Sanitation of the Urban Drainage System 'Bengbu-East'

First Report, Nov. 1991

Institute for Water Resources, University Hannover
Prof. F. Sieker
Institute for Water Resources, Anhui, Bengbu
Prof. Lu Guangping

CONTENTS

List of the figures:

List of the tables:

List of the Appendixes:

Evaluation of a Urban Drainage System (UDS) through Simulation and Development of Sanitation Strategies; Case of Bengbu, People's Republic of China.

Z.Y. Jin*, A. Khelil**, D. Grotehusmann**, M. Siekmann**

* Anhui Water Resources Research Institute, Zhihuai Road 110, Bengbu, China

** Institute for Water Resources Research , Hannover University, Appelstrasse 9a, 3000 Hannover 1, Federal Republic of Germany

Abstract

In the last years, numerical simulation has turned to be an essential tool in the analysis of the UDS performance as well as in the development and evaluation of sanitation concepts. This is due to their reliability (much experience has been acquired with numerical models) and their flexibility (numerous cases can be easily simulated). In developing countries however, such models are more difficult to utilize. Reliable data about the rainfall-runoff-transport-processes (hydrological data-base) and exact knowledge about the existing drainage networks (structural data-base) are not the common case. This study attempts to transpose the methodology applied in Germany to a UDS located in China (Bengbu). The existing capacity of the UDS is evaluated in a first step . In function of the results, alternative sanitation concepts are proposed, which more or less account for the construction and maintenance costs. Their efficiency are evaluated and discussed.

Keywords: hydraulic simulation, sanitation of UDS, disconnection of impervious areas, decentralized retention/infiltration.

I Introduction

Numerical simulation models have become indispensable, whether it be to design new UDS or to analyse existing ones. In the latter case the requirements to modelling are higher, because misfunctionnings (overflow, back water effects) possibly occur,

whose mathematical representation is complex. In this study, a hydrological rainfall-runoff model (HYSTEM) linked with a hydraulic transport model (EXTRAN) is utilized.

The analysis decomposes into 4 steps:

1. Analysis of the existing UDS
2. Development of sanitation concepts
3. Evaluation of the impact of the retained measures
4. Realization of the sanitation

II Analysis of the existing UDS 'Bengbu-east'

II.1 Description of the simulation model

Fig.1 shows the principal model components. The calculation of the losses (for both impervious and pervious area) and the runoff component are depicted in Fig.2-3 . A detailed description of the modeling principles is given in [1].

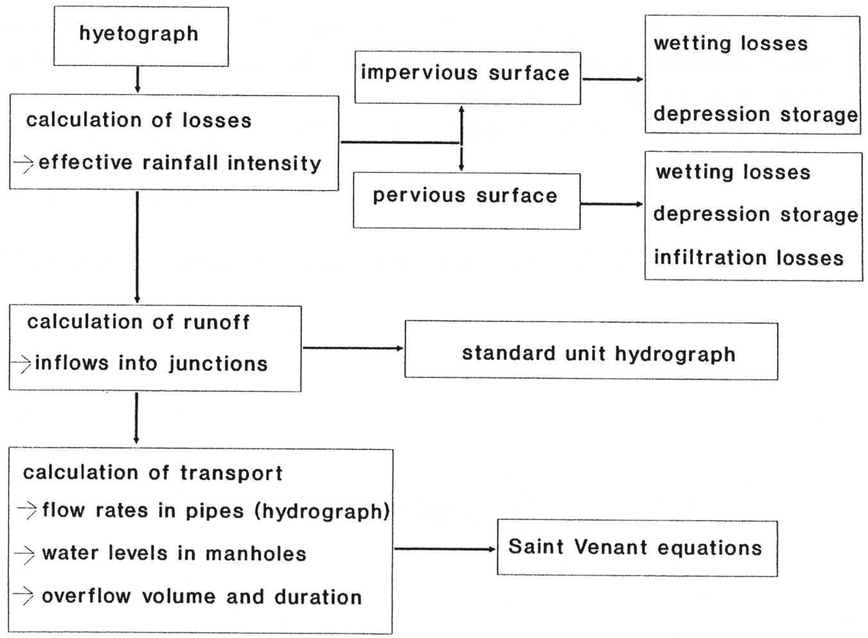


Fig.1: Model components in HYSTEM-EXTRAN

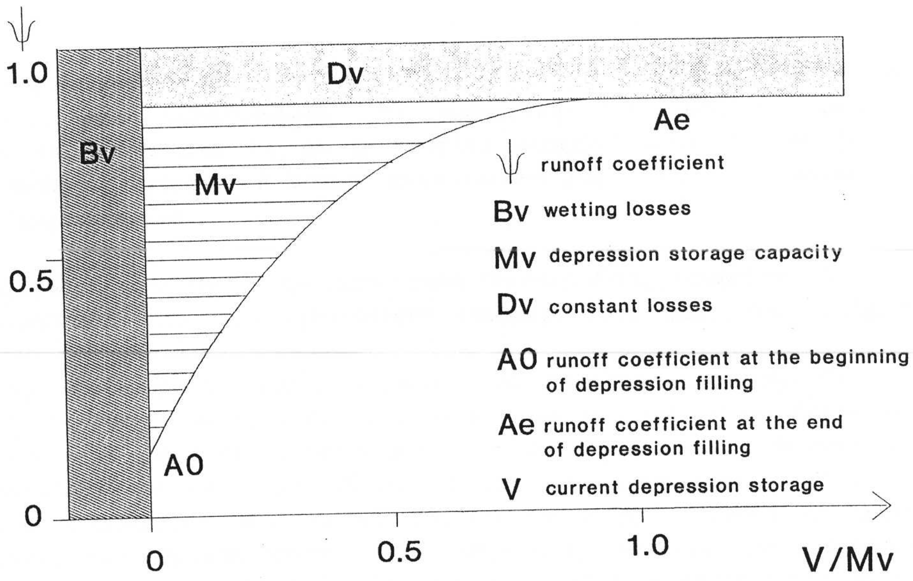


Fig.2a: Calculation of the losses in impervious surfaces (HYSTEM)

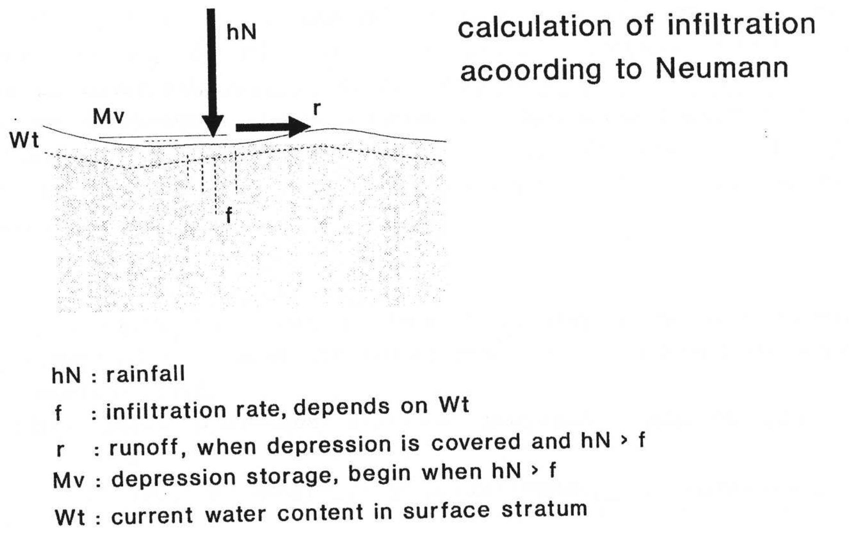


Fig.2b: Calculation of the losses in pervious ares (HYSTEM)

