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1 **Use of continuous simulation model (COSIMAT) as a complementary tool to model**
2 **sewer systems; a case study on the Paruck collector, Brussels, Belgium.**

3
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8
9 **Abstract**

10 The episodic discharge of Combined Sewer Overflow (CSO) discharge, in most of cases,
11 effectively controls the ecological status of a receiving water body. Hydrodynamic models like
12 Storm Water Management Model (SWMM) are used to model such events in a sewer system
13 which requires long computational time especially when performing long term simulations of an
14 integrated modelling system. Hence, we developed a continuous simulation model (COSIMAT)
15 using the MATLAB™/SIMULINK™ in view of using it in an integrated modelling chain. We
16 validated the COSIMAT using the hydrodynamic model SWMM. We tested the methodology in
17 the case of a fairly important Brussels' sewer collector, Paruck. The results showed that the
18 accuracy of the COSIMAT simulation is comparable with the SWMM but with much reduced
19 computation time. We believe that such development would be very helpful to minimize the
20 computation time of an integrated model, especially when the models are linked dynamically,
21 e.g., in OpenMI platform.

22
23 **Key words:**

24 Combined sewerage system, CSO, COSIMAT, SWMM, Integrated modelling, Paruck

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26

27 **1 Introduction**

28 The continuous growth of human population and rapid development in urban areas is affecting
29 the physical characteristics of these areas very considerably, consequently leading to a constant
30 change in the hydrological regime of urban areas.

31 In the past the construction and operation of urban drainage systems was driven by two main
32 objectives: (1) to prevent flooding and (2) to maintain public health and hygiene. Due to
33 concerns been raised on the ecological status of receiving waters; for example, that imposed by
34 the European Water Framework Directive: WFD (EU, 2006), the aspects of waste water
35 treatment plants were introduced to reduce the pollutant loads sent to receiving waters. More
36 importantly, the WFD calls for integrated river basin management to be put in practice in view of
37 achieving good ecological status of all inland or coastal water bodies. The issue of achieving that
38 ecological status and reducing flooding in urban areas is further complicated by the fact that
39 these problems have to be tackled using different and directly opposite approaches. One is to get
40 rid of the storm water out of the urban area as fast as possible to prevent flooding while the other
41 is to delay the water outflow as long as possible in the WWTP to ensure that all the pollutants are
42 removed to maintain the good ecological status of the receiving waters. The objectives of EU
43 WFD can be achieved by using integrated river basin management approach which depends
44 largely on integrated models. To attain the objectives of EU-WFD, one component of the
45 integrated model should be a model that describes the sewer system(s). In a highly urbanized
46 catchment, such model is very important because the effluent from the sewer system can
47 determine the ecological status of a receiving water body. For example, the river Zenne in
48 Belgium, carries more than 50% discharge coming from the Waste Water Treatment Plants
49 (WWTPs) (Garnier et al., 2012) and the river water quality is sometimes very poor because of
50 episodic emissions of CSOs.

51 The design, operation and management of these complex sewer networks have been
52 facilitated recently by the development of numerical simulation packages (hydrodynamic
53 models) and the rapid progress in computer soft/hardware. Though these hydrodynamic models
54 are continuously been developed, most of them are very expensive and can't be applied by most
55 of users, secondly there is a problem of long computation times especially when performing long
56 term simulations.

57 Despite this rapid development of software, the challenge has moved from the simulation
58 of individual sub-systems to an integrated approach of managing urban drainage systems. In this
59 approach, integrated or conceptual models of the whole system(s) can be developed and used to
60 test the performance of the system under historical and future scenarios. However the
61 development of integrated models is a challenging and complicated task. The complex nature of
62 these systems is the main reason why existing models of the sub-systems cannot directly be
63 linked together to form a single entity.

64 The issue of integrated modeling is further complicated by the fact that, when a detailed
65 hydrodynamic model like SWMM is a component of an integrated model and the integrated
66 model is linked dynamically in a platform like Open Modelling Interface: OpenMI (Gregersen et
67 al., 2007; Moore and Tindall, 2005) the calculation time step is too large, as observed by
68 Shrestha et al. (Submitted) and Shrestha et.al. (2012).

69 We tried to solve the above stated problem in this study by developing a continuous
70 simulation model (COSIMAT) in the MATLAB™/SIMULINK™ platform. The conceptual

71 model COSIMAT is then used to calculate the volume of CSO sent to the receiving water during
72 heavy rainfall events. Meirlaen (2002) suggested the use of reservoir or conceptual models to
73 solve the problem of long computational time usually associated with detailed models. The
74 development and application of conceptual models does not require a lot of experience for the
75 modeller(s) as most of the parameters have a physical meaning. In addition, these models can
76 easily be extrapolated and used in other similar systems. An important feature in conceptual
77 models is that their parameters are not directly measurable and must be calibrated from observed
78 data (Beven and Binley, 1992) or from a detailed model. This is very important for what we are
79 heading to, as we want to develop an integrated model including COSIMAT to represent the
80 sewer system(s). The integration is sought to be made via OpenMI which is an interface allowing
81 dynamic data exchange between the component models, which is an opposite the file based
82 offline linking.

83 Our present study will contribute to this research and further investigate the accuracy of
84 the conceptual model, COSIMAT against a detailed hydrodynamic model, SWMM. In order to
85 attend this objective, the SWMM and COSIMAT models are calibrated against a number of
86 storm events. The objective on the calibration process for the models is to accurately estimate the
87 total CSO volume sent to the receiving water. A brief description of the study catchment and
88 models used are given in Section 2. Section 2 also provides details on how the model has been
89 built-up, calibrated and validated. Results are presented and discussed in Section 3. Final
90 conclusions are formulated in Section 4.

