0			156		

average for the 7 rain gauges				
	[mm/a]		[-/a]	year
4174	596	1204	172	1988
3301	472	806	115	1989
3901	557	1043	149	1990
3446	492	909	130	1991
4636	662	1216	174	1992
5159	737	1068	153	1993
4097	585	1138	163	1994
4323	618	1111	159	1995
4910	701	1023	146	1996
3349	478	1076	154	1997
3922	560	1033	148	1998
4614	659	1252	179	1999
4385	626	1125	161	2000
4564	652	1284	183	2001
5510	787	1290	184	2002
2898	414	844	121	2003
4186	598	1047	150	2004
	599.7		155	

Year 2000 - St. Martin rain gauge

Excel file: "Stmartin_total_v_1_1.xls"



Transformation program

The program for the rainfall data transformation was written in Visual BASIC for applications (Excel).
Excel file: "Transformation_v_4_4_6.xls"
Description of the contained modules:

can_Austria_convert:
This module converts Austrian rainseries (file.ixx) to rainseries that can be imported by CANOE

can_CreateCharts_analyse
This module creates an Excel files for each year from the rainfall time series; graphs for each event and an annual graph are added. In the file [filename_total.xls] an overview with all annul graphs is stored. The input file has to be in the CANOE format.

can_GrandLyon
This module extracts a rain gauge from the Grand Lyon data series, deletes events with no data and splits events with dry time>120 min

can_Split_rain
This module splits rain events longer then 1440 minutes to one or more events (Canoe cannot treat rain events with more than 1440 time steps)

Functions
This module contains common functions and procedures used by the other moduls

Global
This module contains all public variables and type definitions

Karen_transform
This module transforms files from the CANOE format to the format used by KAREN. The procedure ConvertCanoetoKaren (everyYear as Boolean) is the main transformation module. The boolean value can be set to true to create one file for each year or to false to convert the whole file.

Matlab_transform
This module transforms files of the CANOE format to the format used by the MATLAB model. For each event one file is created

Format of rainfall data CANOE

1988/01/03 14:42:00 ~001.	Name (max. 34 characters)
0	X (Epicentre)
0	Y (Epicentre)
Gerland	rain gauge (name or number)
1	defined date (1 if date defined, 0 if not)
03/01/1988	date (dd/mm/yyyy)
14:42	starting time (hh:mm:ss)
3	Number of timesteps (integer)
6	Duration of each time step (real) [minutes]
4	intensity (n intensities - one for each timestep) [mm/h], maximum 1 decimal
4	i2
4	i3
Coefficient a	(allows to calculate intensity in a distance from the epicentre
Coefficient b	see canoe manual for details (§3.1.2.3 and §6.3.1)
	Duration of dry time afterwards (real) [minutes]
Any comment	Comment (Zero to n lines)
@@@com	End of comment
1988/01/04 04:36:00 ~000.	Next event
.	
.	
@@@fin	Marks end of file

Format of rainfall data KAREN

```
3 19880103  1442   0   3  6  1.2
 1.111 1.111 1.111
```

First line:
"3" is system value, followed by the date (yyyymmdd), the starting time (hhmmss), the number of time steps, duration of the time steps and total intensity of the rainfall event [mm]

Second line to line "n":
intensities [µm/s] with a maximum of 10 intensities in each line

Format of rainfall data MATLAB model

One file for each event, time step transformed to 1 minute

gl_8801031442	Name
03/01/1988	Date [dd/mm/yyyy]
14:42	starting time [hh:mm]
1	Time step [min]
13	Dry time until next event [h]
18	Nr timesteps [-]
4	intensity (n intensities – one value for each timestep) [mm/h
4	
4	
4	
4	
4	
4	

4
4
4
4
4
4
4
4
4
4
4

Events on 31st of December

St. Martin
1993: 31/12/1993 at 16:40:00 event 9:50h → 01/01/1994 at 02:30:00
next event: 01/01/1994 at 04:30:00

1995: 31/12/1995 at 23:45:00 event 6:10h → 01/01/1996 at 05:55:00

Fußach:
1993: 31/12/1993 at 21:15:00 event 9:45h → 01/01/1994 07:00:00

Tschagguns
1993: 31/12/1993 at 22:30:00 event 4:55h → 01/01/1994 03:25:00
1995: 31/12/1995 at 16:55:00 event 9:55h → 01/01/1996 02:55:00

Parameters for the Grand Lyon transformation program

It was decided that all events should be kept.

“Le seuil d’intensité moyenne maximum observe sur 18 minutes sur au moins un poste pour que l’événement soit conserve” → 2 mm/h

This means that an event will be counted as soon as 2 mm/h are observed on one rain gauge during a period of 18 minutes

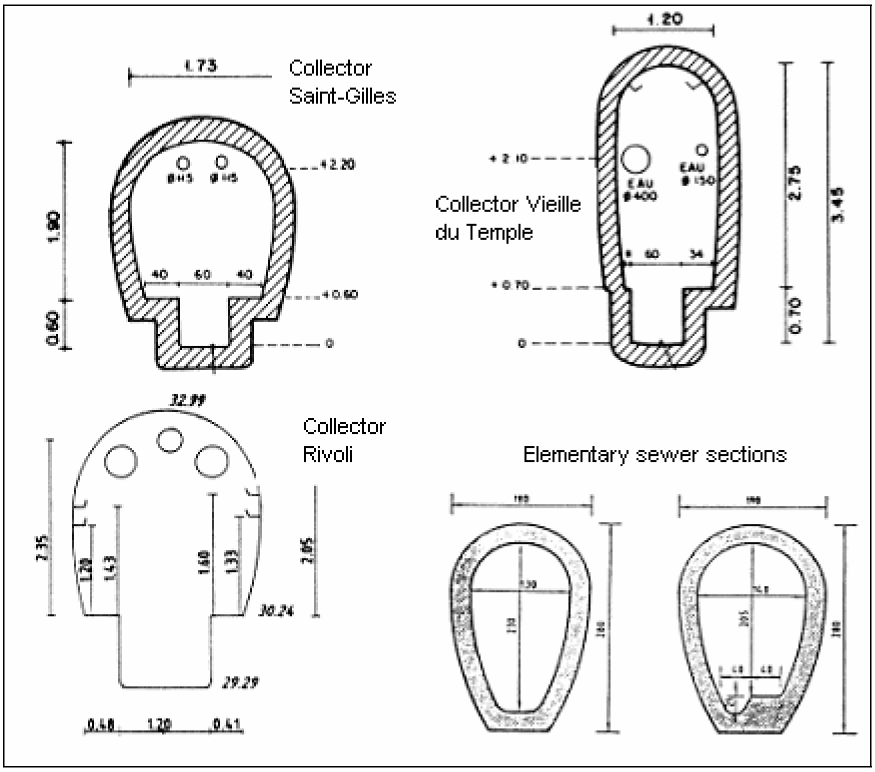
« Le seuil d’intensité moyenne maximum observé sur 18 min pour déterminer le début et la fin de la pluie » → 0 mm/h

This parameter can be used to delete feeble intensities at the beginning at the end of an event. Since the model works with no infiltration this was not of interest.
« Le seuil de la lame d’eau moyenne sur l’ensemble à partir duquel l’événement pluvieux serait conservé » → 0 mm

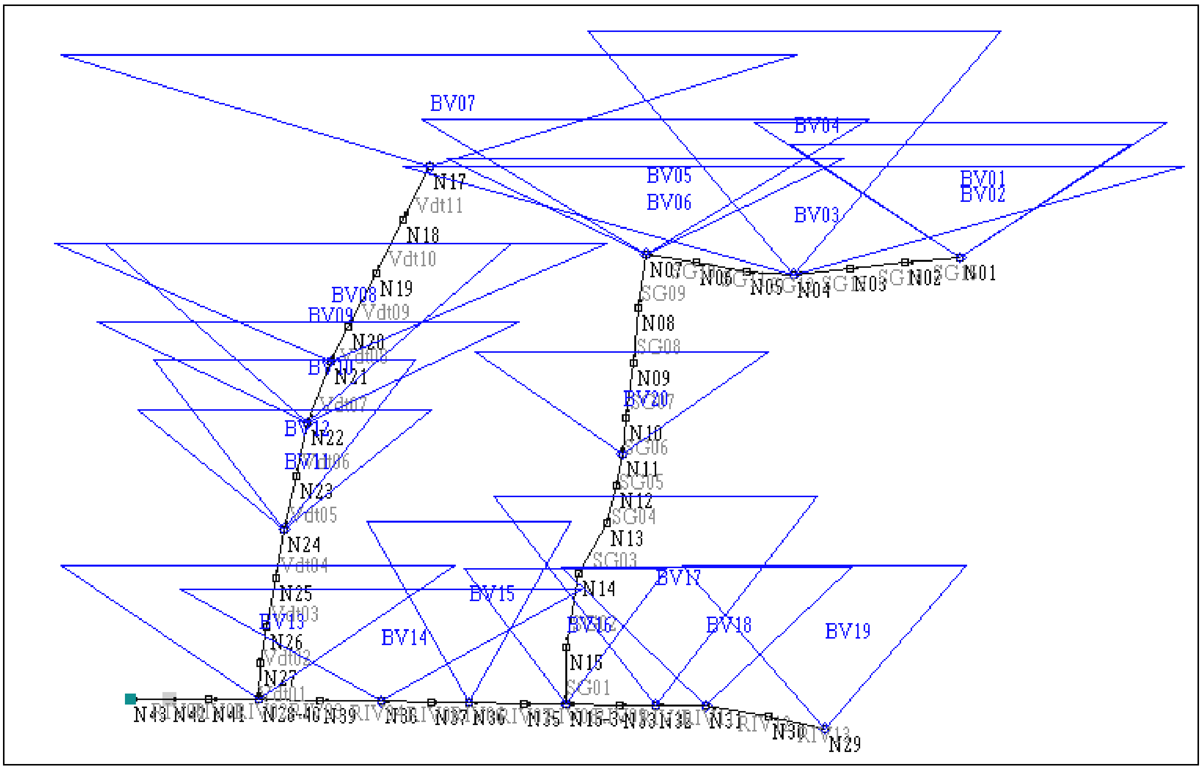
This parameter allows defining a minimal rain depth for which the results are kept. Since feeble intensities have an effect on the runoff this value was set to zero.