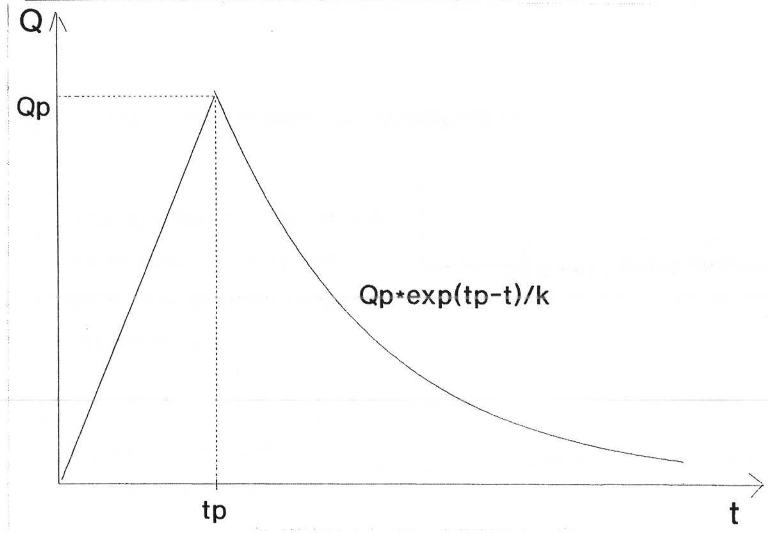


Fig.3: Runoff component (Standard Unit Hydrograph in HYSTEM)

II.2 Description of the UDS

II.2.1 Introduction

The UDS "Bengbu-East" drains the east part of Bengbu city (total area: 8 km^2 and a mean surface slope: 0.3%). It is composed of 2 subcatchments (1 und 2), which are separately drained (Fig. 4). Subcatchment 1 is situated nearby the down town and presents a dense land use; 47% of the catchment area is connected to the UDS. Subcatchment 2 presents a low connection percentage (27%).

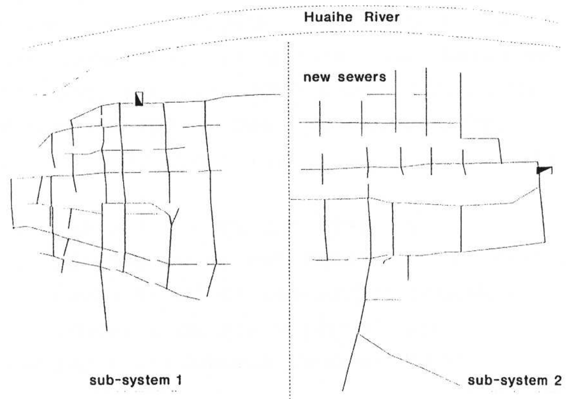


Fig. 4: Catchment "Bengbu-East"

II.2.2 the drainage system

The data about catchment and (combined sewage) network has been collected by two german students (F. Schneider and G. Dorrie) during a three months sojourn in 1990. Detailed informations were not available (among others the exact position of some pipes in specific areas, the exact delimination of the connected areas, the control strategy of the pumps). However, it is assumed that the digitalized description quite fairly accounts for the main characteristics of the UDS. In Tab.1 the values of the important characteristics are reported.

drained surfaces (connected to the pipes):	280 ha
impervious surface:	225 ha
number of reaches :	188 (-)
number of manholes :	171 (-)
total length of canalisation :	3 550 (m)
total storage volume in the pipes :	27 700 (m^3)
number of outlets :	2 (-)

Tab.1 : Characteristics of the UDS 'Bengbu-East'

Dry weather flow data:

The water consumption is supposed to be 120 l/inhabitant/day. To estimate the dry weather flows, 3 zones were considered with corresponding population densities 400, 250, 100 inhabitants per ha [2]. Besides domestic waste water, industrial waste water sources are reported in Subcatchment 2 [2]. The total dry weather flow amounts to 650 l/s.

Special structures:

At both outlets, the flow dynamics depends on the water level in the receiving waters (Huaihe River). In winter (low water levels) the combined sewage flows over weirs (weir1 and weir2). In summer (high levels), the combined sewerage is pumped into the river (pump1 and pump2).

subcat. No.	weirs	length (m)	crest height[1]	chamber height[1]
1	weir1	1.50	0.17	1.67
2	weir2	2.80	0.17	2.97

Tab.2: Characteristics of the weirs

Subcat. No.	pumps	maximum capacity (m3/s)
1	pump1	4.9
2	pump2	10.0

Tab.3 Characteristics of the pumps[2]

supplementary characteristics:

On the basis of the network description, further parameters can be calculated, which characterize the transport process.

available[3] storage volume in the pipes:	25 000 m^3
average transport duration in canalisation:	21 min
average transport length:	1790 m
extreme transport length[4] (L_{10}):	2900 m
characteristic width of the catchment (B):	770 m
coefficient of shape (L_{10}/B):	3.24 (-)

Tab.4: Supplementary UDS characteristics

II.2.3 Determination of the parameters to calculate the losses

In the calculation of the rainfall losses the model differentiates between pervious and impervious surfaces.

B_v	M_v	A_o[5]	A_e[6]
0.7mm	3mm	25%	85%

Tab.5: hydrological characteristics of the impervious surfaces.

1 height above junction invert in m.
2 Because reliable informations about the control of the pumps are lacking, it is assumed that the pumps always transport the corresponding inflow, up to their maximal capacity.
3 storage capacity after substraction of the volume occupied by dry weather flow
4 the transport length, which is exceeded in only 10% of the cases
5 part of impervious areas with direct runoff at the beginning of the depression storage filling
6 part of impervious areas with direct runoff at the end of the depression storage filling

B_V+M_V	W_O[7]	W_T[8]
5mm	10mm	16mm

Tab.6: hydrological characteristics of the pervious surfaces.

Remark:
The relatively high values of depression storage for impervious areas (in comparison to the ones assumed in Germany) account for the very irregular urban pattern (as shown in the pictures of Bengbu), according to which the water drops meet many obstacles, before they eventually reach a manhole.

II.3 Statistical analysis of the rainfall data

We disposed of rainfall records (not continuous) from the Wu Dao Gou hydrological station, which is situated about 40 km away from Bengbu. Every significant event, which was recorded over the period 1963-1989 (excepted years 1973,1986,1987), has been digitalized in five minutes intervals.
A statistical analysis of the data (partial and yearly series) has been conducted. The estimations of yearly series and the estimations of the storm formula (developped by the Bengbu hydrological station) fit fairly well. (Fig. 5)
However, for further analysis the partial series were only used because they are assaumed to provide more precise estimations.

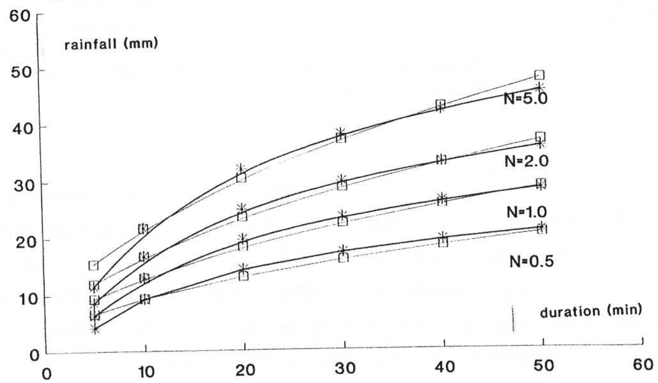


Fig. 5: Rainfall-duration-frequency curves for Bengbu.