91

92 **2 Methodology**

93 **2.1 The Study Area**

94 The Zenne river basin (Figure 1) drains an area of 1162 km² and runs through the three
95 administrative regions of Belgium: the Walloon region (574 km²), the Brussels Capital region
96 (162 km²) and the Flemish region (426 km²). About 103 km downstream, it meets the river Dijle,
97 where it is subject to the tidal influence of the river Scheldt. Parallel to the river runs the canal
98 Brussels-Charleroi and about 1.5 million people are connected to the river. Out of this, more than
99 80% of the population live in Brussels region alone. The hydraulic behaviour of this system is
100 very complex due to the interaction between the different discharge elements at the various
101 outlets (collector, siphons, and weirs), the receiving water (the river Zenne) and the canal and
102 tidal influence at the river outlet (the river Dijle). There exist several WWTPs in the basin and
103 among them, two biggest WWTPs (Brussels South and Brussels North), are found in the
104 Brussels (Figure 2). With a capacity of 1.1 million of equivalent inhabitants, the Brussels North
105 is the biggest of two. The sewer system of Brussels North has four distinct sewer systems,
106 namely, the left bank collector system, the right bank collector system, the collector of Haren
107 and the collector of Woluwe (Figure 2). One of the important trunk sewers of the Left bank
108 collector (of the WWTP North) is the Paruck sewer system (Figure 2).

109 The siphon is placed such that it passes under the canal and discharges its CSO to the river
110 that flows parallel to the canal. The quantification of the volumes of CSO sent to the receiving
111 water during storm events through the siphons and weirs is thus very complex. This complexity
112 was simplified by the application of both hydrodynamic (SWMM) model and a conceptual
113 model.

114

115 **2.2 Models**

116 **2.2.1 The SWMM model**

117 **2.2.1.1 The model**

118 SWMM is a dynamic rainfall-runoff simulation model computing runoff quantity and quality
119 (primarily) from urban areas as developed by the United States Environmental Protection
120 Agency (US EPA). It can be used for both continuous and single event modelling. A drainage
121 system in SWMM is modelled as a series of water and material flow between four major
122 subunits: the atmosphere, the land surface compartment, the groundwater and the transport or
123 conveyance compartment (Gironas et al., 2008; Rossman, 2009). SWMM adopts a distributed
124 non-linear reservoir concept to simulate the runoff from a specific sub-catchment after
125 depression storage; infiltration loss and evaporation are satisfied. While doing so, the sub-
126 catchment is divided into impervious and pervious zones, the infiltration phenomena being
127 considered only from the latter zone. The one dimensional flow routing in the transport
128 compartment is based on the full set of equations of Barré de Saint-Venant.

129

130 **2.2.1.2 The SWMM model build up**

131 The Paruck catchment drains an area of about 1001ha with more than half of the catchment
132 covering about 520ha of impervious area (urbanised). We prepared the system by splitting the
133 catchment into twenty four sub-catchments with 189 conduits of a total length of about
134 19km. There are 188 junctions in the network, two weirs and a battery of four identical siphons
135 placed side by side at the outlet of this catchment. Most of the sewers are brick laid with oval
136 shape of minimum height of 1.30m.

137 In the configuration of the network under study, there is a single collector that receives
138 waste water at the outlet of each of the sub-catchments from the secondary sewers and transports
139 it to the WWTP. The collector is equipped with a device such that it sends all the wastewater to
140 the WWTP during dry weather. When the incoming flow increases because of wet weather:- this
141 device can send only a maximum discharge of 1.8m³/sec to the WWTP. When the maximum
142 discharge to the WWTP is reached, the remaining CSO is sent directly to the river via the
143 siphons. When the capacity of the siphons is also exceeded, the rest of the CSO is first stored in
144 the system by the use of a CSO storage chamber with a capacity of 2200m³ equipped with two
145 sideflow weirs of the same lengths of 19m each and different crest levels of 1.8m and 2m for
146 weirs1 and weir2, respectively and identical discharge coefficients of 2.215. When the storage
147 capacity of the CSO storage chamber is exceeded, the excess CSO is then discharge to the canal
148 through the first overflow weir and the process continues for the second overflow weir. The
149 schematic representation of the system is shown in Figure 3 and some characteristics of the
150 system are presented in Table 1.

151

152 **2.2.1.3 Model calibration and validation**

153 The SWMM model was calibrated and validated using observed flow data recorded at the outlet
154 of the Paruck catchment and recorded by FlowBru (www.flowbru.be), an agency that monitors
155 surface water flows and rainfalls in Brussels. For calibration, a rainfall time series was selected
156 containing a number of high rainfall records with the corresponding discharge at the outlet of the
157 catchment. The results of simulation produced by SWMM at the outlet of the catchment were
158 plotted against the observed flow and the parameters of the model were adjusted to have a good
159 fit between the simulated flow and the observed flow and also the volume of flow recorded.

160 These parameters were maintained and used to validate another rainfall time series containing
161 flood events as well. Due to some errors in the recorded data, the data-sets that were used to
162 calibrate and validate the model were very limited.

163

164 **2.2.2 The COSIMAT**

165 **2.2.2.1 The model**

166 COSIMAT is an acronym for Continuous Simulation Model in
167 MATLABTM/SIMULINKTM. It is a conceptual model that can be used for both continuous and
168 single event simulations to calculate water fluxes (volumes, discharges) sent to the receiving
169 water during flood events.

170 COSIMAT is composed of two main components; the hydrologic and the hydraulic
171 components. The hydrologic component contains the sub model components for routing of
172 runoff including rainfall abstraction losses, Dry Weather Flow (DWF) and flow through the
173 sewer system. Runoff and DWF are first routed into a linear reservoir model using the notion of
174 continuity and storage equations whereby the storage is linearly related to outflow by a reservoir
175 constant as a function of time. This model component is made of three identical reservoirs placed
176 in series and there all have the same reservoir constant (Nash cascade concept). COSIMAT uses
177 the Nash Cascade, which is a reservoir model, to describe the combination of both overland flow
178 and the flow through the sewer pipes. However this approach offers too limited possibilities to
179 model accurately the routing process because it requires only two parameters (reservoir constant
180 (k) and number of reservoirs which is 3) which moreover have to remain constant throughout the
181 simulation period.