ANNEXE B – Modelling and Results

Sewer sections for the 3 main branches



Structural model CANOE



Activation of output for CANOE

To activate this tool, the file delay.txt (found in canoe\noebase\etude\interne\) has to be modified, setting the value 24 (“Ecriture de tout les calculs en sime BSV (recherche Moamad)) to -1
The output files are stored to the directory “canoe\caredas\moamad\”. On each launch of CANOE the current files are replaced.

Parameters of long time simulation (CANOE)

Paramètres généraux: (general parameter):

Simulation continue	Oui
Composant journalière	Non
Durée de temps sec après (Dry time after storm event)	100 minutes
Pas de discrétisation des entrées : (Discretisation of rain data)	1 minute

Paramètres de Barré St. Venant :

Pas d’espace :	30m
Pas de temps :	30 seconds

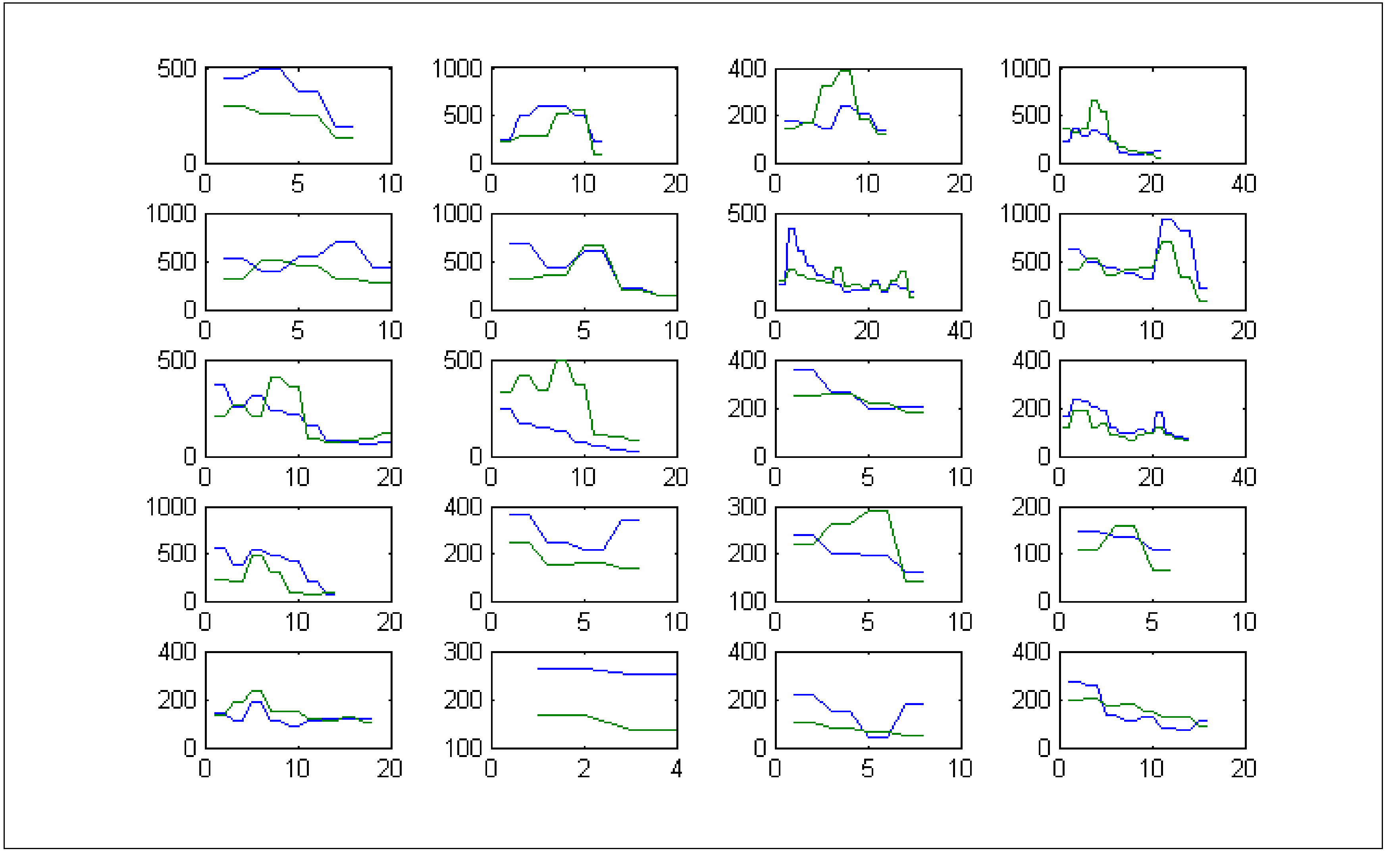
A simulation of 1 year needs about 200 – 300 Mb
ecp eaux composant parasite journaliere   no influence on model

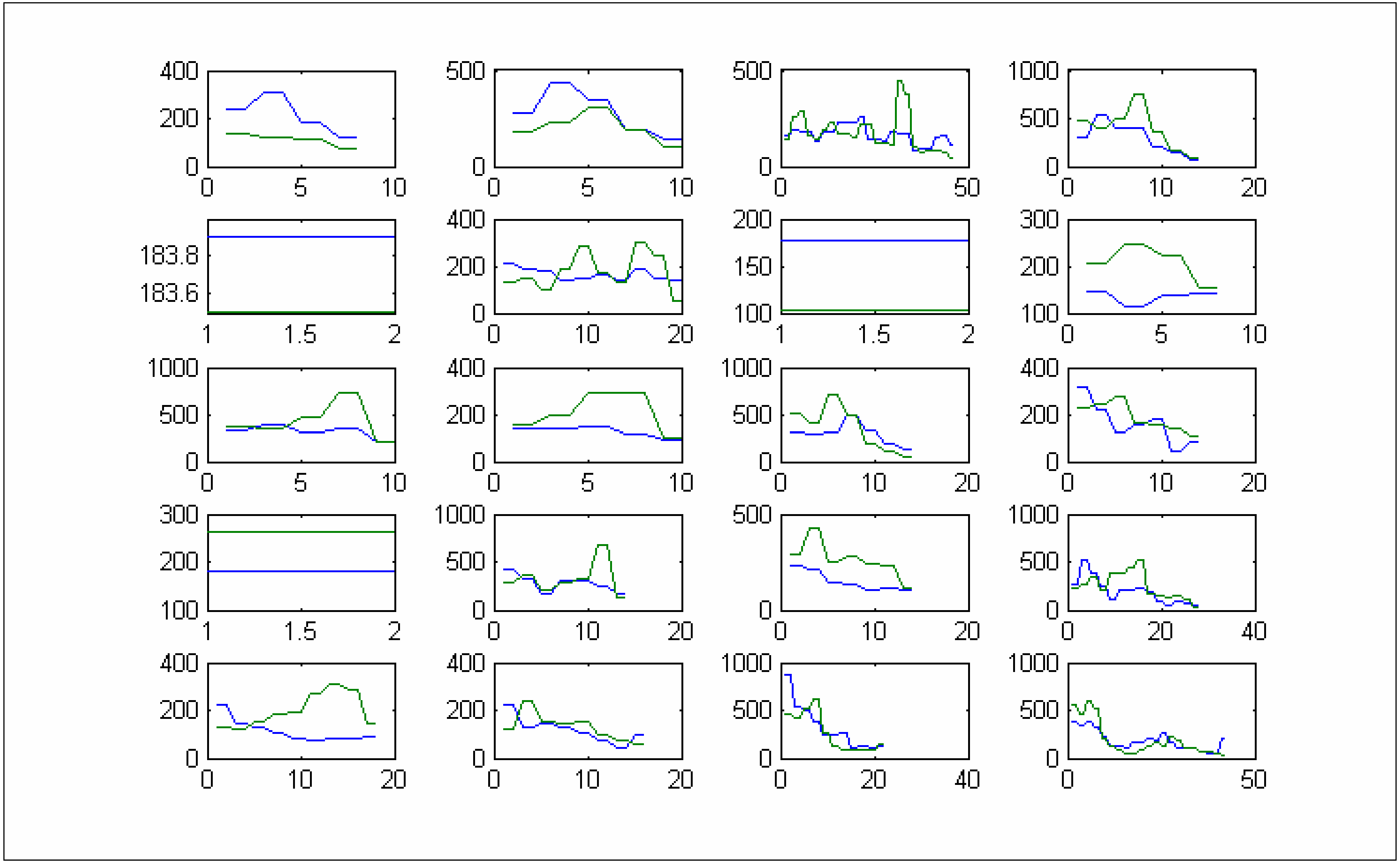
Matlab – File format to link rainfall file to CANOE results