7 water content in the surface stratum at the beginning of the rain event
8 storage capacity of the surface stratum. The infiltration rate will be calculated depending on these two parameters (see Fig.3)

Table 5 illustrates the difference between the rainfall statistics in Bengbu (China) and in Hannover (Germany)

	Statistics in Hannover			Statistics in Bengbu		
	RT=.5	RT=1.0	RT=2.0	RT=.5	RT=1.0	RT=2.0
D= 5	3.9	5.1	6.7	5.6	7.6	9.5
D=10	5.7	7.6	9.9	10.6	14.1	17.7
D=15	6.7	9.0	11.7	13.5	18.0	22.5
D=30	8.3	11.1	14.4	18.4	24.6	30.8
D=60	9.4	12.5	16.3	23.4	31.2	39.0

Tab.7: Rainfall Heights (mm) in function of D and RT (D: Duration in min; RT: Return period in years)

On the basis of the statistics, six design storms (Tab.8) were built. Every hyteograph is represented in Appendix 1.

design storm Nr.	rainfall (mm)	duration (min)	intensity (mm/5min) max.	intensity (mm/5min) mean	frequency (1/year)
001	14.1	10	7.6	7.05	1
002	18.0	15	7.6	6.00	1
003	24.6	30	7.6	4.10	1
004	10.6	10	5.6	5.30	2
005	13.5	15	5.6	4.50	2
006	18.4	30	5.6	3.07	2

Tab.8: Characteristics of the design storms

II.4 Simulation of the existing UDS

II.4.1 The transport capacity

The main points of discussion are the following ones:

1) transport capacity in the network
2) pumps capacities at the outlets

The great rainfall intensities, the relatively small dimensions of the pipes (Fig 6) and the low catchment slope cause high flooding frequencies. A straightforward transposition of the european standards would cost more money than the authorities can invest.
It was therefore decided to diminish the requirements, which means only characterize the UDS behaviour during medium events.

A long term simulation with 33 real events[9] of average magnitude has been first performed. Fig.7 shows the corresponding curve of the flooding frequencies (percentages of junctions are reported in abscisse).

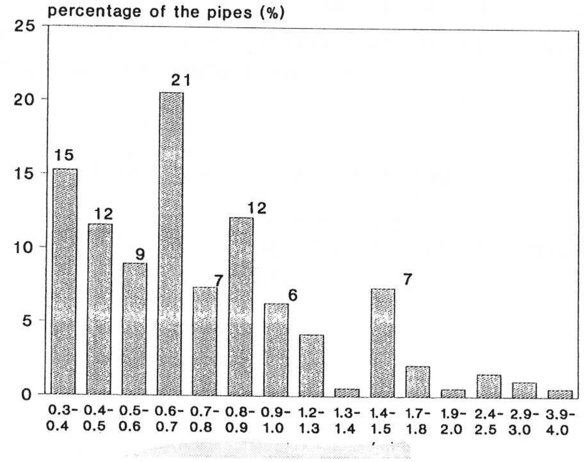


Fig 6: Distribution of the pipe diameters in UDS 'Bengbu-East'.

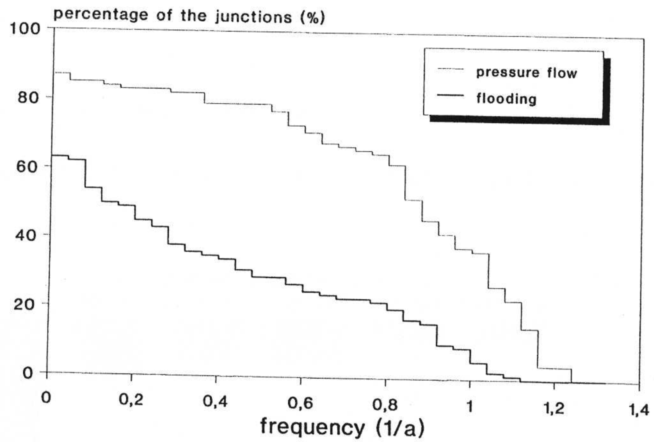


Fig.7: Transport capacity of the UDS (simulation with 33 medium events)

9 To select the 33 events of average magnitude following procedure has been retained:
a. Classification of the recorded events according to the total amount of rainfall and according to the duration
b. Selection of every event, which rank is situated between 20 and 40 (approximate return period between 6 months and 1 year) in either one of the classifications
6 events fulfill the magnitude requirement for both criteria (rainfall amount and duration). These ones are selected for a further detailled analysis.

Fig. 8 and Fig.9 show the flooded junctions during the design storms 001 and 004. Fig.10 and Fig.11 show the distribution of the flooding volumes in the corresponding junctions (the percentage of the total junctions is reported in abscisse).

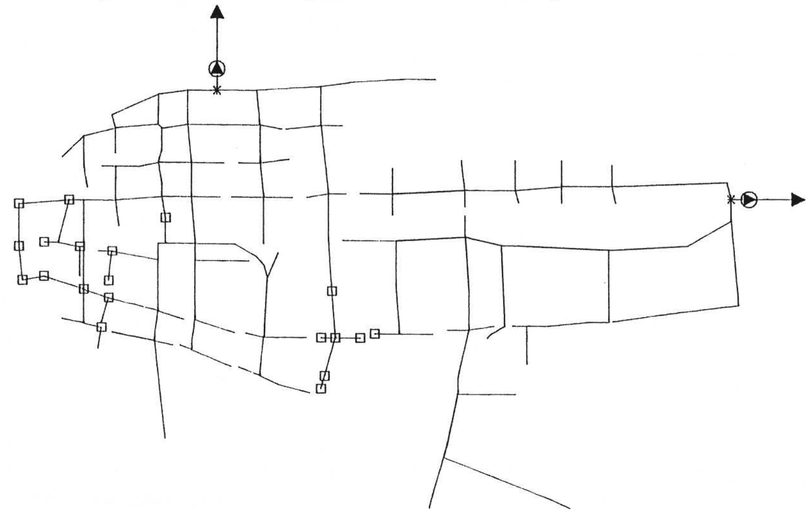


Fig.8: Flooded junctions (design storm 001; config. 1)

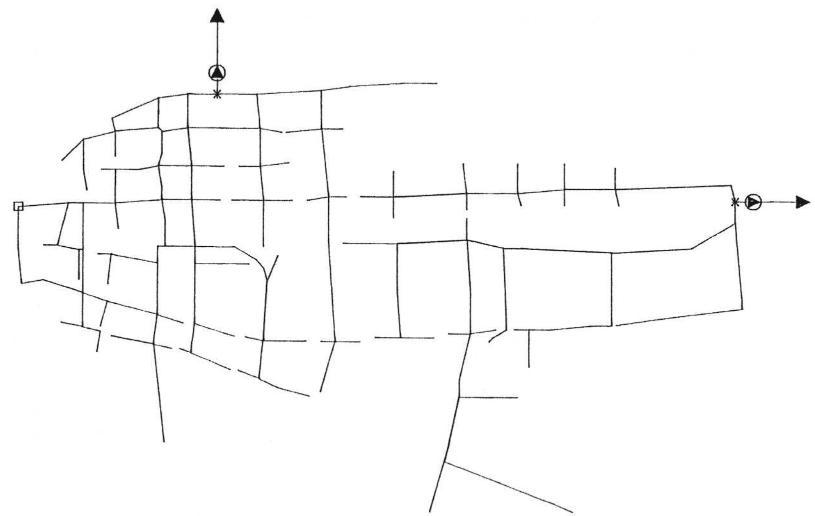


Fig.9: Flooded junctions (design storm 004; config. 1)