182 In the hydraulic component of COSIMAT, the discharge elements at the out let of the
183 catchment are represented by hydraulic equations for collector, siphons and weirs which are
184 programmed using special functions of SIMULINKTM. The storage reservoir at the outlet of the
185 system is represented in COSIMAT by a lookup table function and the storage volume varies as
186 a function of height of water in the reservoir. Most equations used in COSIMAT are physically
187 based equations which are also used in hydrodynamic models, however the difference between
188 the two is that most of the processes in COSIMAT are lumped thus only the most dominant
189 processes occurring in the sewer system are used to study the system using a few parameters as
190 mentioned in the preceding paragraph. The time step of data input into COSIMAT is same as the
191 time step of the rainfall input which is converted into seconds before being used in
192 MATLABTM/SIMULINKTM.

193

194 **2.2.2.2 Model build up**

195 The sub components include: the wetting losses, depression storage, runoff coefficient, dry
196 weather flow, and reservoir model. The hydraulic components include a collector, a battery of
197 four identical siphons, CSO storage chamber and two weirs.

198 The total rainfall is converted into net rainfall and routed as overland flow (discharge). It is
199 added to the dry weather flow and the sum is sent to the linear reservoir model. From the linear
200 reservoir model, it is sent to the various discharge elements at the outlet of the catchment and
201 each of these discharge elements including the storage reservoir is activated depending on the
202 volume of inflow present in the system.

203 Two methods are used for the calculation of net rainfall in the COSIMAT depending on
204 the inflow to the CSO chamber. For design storm simulations, only the runoff coefficient is used

205 to calculate rainfall losses while for continuous simulations, other types of losses are included.
206 This approach was suggested by Viessman et al. (1989). Viessman et al. (1989) suggested that,
207 while estimates of losses due to interception can be significant in annual or long term
208 simulations, accounting for interception losses might be unnecessary for heavy rainfalls during
209 individual storm events. For continuous simulations, other parameters like the wetting losses and
210 depression storage are included and used as fixed values. This is because, in running continuous
211 simulations which usually concern long period of time, it is considered that there are some
212 rainfall episodes which do not generate any runoff. This could be lost either as wetting losses or
213 depression storage. For continuous simulations, 0.5mm and 1.40mm were used for wetting losses
214 and depression storage respectively. These values were obtained from literature (Anonymous).

215 When the maximum discharge at the outlet of the catchment, i.e through the collector and
216 siphons, is reached, storage is activated within the system due to the presence of weirs and the
217 incoming CSO is stored within the system in the storage reservoir. The storage in the system is
218 represented by a hypothetical storage reservoir as shown in the figure 4 below.

219 At the beginning of a rainfall event, the conceptual storage reservoir (Figure 4) is assumed
220 to be completely empty, i.e with $V=0$. In this situation, the lowest level of water in the sewer
221 pipes in the network and the minimum water level upstream of the siphon is Hu_{min} . In this
222 instance, all the flow coming into the system is sent to the WWTP via the collector (not shown
223 here). Storage only occurs in the system when the siphons are full and are flowing at full
224 capacity. During storm events, the volume of storm water in the system may increase eventually
225 to V_{siphon} corresponding to water level of Hu_{siphon} in the system. At that moment, a volume
226 V_{siphon} is already present in the system and the siphons are flowing at full capacity and under
227 pressure. For activation of weir1, the volume of water in the system must be equal to V_{weir1} which
228 corresponds to the crest level of weir1 given by H_{weir1} and this water is fixed. When this level
229 is exceeded, weir1 is activated. For activation of weir2 a fixed volume V_{weir2} corresponding to
230 crest level H_{weir2} must also be present in the system and when this level is exceeded, weir2 be
231 activated.

232 Generally, the maximum water levels Hu_{max} corresponding to the maximum storage of
233 the hypothetical reservoir will hardly occur except the case of backwater. However, this level is
234 needed in order to be used as an upstream boundary condition in COSIMAT. Table 2 shows the
235 parameters of the COSIMAT.

236

237 **2.2.2.3 Model calibration and validation**

238 The strategy for calibration and validation of COSIMAT was the same as that of SWMM but the
239 comparison was done between the outflow hydrographs of SWMM and COSIMAT using the
240 same data. However our interest was to compare the volumes of CSO produced by both models
241 and comparing the hydrographs was only an additional indicator showing the correctness of the
242 calibrated parameter for both models.

243 Among the parameters shown in table 2, only the reservoir constant (k) was calibrated.
244 This is because:- most of the other variables like area, DWF, runoff coefficient, number of
245 inhabitants etc were obtained directly from the SWMM model or determined using the lookup
246 table function in SIMULINKTM (extrapolation graph).

247 The runoff coefficient was maintained at 0.8 as the SCS CN value used throughout
248 SWMM is 80, though this value may not reflect reality and thus have a significant influence on
249 the generation of runoff.

250 The reservoir constant (k) was calibrated because it is a parameter that influences the travel
251 time of water in the system and consequently the shape of the outflow hydrograph and the
252 quantity of CSO discharge at the outlet of the system.

253

254 **2.3 Modelling with design storm**

255 The system was first analyzed using design storms. For this, the analysis made by Delbeke
256 (2001) of The Royal Meteorological Institute (RMI) of Belgium was used. Indeed, the design
257 storms were derived to reduce the number of runs needed to analyze and understand the system's
258 performance and behaviour under design flow conditions. We used a composite design storm
259 corresponding to 20, 10, 5 and 2 years of return period to represent both extreme and moderate
260 storms.

261

262 **2.4 Modelling with historical storm**

263 For this, we selected some interesting historical storms, a time series of hourly rainfall data
264 (recorded by FlowBru) between 2000 and 2008. The storm events of different intensities and
265 different durations were selected to cover the wide variety of rainfall patterns that occur in
266 Belgium. Altogether we selected 16 storm events, with storm duration ranging from 33 hours to
267 310 hours.