gl_8801031442.plu	rbv0001.bvm	rtr0001.trm
gl_8801040436.plu	rbv0002.bvm	rtr0002.trm
gl_8801061100.plu	rbv0003.bvm	rtr0003.trm
gl_8801072130.plu	rbv0004.bvm	rtr0004.trm
gl_8801090630.plu	rbv0005.bvm	rtr0005.trm
gl_8801110412.plu	rbv0006.bvm	rtr0006.trm
gl_8801140506.plu	rbv0007.bvm	rtr0007.trm
gl_8801142253.plu	rbv0008.bvm	rtr0008.trm
gl_8801201400.plu	rbv0009.bvm	rtr0009.trm
gl_8801210448.plu	rbv0010.bvm	rtr0010.trm
gl_8801220836.plu	rbv0011.bvm	rtr0011.trm

With
Name of the file of the event file with results for subcatchments file with results for sewer sections

Comparison of measured and calculated pollutographs (Matlab-model calibration)

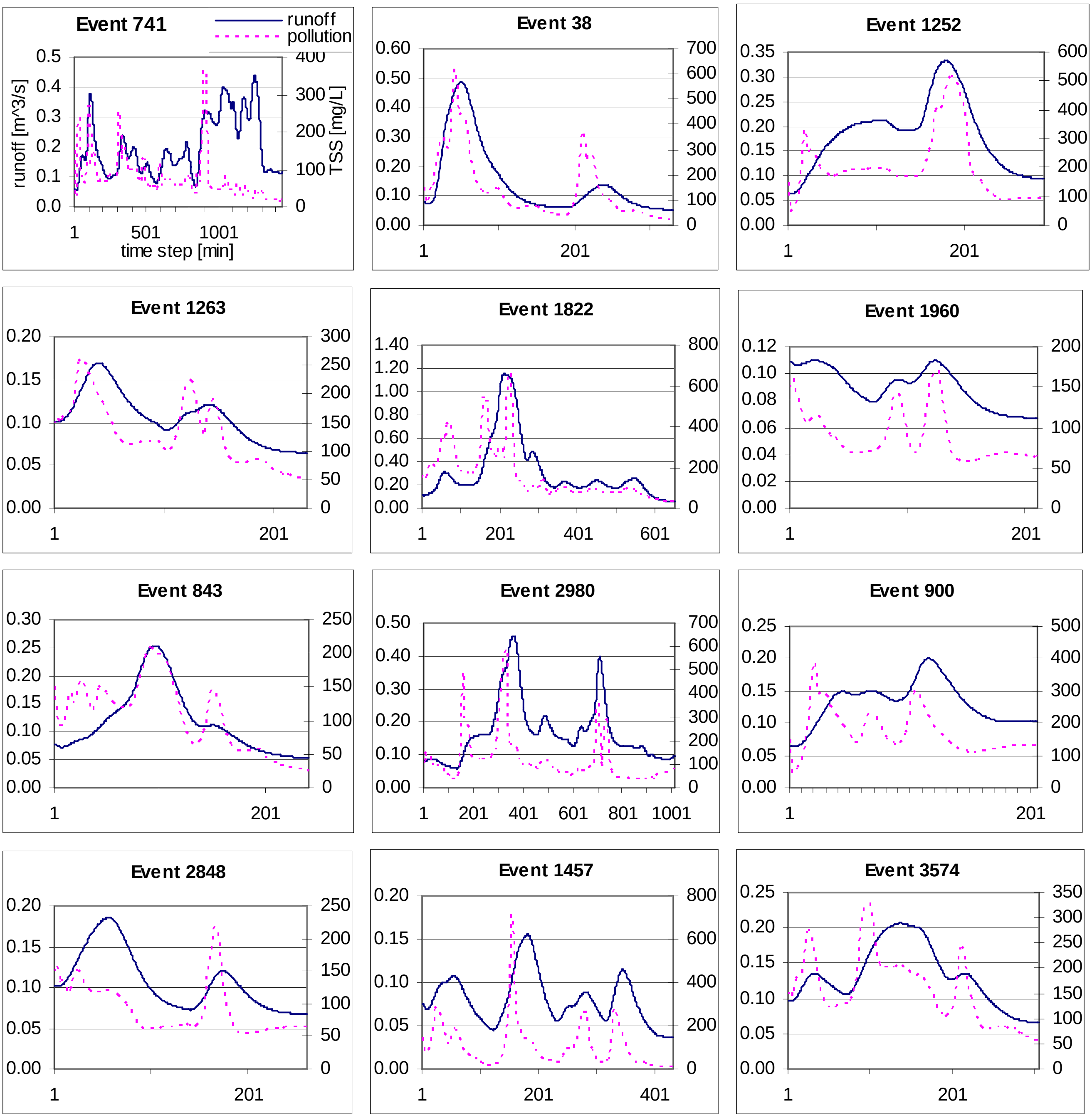


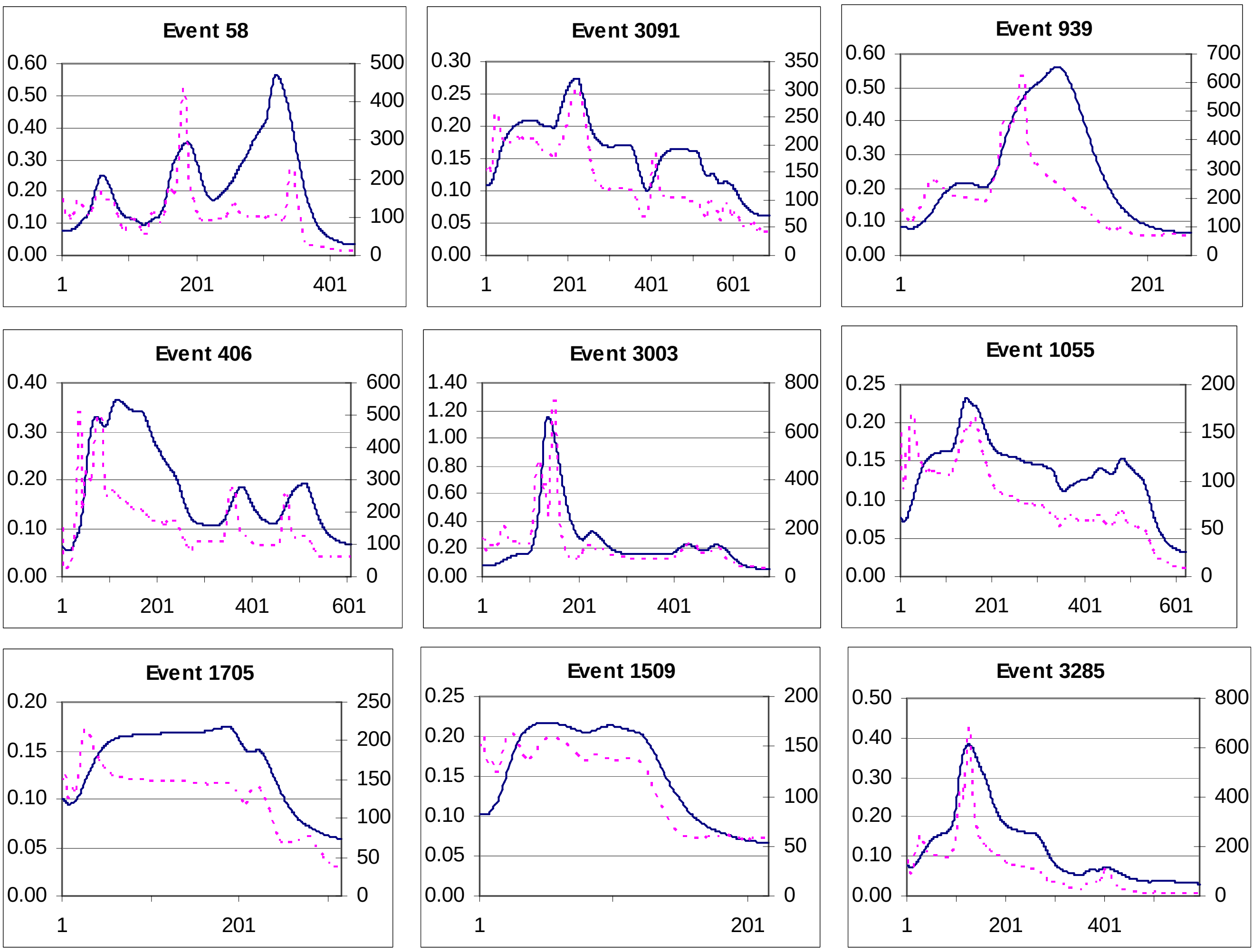


400
200
0
0
5
10
500
0
0
5
10
500
0
0
50
1000
500
0
0
10
20
183.8
183.6
1
1.5
2
400
200
0
0
10
20
200
150
100
1
1.5
2
300
200
100
0
5
10
1000
500
0
0
5
10
400
200
0
0
5
10
1000
500
0
0
10
20
400
200
0
0
10
20
300
200
100
1
1.5
2
1000
500
0
0
10
20
500
0
0
10
20
1000
500
0
0
20
40
400
200
0
0
10
20
400
200
0
0
10
20
1000
500
0
0
20
40
1000
500
0
0
50