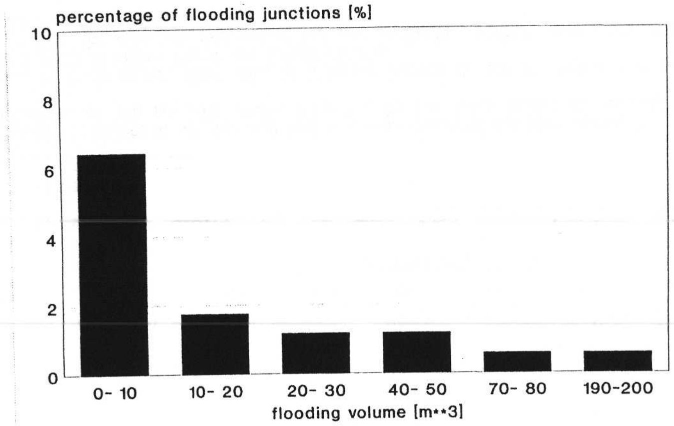


Fig.10: Distribution of the flooding volumes (design storm 001; config.1)

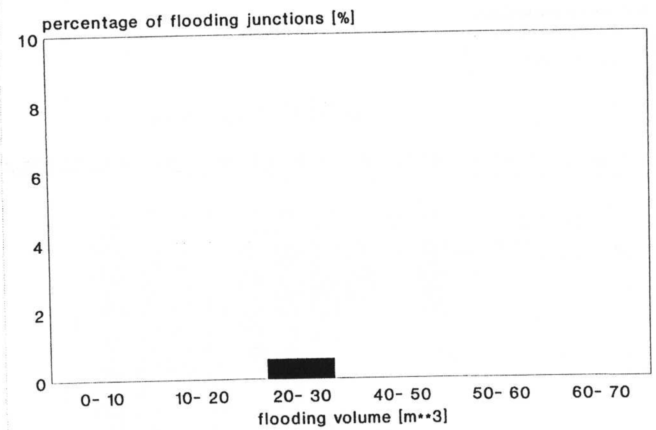


Fig.11: Distribution of the flooding volumes (design storm 004; config.1)

II.4.2. Analysis of the pumps capacity

Fig.12 shows the calculated hydrographs at the both outlets for storm 001 in configuration 1 (the pumps keep their present capacities). Results for configurations 2 (outflow over the weirs)

and configuration 3 (the pumps have an unlimited capacity) are presented in Appendix 3.

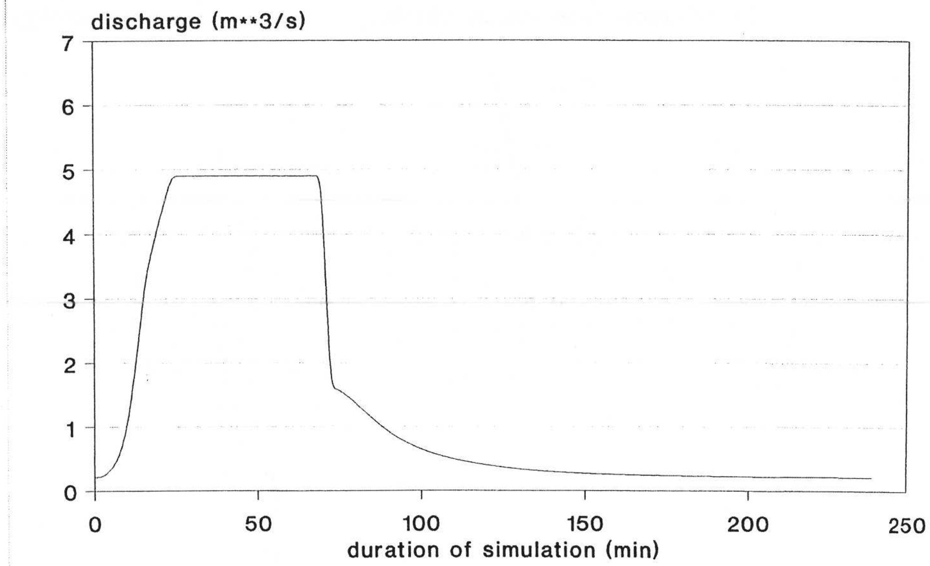


Fig.12a: Hydrograph at outlet 1 (config.1; design storm 001)

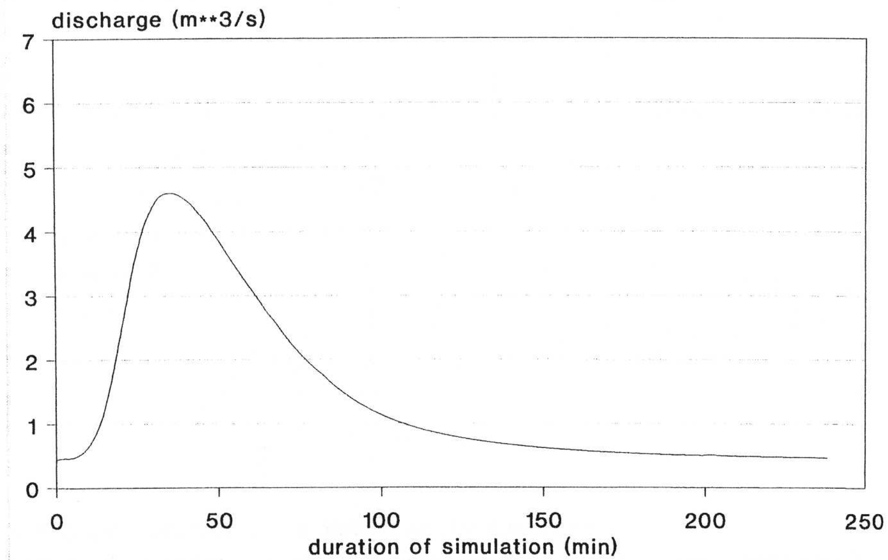


Fig.12b: Hydrograph at outlet 2 (config.1; design storm 001)

Remark:
The number of pressure flow (resp. flooding) junctions is a little bit higher in configuration 1 than in configuration 2 (design storm 001). This is due to the fact that the pump in subcatchment 1 is slightly underdimensioned. The differences are however not very significant (see Tab.9).

design storm	001	004
configuration 1	474	25
configuration 2	469	25

Tab.9: comparison of the flooding volumes (m^3).

II.4.3 Conclusions of the design storm analysis
- Subcatchment 1 needs improvements (in the transport capacity as well as in the pumping capacity) in order to meet the (reduced) requirements.
- Subcatchment 2 satisfies these requirements.

Remark:
In the following, the simulations only deal with subcatchment 1.