268

269 **3 Results and Discussion**

270 **3.1 Modelling with design storms**

271 Table 3 shows the comparison of total CSO volume sent to the receiving water simulated by the
272 SWMM and COSIMAT. As it can be observed, the error in the total CSO volume discharged
273 into the receiving water ranges from 10.6 % to 4.73%. As expected, a lower error was observed
274 in the case of the less extreme design storms with the lower return period. In average the CSO
275 volume simulated by COSIMAT was underestimated by 8.63% which can be evaluated as
276 reasonable regarding the simplifications introduced in the conceptual model compared to
277 SWMM. But for all the cases, the COSIMAT underestimated the CSO volume as compared to
278 the SWMM. This can be explained by Figure 5 which shows the SWMM and COSIMAT
279 simulated hydrograph for one hour duration storm event (total depth 26.41 mm) corresponding to
280 a return period of 10 years. As can be observed, the hydrographs are fairly matching. The
281 problem in particular is in the rising limb as well as the recession limb of the COSIMAT
282 simulated hydrograph. The recession limb of COSIMAT simulated hydrograph ceases too early
283 as compared to the SWMM simulated hydrograph which leads to the underestimation of the total
284 CSO volume. However, the peak discharge of COSIMAT matches closely with that of SWMM
285 and this is typical for most of the CSO volumes sent to the receiving water.

286

287 **3.2 Modelling with historical storms**

288 Table 4 shows the comparison of total CSO volumes sent to the receiving water from SWMM
289 and COSIMAT for 16 historical storms. The difference ranges from -12.57 % (underestimation
290 by COSIMAT) to +4.67 % (overestimation by COSIMAT). In average, the CSO volume
291 simulated by COSIMAT deviates from that of SWMM by 7.40%.

292 Figure 6(a) shows the observed and SWMM simulated hydrographs for storm event 14 (258
293 hours starting on 29/11/2007 at 14:00). As it can be observed, the model fairly reproduced the
294 observed discharge at the outlet of the system. Figure 6(b) shows the scatter plot of the same

295 storm with the discharge transformed using Box-Cox (BC) transformation (Box and Cox, 1964).
296 The parameter ' λ ' of the transformation is chosen to be 0.25 as suggested by Willems (2009).
297 The transformation is needed because the model residuals in rainfall-runoff model increases with
298 higher flow values (Willems, 2009) which is undesirable since these high values significantly
299 influence the model results when calculating goodness of fit statistics such as Nash-Sutcliffe
300 Efficiency – NSE (Nash and Sutcliffe, 1970) and Mean Squared Error (MSE). The BC
301 transformation with appropriate ' λ ' makes sure that the model residuals are homoscedastic
302 (Willems, 2009). As it can be observed in Figure 6(b), the mean deviation is slightly below the
303 bisector line indicating a slight underestimation by the SWMM. Also, the model results show
304 some scatterings (discharge points outside the standard deviation lines) too. In this case, the
305 discharge points are normally distributed; the standard deviation lines represent 68% confidence
306 limits too. The NSE and MSE values are found to be 0.79 and 1.14 m³/s respectively. These
307 goodness of fit statistics complemented by the graphical plots show that the SWMM simulated
308 flows are very good according to Moriasi et al. (2007)'s criterion.

309 Figure 7(a & b) show an identical plot as Figure 6(a & b) but the comparison is between the
310 SWMM simulated discharge and COSIMAT simulated discharge for the same storm event
311 (storm event 14, Table 4). As it can be seen, the COSIMAT has fairly reproduced the SWMM
312 simulated discharge but with lesser accuracy. As it can be seen in Figure 7(a), the COSIMAT
313 underestimated most of the peaks which is reflected in Figure 7(b), where the mean deviation
314 lies slightly below the bisector line. Also, the model results show more scatterings as the number
315 of discharge points could not be contained by the standard deviation lines. The NSE and MSE
316 values are found to be 0.66 and 1.32 m³/s respectively. These goodness of fit statistics
317 complemented by the graphical plots show that the COSIMAT simulated flows are good,
318 according to the Moriasi et al. (2007)'s criterion although the COSIMAT showed problems
319 reproducing the peak flows.

320

321 **4 Conclusions and recommendations**

322 We tested the potential of a continuous simulation model (COSIMAT) to mimic detailed
323 hydrodynamic model, the Storm Water Management Model (SWMM) in view of simulating the
324 total CSO volume sent to receiving water. We tested it to simulate CSO and flow at the outlet of
325 a fairly important collector of WWTP-North, the Paruck collector. We observed that the
326 COSIMAT model could reproduce the total CSO volume sent to the river with some accuracy.
327 The average difference in total CSO simulated volume between the COSIMAT and SWMM was
328 found to be 7.40 % for the 16 considered storm events. COSIMAT also reproduced the
329 hydrograph at the outlet of the considered sewer system with reasonable accuracy and with
330 substantial decrease in calculation time. The problem of COSIMAT showing quick response in
331 simulated hydrographs compared to SWMM is an issue that requires further investigation though
332 this had a little influence on the results of total CSO sent to the receiving water. From this, we
333 conclude that it is not always necessary to represent a sewer system with a detailed
334 hydrodynamic model. Conceptual models like COSIMAT can reproduce the situation with
335 reasonable accuracy, with reduced calculation time and without numerical instabilities. Such a
336 conceptual model can be a part of an integrated modelling system to represent the sewer system
337 which in turn can decrease the calculation time substantially and thus, a feasible integrated
338 modelling system can be put into operation.