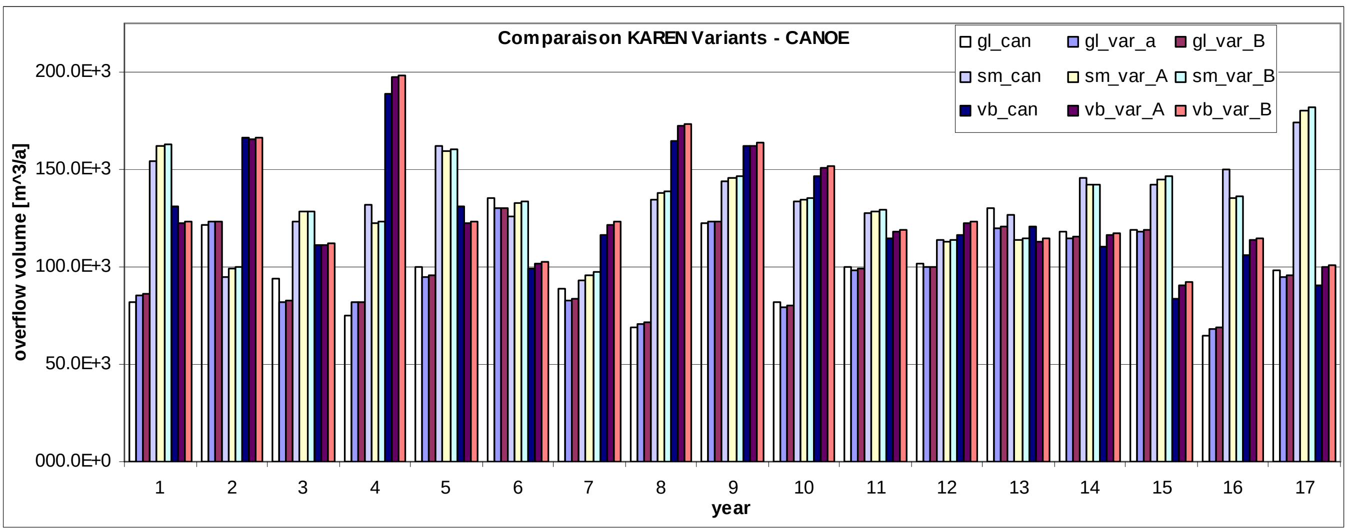
20 random events of the St. Martin time series

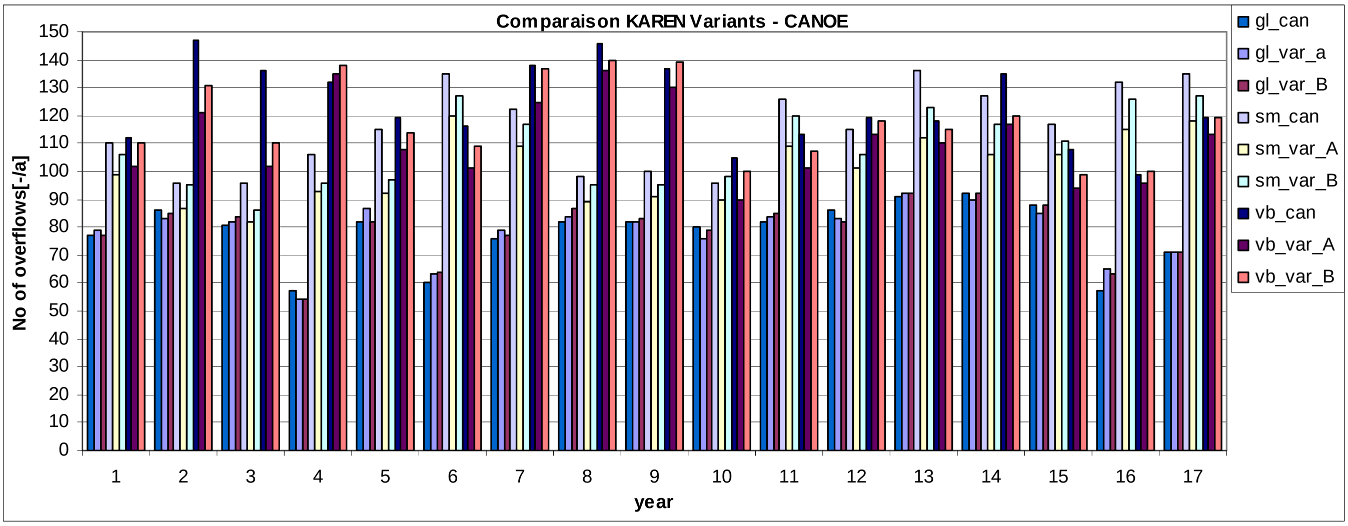
Comparison of the calculated runoff hydrographs and the calculated pollutographs for 20 random events. The axis and legend of the first chart are valid for all the following.

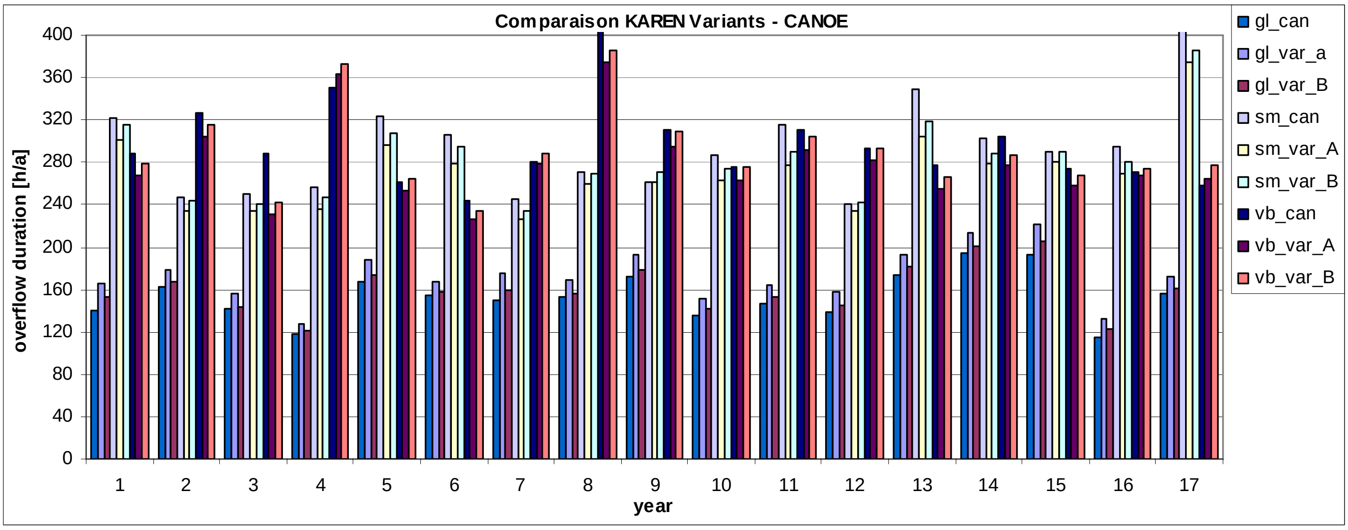




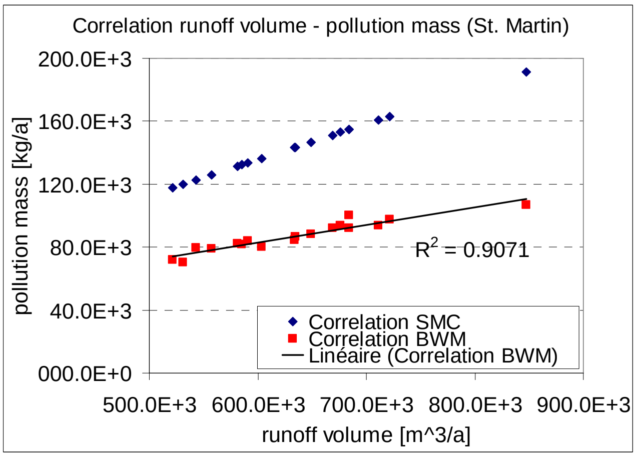
Annual variation of the CSO parameters – KAREN Variant A, B and CANOE