III Development of sanitation concepts

III.1 Introduction

The classical way to reduce the disorders is to provide greater storage and/or transport capacities. This can be achieved in the following ways:
- new dimensioning of the pipes (at least in the critical zones but probably to a greater extent)
- creation of supplementary meshes
- construction of retention basins.

By redimensionning the canalisations, transport as well as the storage capacities are increased. By implementation of supplementary meshes, a better repartition of the runoff waves is obtained, i.e the existing storage capacity will be better utilized. Retention basins only increase the storage capacity of the system.

Depending on the local conditions (outflow limitations, security constraints...), a combination of these solutions can be selected.

Unfortunately, constructive modifications in a UDS are very expensive and their extent should be limited. Alternatives approaches involve a new understanding of UDS and aim at the systematic reduction of the runoff volumes especially from the impervious surfaces .

In this study, following sanitation measures have been examined:
1. creation of meshes in the critical areas, combined with enlargement of the corresponding pipes,
2. disconnection of impervious areas.

The development of each sanitation concept decomposes into 2 steps:
- first analysis with design storms 001-004
- secondary evaluation with the 6 selected real events[9]. - In Appendix 2 these real events are represented and their main characteristics are given.-

III.2 Description of the sanitation concepts

III.2.1 constructive modifications of the sewer system; sanitation concept 1

supplementary reaches	length (m)	diameter (m)	storage volume (m^3)
HA143V	160	0.38	18.14
HA822V	160	0.60	45.24
HA832V	160	0.45	25.45
HA321V	160	0.45	25.45

Tab.10: The supplementary meshes

modified reaches	length (m)	initial diameter (m)	modified diameter (m)	initial volume (m^3)	modified volume (m^3)
HA380b	155	0.375	1.0	17.12	121.74
HA370	185	0.45	1.0	29.42	145.29
HA360	265	0.60	1.0	74.93	208.13
HA350	156	0.80	1.0	78.41	122.52

Tab.11: Redimensioning of some pipes

III.2.2 Disconnection measures

First, it is assumed that the disconnection of the impervious areas uniformly applies on the whole subcatchment 1. The analysis of the simulation results (Tab.12) shows that a 20% disconnection rate is the most efficient (sanitation **concept 2**)

In a second step, the disconnections (20% of the impervious area) are restricted to the critical area (sanitation **concept 3**).

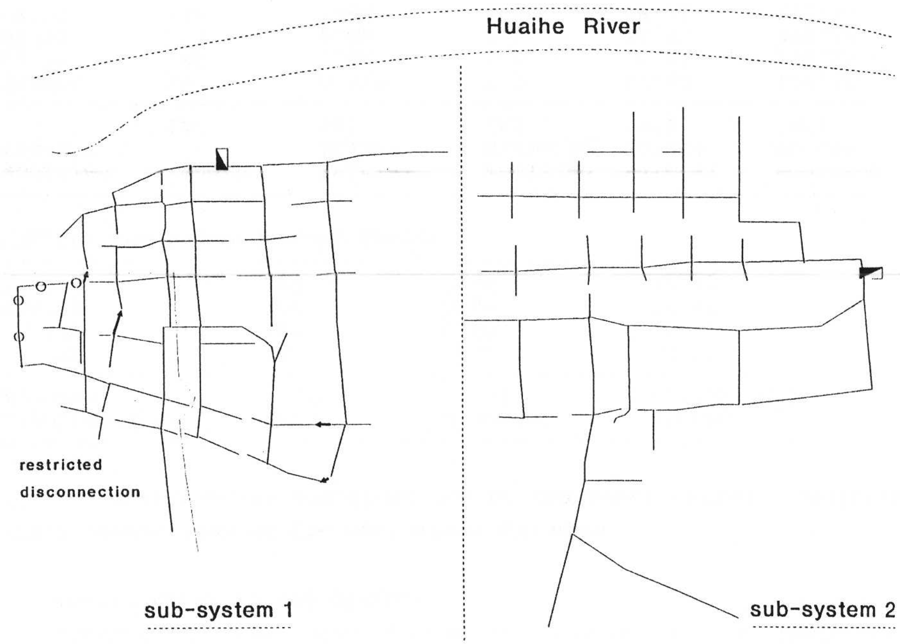
Informations of the critical area (see Fig. 8)

- impervious area : 42.8 ha
- number of reaches : 37

	No1 (%)	No2 (%)	vol1 (m^3)	vol2 (m^3)	peak (m^3/s)
present state	30	11	448	15988	4.9
disconnec. 10%	27	5	228	14602	4.9
disconnec. 20%	20	2	93	13202	4.8
disconnec. 30%	14	1	33	11850	4.5
disconnec. 40%	8	1	4	10490	4.1
disconnec. 50%	4	-	-	9122	3.8

Tab.12: Comparison of the efficiency of the disconnection rates (subcatchment 1; design storm 001; config.1)

Remarks:
No1 Percentage of junctions with pressure flow
No2 Percentage of junctions with flooding
Vol1 Total flooding volume
Vol2 Total outflow volume



concept 1: Sub-system 1 is modified through extension and/or enlargement of the conduits

new conduit installed

conduit enlarged

concept 2: 20% of the connected impervious area of each element is disconnected

concept 3: disconnections are restricted to the critical area

Fig.13: Illustration of the 3 sanitation concepts

IV Evaluation of the sanitation concepts

IV.1 The simulation results

The performances of the UDS according to each sanitation concept are compared for 3 design storms (001, 002, 003).

config.	design storm	No1 (%)	No2 (%)	vol1 (m^3)	vol2 (m^3)	peak (m^3/s)
present state	001 002 003	30 40 46	11 18 20	448 2036 5442	15988 20822 29243	5.50 6.91 7.87
concept 1	001 002 003	30 41 47	2 13 18	44 1535 4912	15998 20813 29227	 6.96 7.97
concept 2	001 002 003	20 32 40	2 9 16	93 598 2592	13202 17254 24267	 6.20 7.19
concept 3	001 002 003	26 37 46	5 13 18	217 1217 4146	15102 19641 27608	 6.84 7.84

Tab.13: Simulation results (subcatchment 1, config.3)

In Fig.14, the corresponding flooding volumes are represented. Further results are given in Appendix 4.

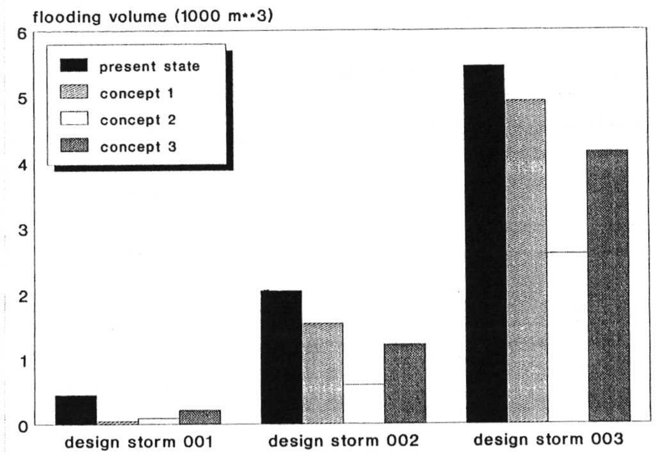


Fig.14: Comparison of the sanitation measures; the flooding volumes during design storm 001, 002, 003

Similar simulations with the 6 selected real events have been conducted. The total flooding volumes in each sanitation case are represented in Fig.15. Further results are given in Appendix 5.