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343

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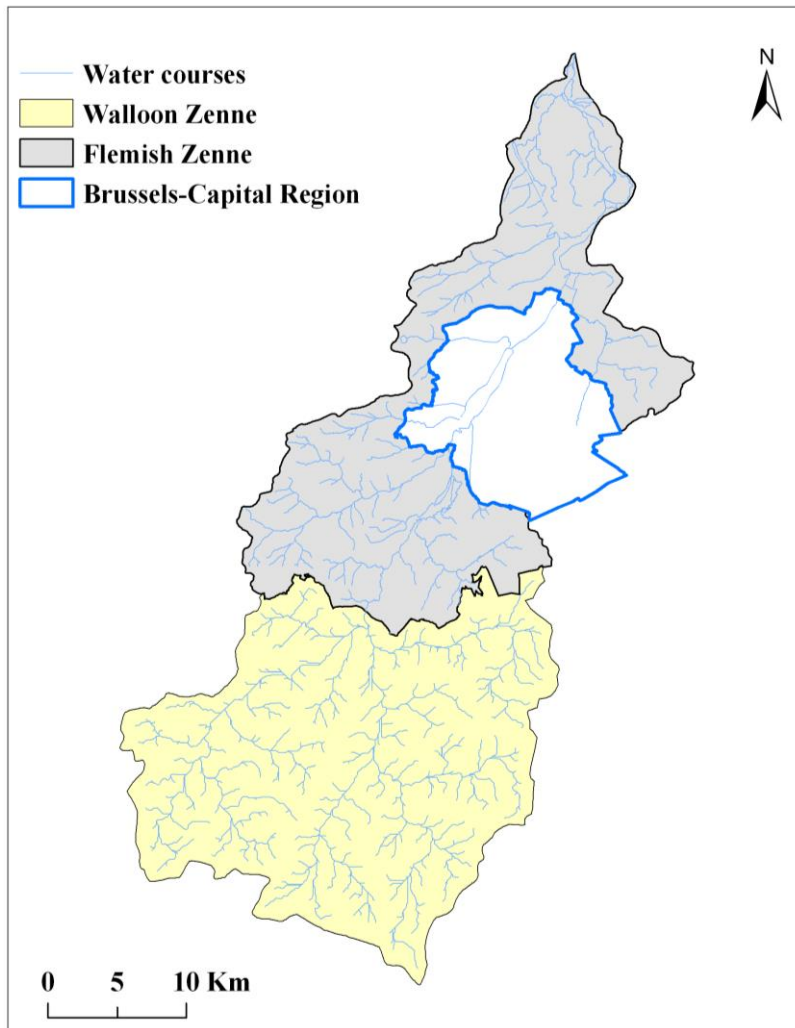
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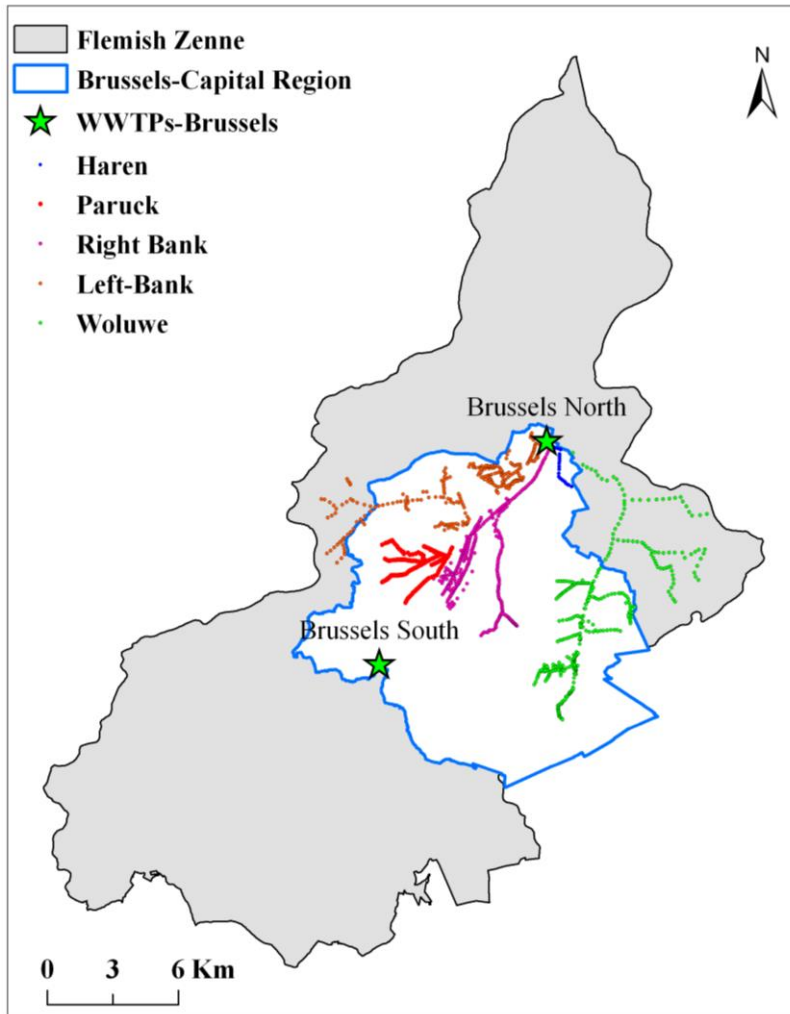
413 **List of Figures**



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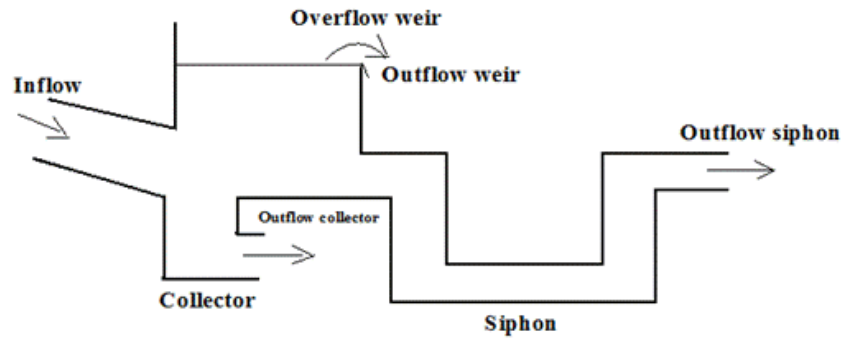
415 Figure 1: The Zenne river basin with its subbasins in three administrative regions of Belgium, and water
416 courses.

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Figure 2: The Flemish subbasin of Zenne with two WWTPs located in Brussels and, the major sewer collectors of the WWTP-Brussels North.