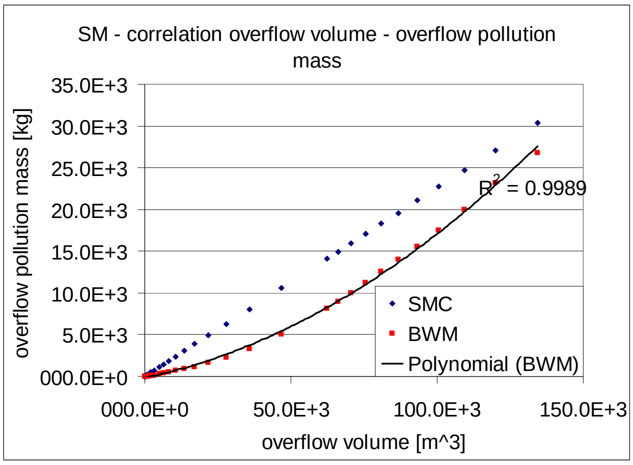


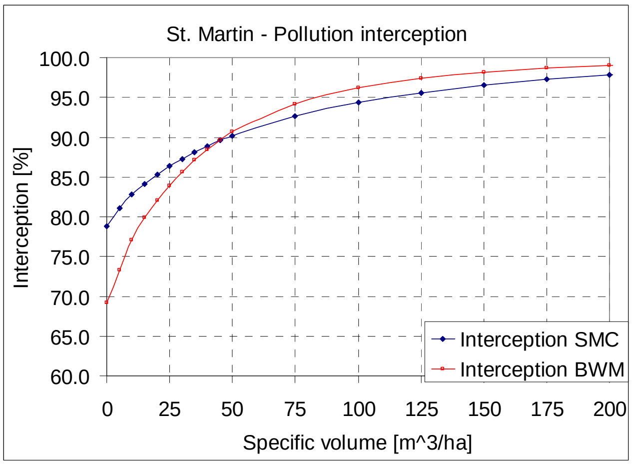




Correlation for the St. Martin rainfall time series







Tables for interception ratio calculations

St. Martin															
Volume [m^3/ha.red]	0	5	10	15	20	25	30	35	40	45	50	75	100	125	150
Interception CANOE |%]	78.8	81.1	82.8	84.2	85.3	86.3	87.3	88.1	88.9	89.6	90.2	92.6	94.4	95.6	96.6
Interception KAREN [%]	69.2	73.3	77.1	79.9	82.1	83.9	85.6	87.1	88.5	89.6	90.7	94.2	96.2	97.4	98.1
Interception BWM [%]	78.8	81.5	83.4	84.9	86.2	87.3	88.3	89.1	89.9	90.6	91.3	93.8	95.4	96.4	97.2
Volume [m^3/ha.red]	175	200	225	250	275	300	350	400	450	500	550	600	700	800	
Interception CANOE |%]	97.3	97.9	98.3	98.7	99.0	99.2	99.5	99.7	99.8	99.9	99.9	99.9	100.0	100.0	
Interception KAREN [%]	98.7	99.0	99.2	99.4	99.5	99.6	99.8	99.9	100.0	100.0	100.0	100.0	100.0	100.0	
Interception BWM [%]	98.2	98.6	98.6	98.8	99.1	99.2	99.5	99.6	99.7	99.8	99.8	99.9	99.9	100.0	

Gerland															
Volume [m^3/ha.red]	0	5	10	15	20	25	30	35	40	45	50	75	100	125	150
Interception CANOE |%]	74.1	76.6	78.5	80.0	81.3	82.4	83.4	84.3	85.1	85.9	86.6	89.5	91.5	93.1	94.4
Interception KAREN [%]	74.5	77.7	79.8	81.6	83.0	84.2	85.2	86.2	87.0	87.7	88.4	91.0	92.8	94.2	95.2
Interception BWM [%]	62.7	67.3	71.5	74.9	77.4	79.6	81.6	83.4	85.0	86.5	87.7	92.2	94.8	96.5	97.6
Volume [m^3/ha.red]	175	200	225	250	275	300	350	400	450	500	550	600	700	800	
Interception CANOE |%]	95.5	96.3	96.9	97.5	97.9	98.2	98.8	99.2	99.4	99.6	99.7	99.8	100.0	100.0	
Interception KAREN [%]	96.1	96.8	97.4	97.8	98.1	98.4	98.9	99.2	99.4	99.5	99.7	99.8	99.9	100.0	
Interception BWM [%]	98.2	98.7	99.0	99.2	99.4	99.5	99.7	99.8	99.9	99.9	99.9	99.9	100.0	100.0	

Design according to the Austrian and German standards

The denominations are given in German as in the respective guidelines.

ÖWAV Regelblatt 19 – 1st edition

Berechnungsgrundlagen

Qt	60	[l/s]	TW - Abfluss
Qara	180	[l/s]	Abfluss zur ARA

rkrit	15	[l/s/ha]	Kritische Regenspende	
Ared	32.7	[ha]	Reduzierte Einzugsfläche	
Qr,krit	490.5	[l/s]	Kritischer Regenwasserabfluss	Qr,krit=rkrit*Ared
Qkrit	550.5	[l/s]	Kritischer Mischwasserabfluss	Qkrit=Qr,krit+Qt

Qkrit>Qara -->
RÜB

Regenüberlaufbecken:

Anordnung als Durchlaufbecken

Vs	15	[m^3/ha,red]	spezifischer Nutzinhalt	
V	490.5	m^3	Beckenvolumen	V=Vs*Ared

ÖWAV Regelblatt 19, Entwurf 2003

Mindestanforderungen an Mischwasserentlastungen im Emmisionsfall

Mindestanforderungen

Mindestwirkungsgrad der Weiterleitung

Eta,r	(VQr-VQe)/VQr	gilt für alle gelösten Inhaltsstoffe

	Größe der Kläranlage (EW)		
	<5000	5000-50000	>50000
NH4N, ges.N, ges.P, CSB, BSB5	55	60	65
AFS	70	75	80

Abminderung für Regenhöhe

Regenserie	Gerland	St Martin	Vorarlberg	
hn	710	1212	1223	[mm/a]
Abminderung	5	15	15	[%]
	5000-50000	5000-50000	5000-50000	
NH4N, ges.N, ges.P, CSB, BSB5	55	45	45	eta [-]
AFS	70	60	60	eta [-]

Forderung: Für den Mischwasserüberlauf: Qdr/Qt24>8

Berechung der Wirkungsgrade der Weiterleitung mit KAREN, Variante B

Durchschnittlicher TW-Abfluss		Qt24	60	[l/s]
Weiterleitung zur Kläranlage:		3*Qt24	180	[l/s]
Durchnittliche Konzentration:		TSS	0.226	[kg/m^3]

Berechnete Wirkungsgrade der Weiterleitung (KAREN) - ohne Sedimentationswirkung					
Spez. Volumen [m^3/ha,red]	Gerland	St. Martin	Vorarlberg		
0	0.57	0.66	0.68	[-]	eta,r
	79	108	118	[-/a]	No. Of overflows
	98.7E+3	134.8E+3	130.7E+3	[m^3/a]	Overflow volume
	160.2	282.2	290.5	[h/a]	Overflow duration
	22.3E+3	30.5E+3	29.5E+3	[kg/a]	Overflow pollution mass
5	0.63	0.70	0.72	[-]	
	52	75	78	[-/a]	
	86.3E+3	117.3E+3	111.6E+3	[m^3/a]	
	107.4	192.0	191.0	[h/a]	
	19.5E+3	26.5E+3	25.2E+3	[kg/a]	
15	0.70	0.76	0.77	[-]	
	34	51	51	[-/a]	
	71.3E+3	95.6E+3	89.2E+3	[m^3/a]	
	79.2	142.7	138.3	[h/a]	
	16.1E+3	21.6E+3	20.2E+3	[kg/a]	

Berechung mit Sedimentationswirkungsgraden nach Tabelle 2

Tabelle 2: Anordnung als Durchlaufbecken:

spez. Volumen [m^3/ha,red]	Wirkungsgrad eta,sed%
Durchlaufbecken	
0	0
5	20
10	35
>15	50

Wirkungsgrad: eta,AFS=eta,r+(sum(Vqe,müb,j)*eta,sed)/VQr

spez. Volumen [m^3/ha,red]	Gerland		
5	233.9E+3	[m^3/a]	Rainfall runoff
	86.3E+3	[m^3/a]	Overflow volume
	0.63		eta, r
	0.2		eta,sed
	0.70	[-]	eta, AFS

Die immisionsseitige Betrachtung kann auf Grund fehlender Daten des Vorfluters nicht durchgeführt werden.