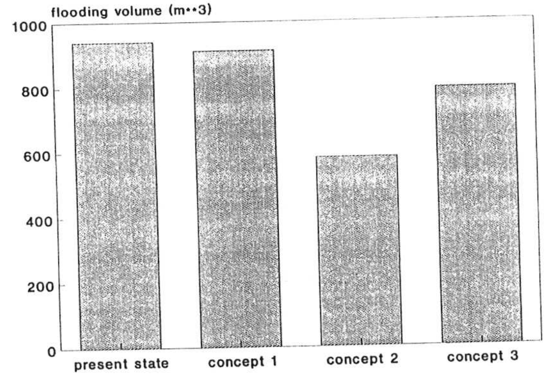


Fig.15: Comparison between the sanitation measures; total flooding volumes for the 6 selected real events

IV.2 Conclusions

For short storm events of small magnitude (return period 6 month till 1 year, duration 10 min) limited modifications (concept 1 or concept 3) can already operate considerable improvements.

For events of greater magnitude, the network is so overloaded, that a general disconnection (concept 2) is necessary. A reduction of the inflow is more relevant than a better repartition of the in-line storage volumes.

V Realization of disconnection measures

Many researches have been conducted about the realization of disconnection measures. Pilot projects have been taking place in Europe and Japan see [3] and [4].

A practical solution in the case of Bengbu would probably include rain water reuse (citerns) and decentralised infiltration of the runoff through a system of trenchs with inlets (see Fig.16).

Other solutions like the installation of permeable pavements or similar (storage and slow transport) structures are probably too expensive as sanitation measures. They should however, be taken into consideration in the conception of new UDS.

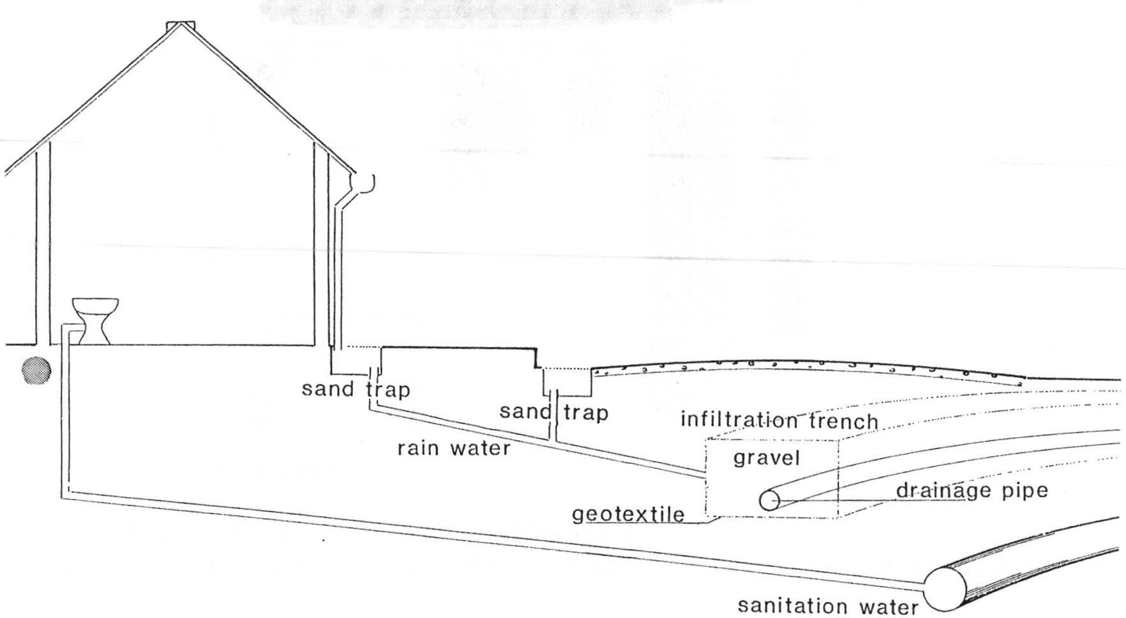


Fig.16: Schema of a trench system

References

[1] L. Fuchs, H.-R. Verworn; 'Microcomputer in Urban Hydrology; Description of the Program HYSTEM-EXTRAN'; ITWH Hannover; 1990 (in German)

[2] Bureau of city planing and construction in Bengbu, documentation 1980 (in Chinese)

[3] Proceedings of the 5th ICUSD, Osaka (Japan), July 23-27,1990, 3 Volumes

[4] Grotehusmann, Khelil, Sieker, Uhl; 'Development of a new concept for the drainage of rainfall water from impervious surfaces in the Emscher catchment'; Final Report (in German)

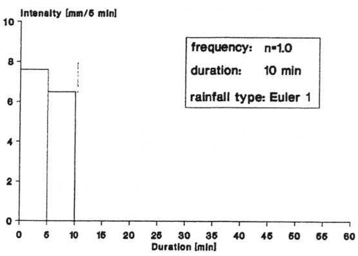
[5] Grotehusmann, Khelil, Sieker, Uhl; 'Drainage of rainfall water through a system of depression and losses', to be published in German in 'Korrespondenz Abwasser (in German)

APPENDIX 1

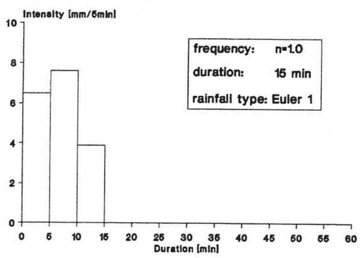
THE DESIGN STORMS

APPENDIX 2
THE SELECTED REAL EVENTS

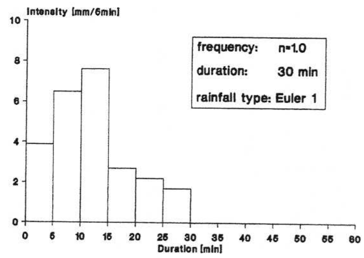
Design storm 001



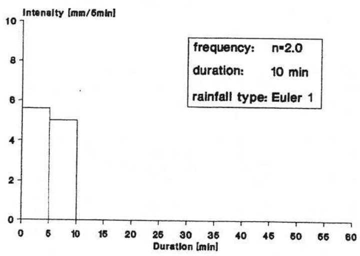
Design storm 002



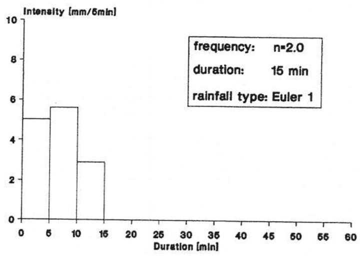
Design storm 003



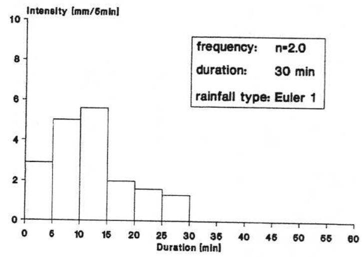
Design storm 004



Design storm 005



Design storm 006



STATISTISCHE UNTERSUCHUNG DER NIEDERSCHLAGSDATEN; ANORDNUNG DER NIEDERSCHLAGSEREIGNISSE

Kriterien zur Bestimmung eines Einzelereignisses

1. Zeitraum der Untersuchung : 1963 bis 1989,
2. Trennzeit zwischen 2 Ereignissen : 4 Stunden
3. Trockenwetter gilt, solange die Niederschlagshöhe weniger als 0,1 mm in 5 Minuten beträgt.
4. Es werden nur Ereignisse aufgelistet, deren gesamte Niederschlagshöhe mehr als 20 mm beträgt.