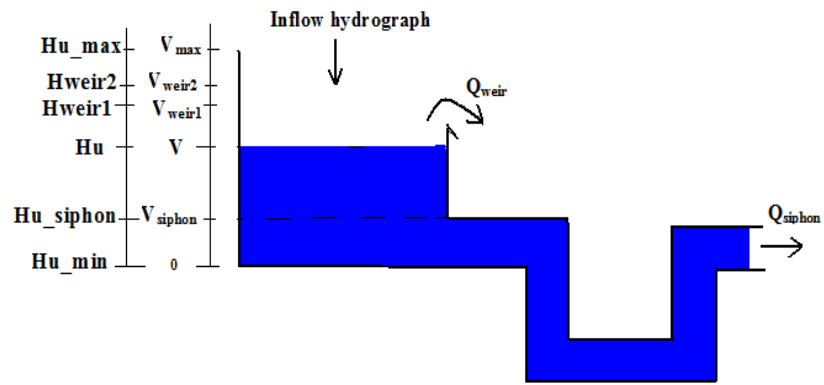


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423 Figure 3: Schematic representaion of flow partitioning at the outlet of the Paruck collector in the SWMM

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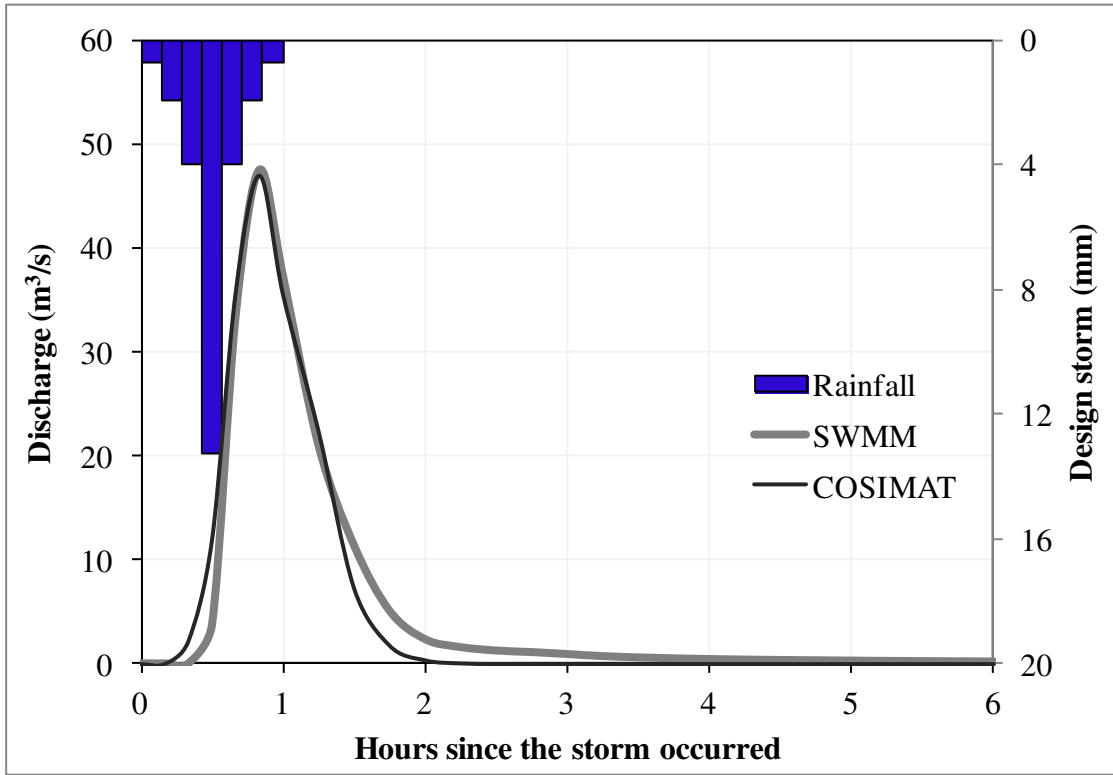
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427 Figure 4: Schematic conceptual representation of the system in the COSIMAT