ATV A 128

6. Berechnungsgrundlagen

		Gerland	St Martin	Vorarlberg		
Jahresniederschlagshöhe	hna	710	1212	1223	mm/j	
	VQr	233.9E+3	392.2E+3	392.0E+3	m^3/a	
	r,krit	15	15	15	l/(s*ha)	
Beitragsflächen	Aek	42			ha	
	Ared	32.7			ha	
	Au	32.9	32.4	32.1	ha	Au=VQr/(10*hna,eff)
Fließzeit	tf	56			min	

Abflüsse	TW	Qt24	60	60	60	l/s	
	TW-Spitze	Qtx	105			l/s	
		Qr24	120	120	120	l/s	Qr24=Qm-Qt24
		Qr,krit	490.5			l/s	Qr,krit=rkrit*Au
		Qkrit	550.5			l/s	Qkrit=Qr;krit+Qr24
mittlerer RW-abfluss während der Entlastung		Qre	300.97	246.90	239.50	l/s	Qre=Vqe/(Te*3.6)+Qr2

Abflussspenden:	TW Abflussspende	qt24	1.82	1.85	1.87	l/(s*ha)	qt24=Qt24/Au
	RW Abflussspende	qr	3.64	3.71	3.74	l/(s*ha)	qr=Qr24/Au
		da qr> 2: detaillierter Nachweis					

Mischverhältnis im Überlauf	m	5.02	4.11	3.99	[-]	m=(Qre)/Qt24

7. Bestimmung des erforderlichen Gesamtspeichervolumens

Konzentrationen	TW	ct	600			mg/l	
	RW	cr, neu	84.51	49.50	49.06	mg/l	siehe Nebenrechnung
	ARA Abfluss	ck	70			mg/l	

Starkverschmutzungsfaktor	ac	1	1	1	Annahme: CSB TW<600 mg/l	
Einfluss hn	ah	0	0	0	[-]	
Kanalablagerung	xa	13.71				
	aa	0.4	0.4	0.4	aus nomogramm	
Bemessungskonzentration TW	cb	840	840	840	mg/l	cb=600*(ac+ah+aa)

Entlastungskonzentration	ce	210.08	204.05	207.51	mg/l	ce=(m*cr+cb)/(m+1)
zulässige Jahresentlastungsrate	e0	26.41	27.60	26.91		e0=3700/(ce-70)
berechnete Entlastungsrate V=0		42.77	34.26	32.41		e berechnet

ANNEXE C - Questionnaire

Example of the sent questionnaire

Rainfall data used for designing combined sewer overflows (CSOs) and settling tanks in combined sewer systems.

A comparison of design rules and standards from different countries, detailing on used rainfall data.

Date: 23/02/2006 [day/month/year]

Contact data

First name: Last Name:

☐ University / Research laboratory ☐ Other

☐ Private company

☐ Public company

Address:

Country: Country

Telephone:

(Telephone 2):

E-mail:

Additional information

Standards and Guidelines

In Country , **national standards** exist for designing
(Mark if yes, indicate name of the national standard)

☐ CSOs

☐ Storage and settling tanks

Additional remarks

In Country , guidelines exist for designing
(Mark if yes, indicate name of the guideline)

☐ CSOs

☐ Storage and settling tanks

Additional remarks

If neither standards nor guidelines exist, what references are used when designing CSOs / settling tanks? e.g. recommendations, technical guides

Where can these documents be obtained?

Are there references available on which these documents are based?
E.g. papers, reports… If yes, where can they be obtained?

Rainfall data

When designing CSOs, settling and storage tanks what kind of rainfall data is used…

according to the national standards?

- ☐ A single design storm
- ☐ More then one design storm
- ☐ A measured event
- ☐ Synthetic series
- ☐ Real rainfall time series

Additional remarks / other

☐ It is mandatory to design according to the national standards

according to the indicated guidelines?

- ☐ A single design storm
- ☐ More then one design storm
- ☐ A measured event
- ☐ Synthetic series
- ☐ Real rainfall time series

Additional remarks / other

☐ It is mandatory to design according to these guidelines

in general practice?

- ☐ A single design storm
- ☐ More then one design storm
- ☐ A measured event
- ☐ Synthetic series
- ☐ Real rainfall time series

Additional remarks / other

If you are obliged to use specific rainfall data how is this justified in the documents?

Real rainfall time series:

If rainfall time series are used for designing CSOs or storage tanks:

What duration of the rainfall time series is used or demanded?
e.g.: 10 year time series

What time step is used for recording the time series?
e.g.: time step of 6 minutes, time step of 24 hours…

Are rainfall series available for the whole country?
If no, what rain data is used when there are no time series available for a site?

Where lays the responsibility to furnish the time series?
Are the time series provided by e.g. the city/region, do the companies have to acquire them by themselves? Are they for free or do they have to be paid?

Simulation

What simulation models are used for simulating rainfall time series in CSO and storage/settling tank design?

☐ Detailed hydrodynamic models

☐ Simplified models

Additional remarks:

How are the results of long time simulations exploited/treated?
What parameters are calculated for CSO/settling tank design?

Answers in detail by countries

AUSTRALIA

General information

Since in Australia almost all sewer systems are separate sewers (only one significant combined sewer system exists, in Sydney), CSO design is not an important issue. However, there are many systems for storm water treatment including retention basins for stormwater (wetlands, retention ponds, infiltration systems…). Design practices vary greatly between the regions, although as the industry matures, more of a consensus is developing.

Standards/Guidelines

There are national guidelines, that do not contain specific design rules but rather describe objectives to achieve, and design principles. Standards vary by state (Australia is composed of 7 states) and in some of the states they are applied as regulations. They tend to focus on the modelled outcome (e.g. TSS reduction).
In addition each region has its own guidelines. For Melbourne it’s the “best practice environmental guideline” that was written about 10 years ago. It gives general advice on how to treat stormwater, an interception of 80% TSS and 45% N, P (in terms of annual load) is demanded. However, no indications are included of how to proof the obtained interception ratio. More recently, a more detailed design document was provided, which includes a “step-by-step” design process (including design drawings) for a wide range of stormwater treatment systems In addition policies from Melbourne Water indicate how to do the modelling. They generally have to be applied, before development approval will be given. For the simulations the MUSIC model is proposed. Melbourne Water checks the modelling parameters that are used for the MUSIC model. The procedure is very similar for most of eastern Australia; modelling in the western parts are less developed.

A draft for a national standard was proposed about 2 years ago by the Institution of Engineers. These Australian guidelines, called “Australian Runoff Quality” (Wong, et al. 2006), have now been released. Details are available at www.arq.org.au.

Rainfall data

Pre-1990s a single design rainfall was used in stormwater basin design (according to the "Australian Rainfall and Runoff", which is the standard design guideline).
From about 1993, the move was to analyse long term real rainfall time series, and to analyse frequency of overflows (and long-term overall treatment performance) with that. This was combined with an analysis of detention time (for treatment) to come up with an integrated measure of "hydrologic effectiveness", representing the proportion of treated mean annual runoff, and "how well it is treated".

Generally real rainfall time series are used in design. Especially for big cities continuous modelling is common. In some cases synthetic series are employed and few people still use the rational method but the tendency is to move towards real time series. Since the interview, this has become even stronger. The length of the time series varies between 1 to 50 years with a timestep of 6 minutes to 24 hours. In common practice the design is developed with a 1 year rain series and validated in a model with a 5 or typically a 10 year series.

Rainfall data is furnished by the Bureau of Meteorology (the national meteo service). The data is pretty good with a better coverage for cities. Normally the rainfall data has to be paid for except if there are some special arrangements with the Institute (e.g. at Melbourne, Brisbane).

Simulation models
The MUSIC software can use readily-available rainfall data for 600-700 sites in Australia that are updated every year. When designing for a site that has no measurements the closest reference town is taken and the data is adjusted. 50 cities are included in the 'default' series. The price of local data is not excessive (about 20€ for 20 years of 6 minute data.) MUSIC is a full hydrological model that also includes pollution transport modelling. More details are available at www.toolkit.net.au/music. This is the main conceptual design model that is used, although there is also some use of XP-AQUALM, and XP-SWMM.

BELGIUM (Flanders)
General information
The given information is only valid for Flanders. Belgium is divided into 3 very independent regions (Flanders, Brussels, Wallonia). In addition the information given expresses the point of view of Aquafin, additional information could be obtained from Universities. Preliminary note: Although the rainfall time series of Ukkel (Brussels) forms the basis for all the items described below, the following text is only applicable for the Flemish part of Belgium. In the Walloon and Brussels region, other regulations apply, and it is likely that other statistical derivations from the original rainfall time series have been made. Different types of rainfall data available Time series rainfall (10 min intensity) for the meteorological station of Ukkel (Brussels) exists from around 1900 until today. Similar series exist in a number of other locations for a much shorter period (from around 1970). All other recordings (around 200 locations across Belgium) are restricted to daily totals. This data is managed by the Royal Meteorological Institute of Belgium and is not freely available, unless under very strict conditions for scientific research projects. In order to be able to use these data in a more flexible way for both research and operational purposes, Aquafin decided to buy parts of the time series of Ukkel (10 min intensity between 1967 and 2003). Other Flemish public bodies involved in river modelling did the same for the full time series (possibly in hourly intensities only). It is unlikely that anybody in Flanders has obtained a lot of detailed data from other locations. Around 1994, a new statistical processing of the original time series was performed by the University of Leuven, resulting in so called composite design storms. These differ from the classic design storms of a given return period and duration (based on IDF relationships) in the sense that there is only one storm per return period. The intensities, corresponding to the shorter durations are implicitly embedded in the longer durations. To this end, these design storms have a very specific profile (sharp centered peak intensity and low intensity period before and after the peak). The original version of these composite storms had a duration of 6 hours (12 hours for shorter return periods) and a revised processing in 2000 resulted in a 48 hours duration for all return periods (ranging from T = 1/20 yr to T = 100 yr). These design storms are publicly available. Design of sewer systems Distinction should be made between on the one hand the design of pipes (transport elements) and on the other hand the design of specific structures (overflows, storage basins) which are more affected by volumes than by peak flows (although there is obviously an intense hydraulic interaction between both).