Sortierung nach der gesamten Niederschlagshöhe im mm

RSUM : gesamte Niederschlagshöhe
R : Regenspende

ANF-DAT./ZEIT	END-DAT./ZEIT	RSUM (mm)	R (l/s*ha)
23 6 1980 1955	24 6 1980 8 0	153.42	35.2690
3 8 1965 22 0	4 8 1965 1115	135.28	28.3606
24 8 1989 2045	25 8 1989 545	130.00	40.1235
3 3 1966 16 0	4 3 1966 650	115.89	21.7022
18 7 1977 2335	19 7 1977 17 5	114.69	18.2048
3 7 1967 2025	4 7 1967 17 0	108.38	14.6262
21 7 1970 220	21 7 1970 11 5	103.62	32.8952
28 7 1964 1510	28 7 1964 18 0	102.10	100.0980
12 8 1974 1115	13 8 1974 745	99.57	13.4919
20 7 1984 4 5	21 7 1984 055	98.00	13.0667
6 9 1984 1010	7 9 1984 1135	97.40	10.6448
2 7 1965 2335	3 7 1965 315	97.20	73.6364
30 6 1983 19 5	1 7 1983 855	90.39	18.1506
28 9 1969 835	29 9 1969 8 0	84.94	10.0759
24 7 1984 2340	25 7 1984 11 0	83.84	20.5490
11 6 1971 2 5	12 6 1971 8 0	81.96	7.6100
9 7 1982 2135	10 7 1982 255	79.42	41.3646
23 5 1980 2335	25 5 1980 3 0	78.46	7.9493
11 6 1983 1420	11 6 1983 2320	77.39	23.8858
27 7 1965 13 5	28 7 1965 1 5	76.78	17.7731
15 7 1979 9 0	15 7 1979 1055	75.47	109.3768
24 7 1981 930	24 7 1981 2050	72.68	17.8137
1 8 1965 1850	2 8 1965 115	68.76	29.7662
11 7 1969 1155	11 7 1969 1815	65.80	28.8596
19 7 1963 1245	20 7 1963 7 0	64.43	9.8067
29 8 1977 8 0	29 8 1977 1755	63.84	17.8824
15 7 1989 530	15 7 1989 1015	63.63	37.2105
15 7 1979 20 0	16 7 1979 610	63.53	17.3579
20 6 1975 1255	20 6 1975 2130	62.06	20.0841
21 7 1969 1735	21 7 1969 2155	62.01	39.7500
29 9 1971 1055	30 9 1971 1740	58.96	5.3261
7 5 1972 1315	7 5 1972 1825	55.17	29.6613
8 8 1976 1650	8 8 1976 18 0	54.83	130.5476
11 8 1974 1530	11 8 1974 1925	54.83	38.8865
17 7 1968 2320	18 7 1968 7 5	54.80	19.6416
20 7 1983 1250	21 7 1983 7 5	53.58	8.1553
9 9 1988 225	9 9 1988 1655	53.20	10.1916
19 7 1970 855	19 7 1970 1520	51.77	22.4113
17 8 1964 1055	17 8 1964 14 5	51.63	45.2895
3 7 1969 825	3 7 1969 1910	51.46	13.2972
23 7 1983 615	23 7 1983 17 5	50.26	12.8872
17 7 1970 1125	17 7 1970 1425	49.22	45.5741
16 5 1964 8 0	16 5 1964 2220	48.66	9.4302
29 6 1979 1730	29 6 1979 1840	48.36	115.1429
4 9 1969 530	4 9 1969 8 0	46.70	51.8889
12 6 1989 14 5	12 6 1989 2110	46.51	18.2392
9 8 1982 1450	9 8 1982 1545	45.93	139.1818
21 6 1972 120	21 6 1972 1520	44.60	8.8492
27 7 1964 1645	27 7 1964 1830	44.45	70.5556
31 5 1980 22 0	1 6 1980 710	43.77	13.2636
11 7 1969 2230	12 7 1969 625	42.95	15.0702
4 9 1970 010	4 9 1970 445	42.38	25.6849
19 7 1980 2155	20 7 1980 1015	42.20	9.5045
9 7 1964 1650	9 7 1964 2135	42.05	24.5906
29 7 1981 1710	29 7 1981 1740	41.63	231.2778
5 8 1989 2350	6 8 1989 445	41.40	23.3898
22 6 1975 8 0	22 6 1975 1445	41.30	16.9959
13 8 1970 1730	13 8 1970 1845	41.24	91.6444
10 8 1977 850	10 8 1977 1250	41.17	28.5903
7 8 1969 1425	7 8 1969 1645	40.90	48.6905
2 3 1966 2120	3 3 1966 1015	40.67	8.7462
19 6 1981 1920	20 6 1981 025	40.55	22.1585
4 7 1983 055	4 7 1983 9 5	39.00	13.2653
9 8 1964 2145	9 8 1964 2340	38.93	56.4203
15 8 1967 1720	16 8 1967 750	38.90	7.4521
24 7 1988 1740	25 7 1988 415	38.80	10.1837
23 9 1981 9 5	23 9 1981 2115	38.31	8.7466
10 6 1971 250	10 6 1971 20 5	37.91	6.1047
24 8 1981 710	24 8 1981 1050	37.38	28.3182
30 8 1984 2125	31 8 1984 1135	37.29	7.3118
28 8 1971 350	28 8 1971 1210	36.87	12.2900
17 8 1976 2225	17 8 1976 2255	35.45	196.9444
15 7 1965 1745	15 7 1965 2110	34.33	27.9106
6 3 1966 3 0	6 3 1966 1745	34.10	6.4218
21 7 1983 1125	21 7 1983 20 0	33.83	10.9482
6 7 1965 1725	6 7 1965 2225	32.23	17.9056
29 7 1980 1540	29 7 1980 1655	32.08	71.2889
12 8 1984 1610	12 8 1984 2045	31.98	19.3818
13 7 1968 510	13 7 1968 1315	31.47	10.8144
20 8 1985 16 0	20 8 1985 1645	31.42	116.3704
7 6 1976 1230	7 6 1976 1720	30.80	17.7012
25 6 1981 2350	26 6 1981 735	30.37	10.8853
30 7 1975 340	30 7 1975 925	29.94	14.4638
9 6 1981 8 0	9 6 1981 1715	29.70	8.9189
5 8 1989 1530	5 8 1989 1720	29.39	44.5303
25 6 1981 820	25 6 1981 1330	28.93	15.5538
2610 1978 435	2610 1978 820	28.52	21.1259
10 9 1983 445	10 9 1983 1230	27.70	9.9283
21 6 1972 21 0	22 6 1972 525	27.35	9.0264
13 7 1968 2210	14 7 1968 4 5	27.14	12.7418
11 7 1963 8 0	11 7 1963 1315	26.36	13.9471
12 5 1985 1250	12 5 1985 1945	25.36	10.1847
22 7 1983 2 0	22 7 1983 1625	24.37	4.6956
12 7 1963 310	12 7 1963 8 0	22.80	13.1034
30 7 1980 555	30 7 1980 1240	21.17	8.7119
11 7 1963 19 0	11 7 1963 2155	20.11	19.1524

STATISTISCHE UNTERSUCHUNG DER NIEDERSCHLAGSDATEN;
ANORDNUNG DER EREIGNISSE

Kriterien zur Bestimmung eines Einzelereignisses:

1. Zeitraum der Untersuchung : 1963 bis 1989
2. minimale Trennzeit zwischen 2 Niederschlagsereignisse : 4 Stunden.
3. Trockenwetter gilt, solange die Niederschlagshöhe kleiner als 0,1 mm in 5 Minuten beträgt.
4. Nur die Ereignisse, deren gesamte Niederschlagshöhe mehr als 20 mm beträgt, werden aufgezeigt.