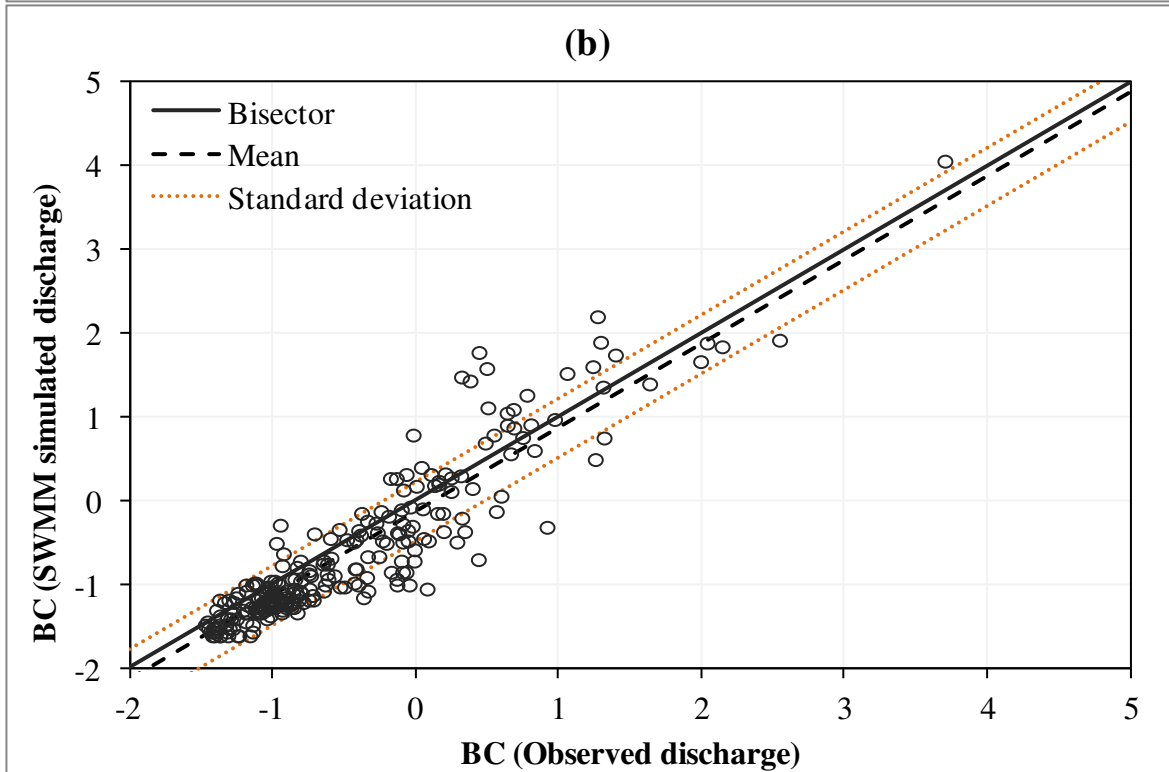
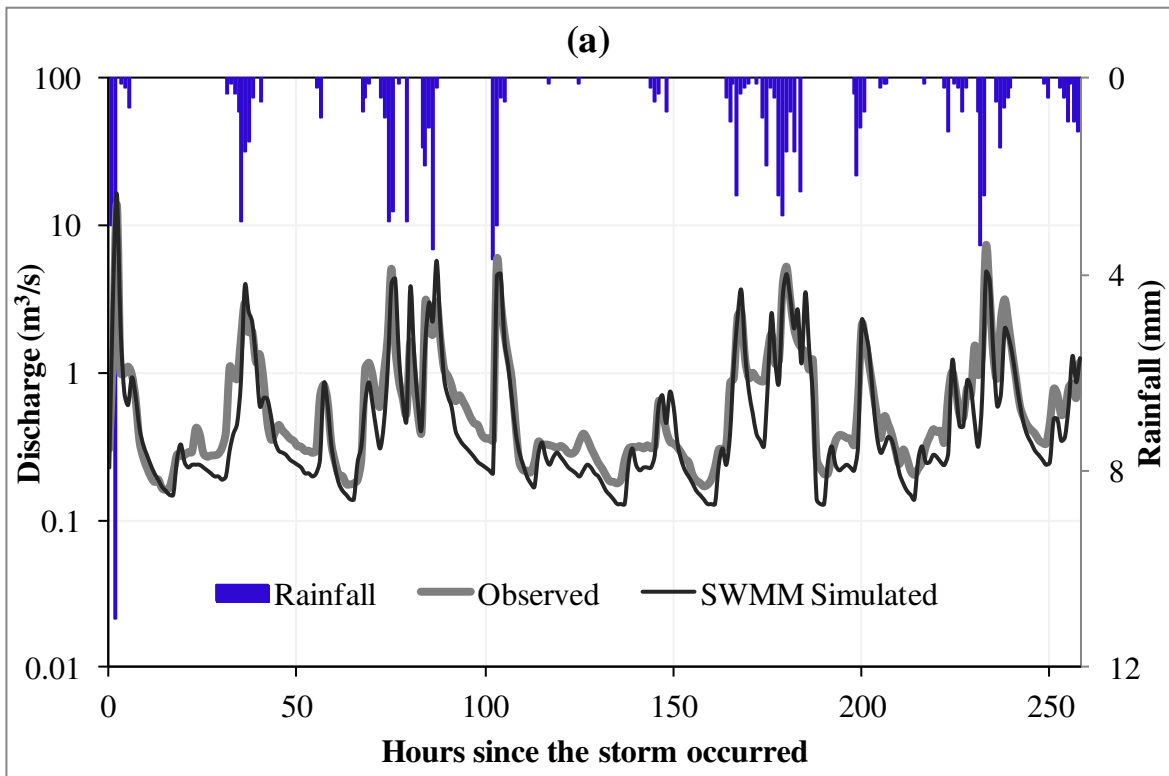
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430 Figure 5: SWMM and COSIMAT simulated hydrograph for one hour design storm corresponding to 10
 431 years of return period

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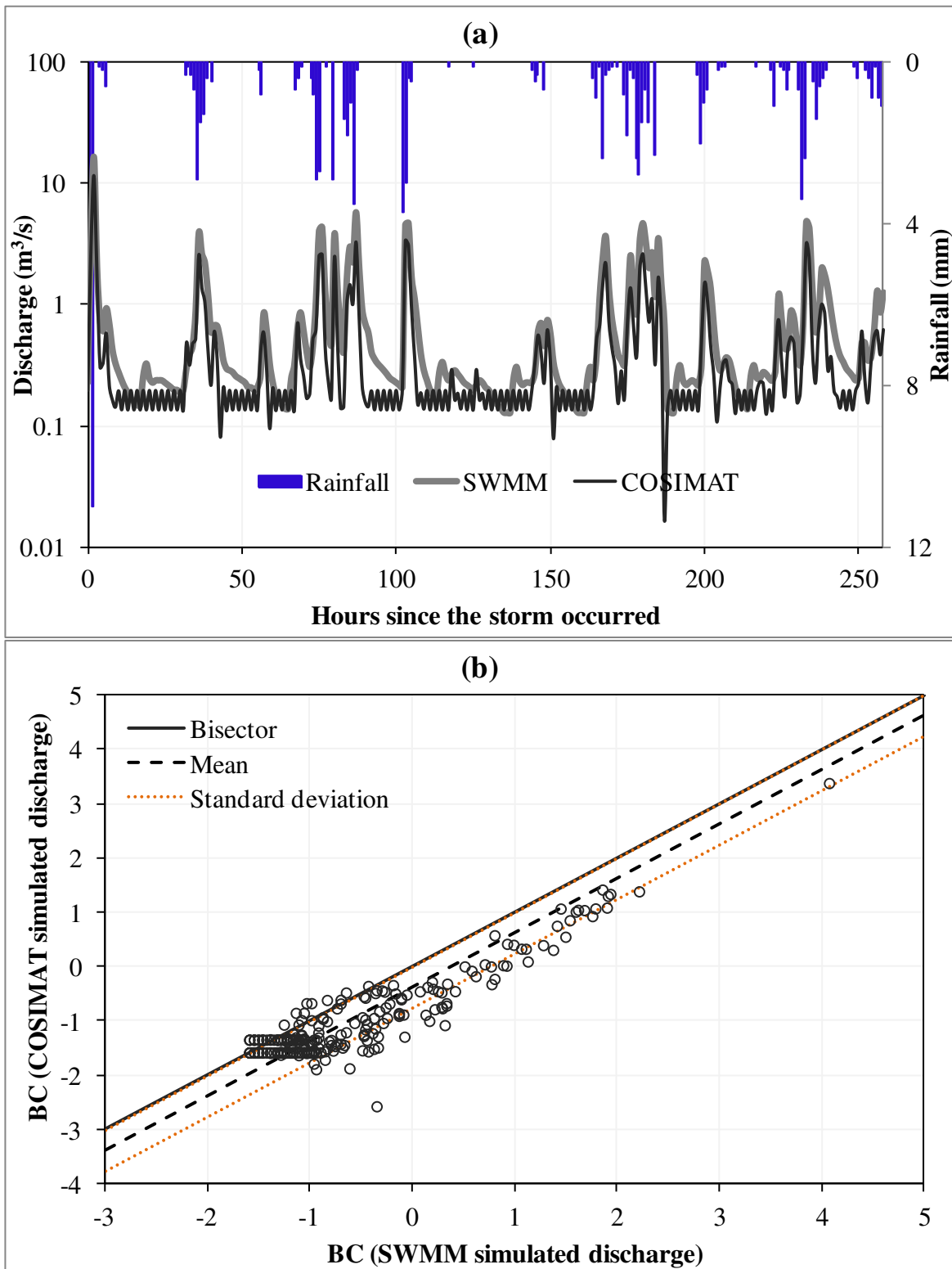
Figure 6: (a) Hydrograph and (b) scatter plot after applying Box-Cox transformation ($\lambda = 0.25$) with bisector, mean and standard deviation of observed and SWMM simulated discharge for the storm event