By design, pipes should have a hydraulic capacity to transport peak flows corresponding to a two year (T = 2 yr.) design storm. Water levels in manholes, resulting from a hydrodynamic simulation with a 2 yr. design storm should remain minimum 50 cm below ground level.
In hydrodynamic simulations with a 5 yr. design storm (or higher in specific vulnerable areas), no flooding from manholes should occur.

The design of overflow and storage structures is more complicated. From a proper scientific basis, it is clear that continuous simulations with long term time series of rainfall are the only valid way to assess how these structures really behave.

Two important points to consider in this respect are :
the limited availability of the time series rainfall for large scale modelling. 90% of the sewer design and simulations in Flanders is done on the basis of commercial contracts between Aquafin (or municipal bodies) and consultants. The use rights of the detailed rainfall data is not such that the time series can be made available at large scale for these commercial contracts
the large amount of simulations requested for a single modelling study. On the one hand there are still many large trunk sewer investments ongoing in Flanders, and on the other hand the transition from completely combined systems over many types of hybrid situations to a final stage (in the far future) of separate systems has only started less than ten years ago. The effect of this is that for each model many different scenarios and frequent updates or revisions have to be calculated to take both types of continuous development into account. As a result, it is not practically feasible to perform very time consuming simulations or to calibrate and maintain a lot of conceptual models in parallel with the hydrodynamic simulations.

Both considerations led to the conclusion that a practical solution had to be found for the assessment of overflow and storage stuctures within commercial modelling contracts.

Currently the only official regulation for CSO operation is still based on spill frequency[4] (there should be no more than 7 days with CSO spill per year). In order to assess this, composite storms with a short return period (typically T = 1/7 yr. and T = 1/10 yr.) are used to check if overflows are still operating at these low intensities. If they are not, they are assumed to comply (although it is widely recognised that this approach is often underestimating the real spill frequency). If they are still operating at these intensities, the remaining spilled volume is taken as the necessary design capacity of an additional off-line storage tank.
Simulations with higher design storm (T = 2 to 10 yrs) are performed to optimise the necessary length of the weirs (in order to avoid excessive increase of the water height above the weir during large storms).

While the above is the main procedure from the point of view of CSO design, often additional regulations are imposed by the river authorities to limit peak discharges from CSOs or from storage tanks into the water course. These additional regulations can vary between regions and can be dependent on local circumstances. But most of them are based on maximum throughflows and limitation of occurrence of emergency spills. Many of these additional prescriptions have been recognised to be often highly conservative, which may lead to rather severe requirements for additional storage. These regulations are under revision, but this is a difficult process with many actors involved, and no short term outcome is expected.

Additional research

Whilst the above described practice relates to the majority of the sewer modelling and design work in

[4] Only for overflows located on ecologically vulnerable watercourses, a more detailed approach involving continuous simulations and river impact assessment should be used, although there are little concrete prescriptions about how this should be done in practice.

Flanders, there is obviously additional research going on (both internally in Aquafin and at different universities and technological institutes) where rainfall time series are used to obtain a better insight in the behaviour of CSOs and storage structures. This involves the use of conceptual models on the one hand, enabling issues such as probabilistic modelling of whole catchment systems etc. (this is especially the domain of university research, e.g. at Leuven University). On the other hand, it involves the use of many new features (adaptive timestepping, selective generation of results, model thinning, …) in commercial hydrodynamic modelling software to enable continuous simulations. It is hoped that the latter one will in relatively short term create the possibility for Aquafin to re-evaluate many of the models which were based on design storms, and to draw practical conclusions as to how or whether a practical approach can be maintained for commercial design.
Standards/Guidelines
In Belgium no national standard exist, there are however guidelines for the 3 regions. Guidelines give recommendations on how to design CSOs and settling tanks, including comments on the scientific approach of the described design rules (indication that the use of rainfall with short return periods is not necessarily scientifically proved) The latest approved guidelines date from 1996, a revision is being worked on but so far has not been put into place.
Rainfall data
Generally composite design storms are used. They are composed from 27 years of the Brussels time series. These design storms are independent from the duration, covering all storms up to 48 hours. Real Rainfall time series are only used for internal studies (Aquafin). A detailed rainfall time series exists for Ukkel (Brussels) from which the composite design storms are derived. The time step is 10 minutes. Other detailed rainfall time series exist but are not used due to the high costs. About 200 stations from the Royal Meteorological Institute cover the whole country recording daily intensities. For CSO design storms with a short return period (1/7 to 1/10 year) are used. This is linked to the spill frequency that should not surpass 7 events / year (see above – General information)
Simulation models
Detailed hydrodynamic models are used for CSO design, applying the composite design storms. For long time simulation no official rules exist, normally spill frequency and volume are analysed.

DENMARK

General information

In Denmark CSOs and settling tanks are designed according to the “Best Practice” method. This means that there are no mandatory rules or limits for the design and that every construction should be designed in the most satisfying way (in accordance with the municipalities). The system apparently works quite well. However, minimal design standards would sometimes seem appropriate.

Generally CSOs in combination with storage tanks are common in Denmark, the sewer systems being about 50/50 combined and separate systems.

Standards/Guidelines

No national standards exist in Denmark. A Guideline (published by the Danish Waste Water Committee) exists, containing recommendations on design rainfall and impact analysis.
The guideline (in Danish) can be obtained from this organization against payment.

Rainfall data

It is recommended to use real rainfall time series.
Depending on the design purpose different rainfall data is used, ranging from design storms to rainfall time series. According to the “best practice” method, the rainfall data used in design can be chosen. For example long time rainfall series are used in impact studies while for CSO design rather a single design storm (e.g. 10 year return period) will be employed.
As stated above the applied rain data can be chosen freely by the consulting engineer/designer.

Real rainfall time series are available for most of the country, a good network of measurement stations exists, maintained by the Danish Meteorological Institute (DMI). In addition municipalities and private companies have their own rain gauges. Duration of the rainfall time series varies between 80 years for some cities, many series of about 30 years and for the newer measurement stations about 10 years. The use of rain radar is currently being tested in Denmark with some data already used in several projects.
The data from DMI has to be paid for if used in a study.

The time step for the rain series also varies between the rain gauges. Generally a small time step (1-2 minutes) is used, depending on the further use of the data.

Concerning design storms for CSO design Denmark is divided into different regions for which design rain storms for given return periods can be calculated by a national tool that is based on real rainfall time series.

Simulation models

In Denmark only hydrodynamic models are used for sewer, CSO and settling tank design.
The MOUSE software, developed in Denmark, is more or less a standard for design.
Sometimes more complex models (advection/dispersion) are applied; simplified hydrological models are only used when simulating surface runoff.

Normally long term simulations are carried out with about 30 years of rainfall data, allowing a thorough statistical analysis of the CSO, sometimes including pollution models. Depending on the receiving water also impact studies are carried out.

FRANCE
General information
Standards/Guidelines In France, no national standards exist for designing CSO or storage tank structures. Frequently the objectives are defined by the local Prefecture (arrêté préfectoral) In 1977 a circular was designed. While the idea was that it should only be for internal use in the ministry, it was nevertheless applied by practitioners to avoid problems. The state has no right to prescribe rules to the Prefectures. In 2003 a guideline was developed by CERTU. It is not meant as a replacement for the circular. There are no detailed design rules for CSO and storage tanks included just general principles for the design and modelling approaches. – Nevertheless practitioners tend to look for “simple design recipes”. In general the following parameters are accepted for CSO design: For settling tanks: Interception ratios for rainfall events with a return period of 3-6 months, sometimes a year. For flooding storage tanks: T=10 years, sometimes higher if critical conditions or local recurrent problems appear (T up to 50 years) The CERTU guideline can be obtained on CD-Rom or be downloaded from the Ministry of environment website (in French)
Rainfall data
Depending on the practitioner nearly all types of rainfall data are used in CSO and storage tank design. Ranging from a single design storm, measured events, synthetic series to real rainfall time series. In the CERTU guideline the use of real rainfall time series is recommended. In France a few municipalities have their own network of rain gauges (e.g. Marseille. Seine St. Denis, Lyon, Nancy, Bordeaux, Nantes…) for urban drainage purposes. Other municipalities have to buy the rainfall time series from Meteo France at high costs. In addition these series are not always adapted for urban drainage needs. A minimum 10 years duration is recommended. Recording timesteps range from 5-6 minutes (more and more gauges use a 6 minute time step) to daily records. A good coverage exists for timesteps of 12-24 hours. The data is, however, often not adapted to the needs in urban hydrology. Cities often have their “own” consulting companies and rain gauge network. In the interest of the city this data is normally for free.
Simulation models
Simplified models are most frequently used, the use of detailed hydrodynamic models is not common Number of overflows, Volume and frequency. May depend on the local discharge permit.

GERMANY
General information
In Germany rules for designing CSOs and storage tanks as well as for the use of rainfall data vary greatly between the federal states (*Bundesländer*). Each Bundesland has its own laws concerning CSO and storage tank design, leading to 16 different sets of rules and laws.
Standards/Guidelines
There are no national standards for the design (e.g. DIN), but the DWA Arbeitsblatt 128/92 (formerly ATV A 128) guideline is, in most of the states, the minimum requirement. This guideline is based on emission restrictions. Another guideline, the Merkblatt M3 (DWK) is also applied, this one being based on immision limits. The two guidelines can be obtained from the respective associations (DWA, BWK) against payment.
Rainfall data
As stated above the rainfall data used for the design of CSOs varies greatly between the federal states. For simple structures single design events with predefined parameters (e.g. return period) are used. In some states 20-year rainfall time series are used, in others a series of measured events, in others again a synthetic ¾ year composed from longer time series. Each state has its own rules how to treat the rainfall time series. The availability of rainfall data is also highly dependant on the state. The “old” states (former FRG/ *BRD*) are equipped with either area wide measurements or neuralgic measurement stations. The “new” states (former GDR/*DDR*) posses of fewer measurement facilities. The measurement stations are maintained by various operators: communities, water associations, the states or the “*Deutscher Wetterdienst*” (German meteorological service). Acquiring rain data from the *Deutscher Wetterdienst* is expensive. In addition the rain data that was paid for can only be used for one single project. In states that have their own measurement network, data can be obtained through a central *Landesamt*. Generally these records are less expensive since the states have interest in the development.
Simulation models
Hydrodynamic simulation is rare and only used for complex systems. For most of the design purposes hydrological models are used. According to the DWA Arbeitsblatt 128/92 the COD load and an efficiency coefficient (spilled volume to total runoff volume) are examined for CSO/ storage tank design

NORWAY
Standards/Guidelines
In Norway a national standard based on the EN 752 (NS-EN 752) exists. It is, however, not mandatory to apply it and only a few cities do so. In general, each Norwegian city has its own set of rules for CSO design In addition to the national standard two different guidelines exist. One of them comes from the Norwegian State Pollution Agency (SFT), the other is proposed by the water service organization (NORVAR). The documents can be obtained from the corresponding organizations (in Norwegian).
Rainfall data
CSO design is mostly carried out with single design storms with a return period of 10 years. This includes modelled design storms as well as statistically calculated design storms from real rainfall time series. Sometimes more than one design storm or measured events are used for the design. Real rainfall time series are mainly used for analysis of sewer networks. (e.g. taking a big storm event of every year and compare the results) The national standards use rainfall time series of 10 years, there are several time series of 15-20 years available. The most detailed time series use a 2 minute timestep. About 10 measurement stations are spread over the country, maintained by the Norwegian agency for river catchments NVE, measuring precipitation and runoff. Municipalities often have their own network of rain gauges. In addition the national meteorological center provides a good coverage of rain gauges with larger timesteps (12 hours). While the data is generally free for research purposes, consulting companies have to pay a moderate service fee.
Simulation models
In recent years MOUSE became sort of a national standard in sewer design. For simple tasks also hydrological models (time area models) are used, but MOUSE is becoming more and more common. For CSOs operation frequency and pollution transfer are calculated. Detailed pollution models are very rarely used (recently some have been applied), normally only simplified assumptions are made. For main sewer trunks some more advanced models are sometimes used (e.g. sedimentation models)

PORTUGAL
General information
Until the seventies public sewer systems existed mostly in cities in Portugal. Most rural sewer systems used decentralized solutions. Today 70-80% of the population is connected to public sewer systems, but newer systems are separate. Current regulations impose the use of separate systems. Therefore CSOs are mainly found in some cities with old, combined sewer systems. Storage tanks are not a generalised solution (there are some cases of use of small storage capacities upstream the WWTP).
Standards/Guidelines
There are no specific national standards. Nevertheless, there are references for designing CSOs in the Decree-regulation nº 23/95 of 23 August 1995 (*Decreto-* *- Regulamentar* nº 23/95), articles 167 and 168 (objectives and design criteria), and retention tanks (“*bacias de detenção*”) in articles 176 to 180 (objectives, types, components, hydraulic design and construction aspects). The decree is mandatory to apply. It contains mainly general principles and required performance values for the system (mainly hydraulic); no specific design rules are included. For design of stormwater structures in combined sewers, the german ATV-Standard A 128/92 (“Standards for the Dimensioning and Design of Stormwater Structures in Combined Sewers”) is sometimes used by consulting engineers. The Decree-regulation nº 23/95 may be obtained in “Imprensa Nacional” (http://dre.pt/) and in some libraries and book shops. The A 128 may be obtained by post from the DWA Association (ATV in the past). The application of A 128 in Portugal was evaluated in some research studies.
Rainfall data
The Decree-law does not specify the type of rainfall data for the design of overflows and storage tanks. In general practice a single (or more than one) design storm is used. In rare situations real rainfall time series have already been used for complex simulations. Portugal has different rainfall zones with varying dry weather flow, rainfall duration, intensity and frequency (idf) characteristics. For some decades the whole country is covered by measurement stations. Rainfall time series are already digitalized for 27 measurement stations covering the country. Duration of the digitalised rainfall series varies between 20 to 60 years. The time step is not standardised. Nowadays, most of the more than 600 automatic meteorological stations use tipping-bucket raingauges associated to digital dataloggers. The data is provided by the IM (*Instituto de Metereologia*) and INAG (*Instituto da Água*). It is free for research projects and specific studies if an appropriate demand is made, consulting engineers have to pay for the data.
Simulation models
Hydrodynamic simulations are used mostly for the evaluation of existing sewer systems and structures. These models are not commonly used for design. The most common programs are MOUSE, Hydroworks and SWMM used by some consulting engineers and research units.

SPAIN

General information

The practice for CSO design varies throughout Spain. The detailed information given below concerns the practice of CLASBA in Barcelona (CLABSA being responsible for the Barcelonan sewer system)

For a very preliminary volume design of the storage tanks against floodings a synthetic rainfall event of T = 10 years is used. The resulting volume is then multiplied by 1.3. This multiplying factor has its origin in the first storage tanks that were built some years ago when the volume was calculated with the highest rain events measured since 1927.

For the final volume design of the storage tanks against floodings, calculated during the construction project of the tank, we calculate it in a more accurated way than in point 1, using the 12 highest rain events since 1927.

For storage tanks against CSO they are actually designed with 70 m3/ha imp. The number was first calculated with the full time series since 1927 using a very simplified model. That number was obtained in order to reduce the CSO volumes to 50 % and the number of overflow events to 1/3rd

Actually the storage tanks against CSO are verified by modelling 3 summer rainfall events with a more detailed model including the receiving waters. In addition it is assured that the duration of non-compliance hours of the bathing waters directive is lower than 1.5 % of the bathing season time.

Overflow structures were designed many years ago with a dilution factor of 1:3 which means that the interceptor leading to the WWTP has a capacity of 4 times the dry weather flow.

In general practice usually a single design rainfall is used, especially to design infrastructures against floodings. Designing structures against CSO pollution is unfortunately not a common practice yet in Spain but in some parts we are working on it and we are quite advanced but there are no general standards, regulations or recommendations about how long should the rainfall series be.

Standards/Guidelines

Neither national standards nor guidelines exist. At the moment there are 2 different laws in place:

UNE-EN752-4: a European law that contains environmental considerations for the impact of the drainage systems on the receiving waters. According to these rules CSOs must not be active before a specific discharge of 10 to 30 L/(s*ha,imp) or the dilution factor of the overflow os between 5 and 8 times the dry weather flow.

Orden de 13 de julio de 1993 "Instrucción para el proyecto de conducciones de vertidos desde tierra al mar". A law for new projects of structures discharging waters from land to sea. This law is usually applied to submarine emissaries but should be applied to all other weirs and it says that the capacity of the emissary should be enough so that for the rain corresponding to a 10 year return period the weir should not work more than 450 hours per year and less than the 3% the hours of the bathing season.

These laws define very clear objectives but usually they aren't put into practice for the CSO design.

In northern Spain sometimes the British standard (urban drainage management) is applied, using a design storm event with 10-20L/s*ha
CLABSA got their own method for designing CSOs using real rainfall time series.

Rainfall data

Details on the rainfall data applied in Barcelona can be found in the paragraph above. In northern Spain single design storms are used for the design of CSOs For Barcelona a rainfall time series is available starting in 1927. A national network of rain measurement stations exists. Most rain gauges, however, only give 24 hour- intensities. Some measurement stations work with smaller time steps. In addition to the national network there are several local networks of rain gauges (e.g. Barcelona). The rain data can be obtained from the national network, it has to be paid for.
Simulation models
In Barcelona detailed hydrodynamic Models are used, including the receiving waters (bathing quality, see above). The aim is to reduce the number of overflow events.