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14 (29/11/2007 14:00 - 11/12/2007 03:00)

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439 Figure 7: (a) Hydrograph and (b) scatter plot after applying Box-Cox transformation ($\lambda = 0.25$) with
 440 bisector, mean and standard deviation of SWMM and COSIMAT simulated discharge for the storm event
 441 14 (29/11/2007 14:00 - 11/12/2007 03:00)

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447 Table 1 The SWMM model characteristics of the Paruck system

Characteristics	Values/Methods
Area	1001ha
Impervious area	520ha
Number of subcatchments	24
No of inhabitants	101900
Dry Weather Outflow	340 lit/ha/day
Infiltration model used	SCS-CN
Number of rain gage	1
Routing model	Dynamic wave
Force main equation	Darcy-Weisbach
Number of conduits	189
Number of junctions	188
Number of weirs (side flow weirs)	2
Number of siphons (same characteristics)	4

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474 Table 2: Parameters values of the COSIMAT used for the Paruck system

Model Components		Parameter	Symbol	Values	Unit
Hydrologic		Area	A	5200000	m ²
		Wetting loss	-	0.50	mm
		Depression storage	L _{max}	1.40	mm
		Runoff coefficient	C	0.80	-
		No of inhabitants	Inh	101900	-
		Dry weather flow	DWF	340	lit/ha/day
		Reservoir constant (subjected to be calibrated, varies with the storm events)	K	180-360	sec
		Maximum storage capacity of reservoir	S _{max}	2198	m ³
		Minimum storage capacity of online reservoir	S _i	0	m ³
Hydraulic	Collector	Minimum discharge capacity	Q _{min}	0	m ³ /sec
		Maximum discharge capacity	Q _{max}	1.80	m ³ /sec
	Siphon	Diameter of siphon	D	1.20	m
		Length of siphon	L	60	m
		Roughness coefficient	f	0.016	-
	Weir 1+2	Level of weirs crests	H _{weir}	14.35&14.55	m
		Weir discharge coefficient	C _d	2.215	-
		Width of weir	W _{weir}	19	m

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493 Table 3: Comparison of total CSO sent to receiving water from SWMM and COSIMAT models
 494 for different design storms

Return periods (yrs)	CSO volume (m³) SWMM	CSO volume (m³) COSIMAT	Error (%)	Average error (%)
20	132659	118600	10.60	8.63
10	113546	102100	10.08	
5	94099	85510	9.13	
2	66663	63510	4.73	

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526 Table 4: Comparison of total CSO for SWMM and COSIMAT models for 16 historical storm events

S N	Storm start date/time	Storm end date/time	Storm duratio n (hr)	Rainfall (mm)	CSO volume (m³) SWMM	CSO volume (m³) COSIMAT	Error (%)	Average error (%)
1	07/02/2000 19:00	07/08/2000 17:00	142	48.1	134962	119600	11.4	7.40
2	07/23/2001 5:00	08/02/2001 23:00	258	55.91	280268	267000	4.73	
3	09/04/2001 13:00	09/09/2001 22:00	129	82.26	320486	280200	12.6	
4	07/22/2004 16:00	07/24/2004 1:00	33	44.92	204844	197400	3.63	
5	08/06/2004 20:00	08/19/2004 18:00	310	82.48	191555	177000	7.60	
6	06/29/2005 3:00	06/30/2005 23:00	44	61.56	254534	223900	12.0	
7	07/04/2005 09:00	07/08/2005 15:00	102	72.72	291227	254700	12.5	
8	09/10/2005 21:00	09/16/2005 5:00	128	59.48	253827	231200	8.91	
9	10/22/2005 15:00	10/25/2005 11:00	68	42.34	126681	132600	-4.67	
10	08/02/2006 21:00	08/04/2006 14:00	41	73.98	336183	298400	11.2	
11	08/11/2006 01:00	08/18/2006 7:00	174	89.54	324771	293900	9.51	
12	08/21/2006 14:00	08/29/2006 13:00	191	75.65	264964	239000	9.80	
13	05/07/2007 03:00	05/20/2007 20:00	314	47.7	50801	53410	-5.14	
14	29/11/2007 14:00	11/12/2007 03:00	258	94	185059	167400	9.54	
15	03/15/2008 23:00	03/22/2008 17:00	162	58.2	160216	149580	6.64	
16	08/03/2008 21:00	08/08/2008 17:00	116	60	246252	226300	8.10	

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