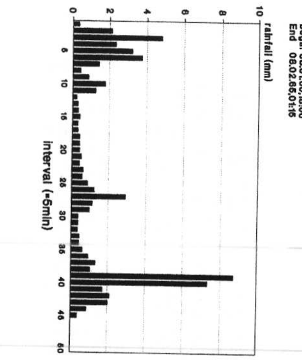
Sortierung der Ereignisse nach der Regenspende R (l/s/ha).

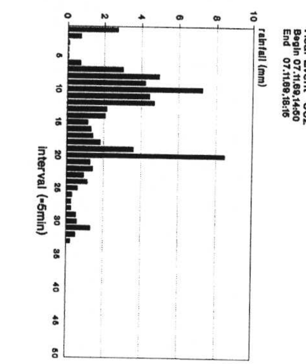
RSUM : gesamte Niederschlagshöhe (mm),
R : Regenspende (l/s/ha).

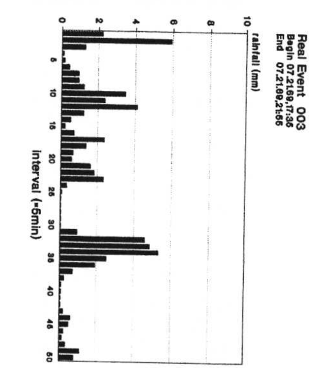
ANF-DAT./ZEIT	END-DAT./ZEIT	RSUM	R
29 71981 1710	29 71981 1740	41.63	231.2778
17 81976 2225	17 81976 2255	35.45	196.9444
9 81982 1450	9 81982 1545	45.93	139.1818
8 81976 1650	8 81976 18 0	54.83	130.5476
20 81985 16 0	20 81985 1645	31.42	116.3704
29 61979 1730	29 61979 1840	48.36	115.1429
15 71979 9 0	15 71979 1055	75.47	109.3768
28 71964 1510	28 71964 18 0	102.10	100.0980
13 81970 1730	13 81970 1845	41.24	91.6444
2 71965 2335	3 71965 315	97.20	73.6364
29 71980 1540	29 71980 1655	32.08	71.2889
27 71964 1645	27 71964 1830	44.45	70.5556
9 81964 2145	9 81964 2340	38.93	56.4203
4 91969 530	4 91969 8 0	46.70	51.8889
7 81969 1425	7 81969 1645	40.90	48.6905
17 71970 1125	17 71970 1425	49.22	45.5741
17 81964 1055	17 81964 14 5	51.63	45.2895
5 81989 1530	5 81989 1720	29.39	44.5303
9 71982 2135	10 71982 255	79.42	41.3646
24 81989 2045	25 81989 545	130.00	40.1235
21 71969 1735	21 71969 2155	62.01	39.7500
11 81974 1530	11 81974 1925	54.83	38.8865
15 71989 530	15 71989 1015	63.63	37.2105
23 61980 1955	24 61980 8 0	153.42	35.2690
21 71970 220	21 71970 11 5	103.62	32.8952
1 81965 1850	2 81965 115	68.76	29.7662
7 51972 1315	7 51972 1825	55.17	29.6613
11 71969 1155	11 71969 1815	65.80	28.8596
10 81977 850	10 81977 1250	41.17	28.5903

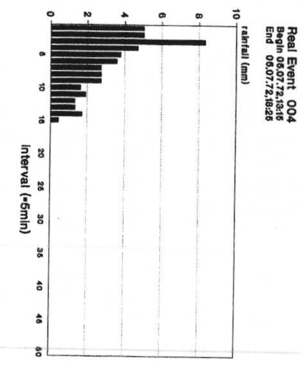
ANF-DAT./ZEIT	END-DAT./ZEIT	RSUM	R
3 81965 22 0	4 81965 1115	135.28	28.3606
24 81981 710	24 81981 1050	37.38	28.3182
15 71965 1745	15 71965 2110	34.33	27.9106
4 91970 010	4 91970 445	42.38	25.6849
9 71964 1650	9 71964 2135	42.05	24.5906
11 61983 1420	11 61983 2320	77.39	23.8858
5 81989 2350	6 81989 445	41.40	23.3898
19 71970 855	19 71970 1520	51.77	22.4113
19 61981 1920	20 61981 025	40.55	22.1585
3 31966 16 0	4 31966 650	115.89	21.7022
26101978 435	26101978 820	28.52	21.1259
24 71984 2340	25 71984 11 0	83.84	20.5490
20 61975 1255	20 61975 2130	62.06	20.0841
17 71968 2320	18 71968 7 5	54.80	19.6416
12 81984 1610	12 81984 2045	31.98	19.3818
11 71963 19 0	11 71963 2155	20.11	19.1524
12 61989 14 5	12 61989 2110	46.51	18.2392
18 71977 2335	19 71977 17 5	114.69	18.2048
30 61983 19 5	1 71983 855	90.39	18.1506
6 71965 1725	6 71965 2225	32.23	17.9056
29 81977 8 0	29 81977 1755	63.84	17.8824
24 71981 930	24 71981 2050	72.68	17.8137
27 71965 13 5	28 71965 1 5	76.78	17.7731
7 61976 1230	7 61976 1720	30.80	17.7012
15 71979 20 0	16 71979 610	63.53	17.3579
22 61975 8 0	22 61975 1445	41.30	16.9959
25 61981 820	25 61981 1330	28.93	15.5538
11 71969 2230	12 71969 625	42.95	15.0702
3 71967 2025	4 71967 17 0	108.38	14.6262
30 71975 340	30 71975 925	29.94	14.4638
11 71963 8 0	11 71963 1315	26.36	13.9471
12 81974 1115	13 81974 745	99.57	13.4919
3 71969 825	3 71969 1910	51.46	13.2972
4 71983 055	4 71983 9 5	39.00	13.2653
31 51980 22 0	1 61980 710	43.77	13.2636
12 71963 310	12 71963 8 0	22.80	13.1034
20 71984 4 5	21 71984 055	98.00	13.0667
23 71983 615	23 71983 17 5	50.26	12.8872
13 71968 2210	14 71968 4 5	27.14	12.7418
28 81971 350	28 81971 1210	36.87	12.2900
21 71983 1125	21 71983 20 0	33.83	10.9482
25 61981 2350	26 61981 735	30.37	10.8853
13 71968 510	13 71968 1315	31.47	10.8144
6 91984 1010	7 91984 1135	97.40	10.6448
9 91988 225	9 91988 1655	53.20	10.1916
12 51985 1250	12 51985 1945	25.36	10.1847
24 71988 1740	25 71988 415	38.80	10.1837
28 91969 835	29 91969 8 0	84.94	10.0759
10 91983 445	10 91983 1230	27.70	9.9283
19 71963 1245	20 71963 7 0	64.43	9.8067

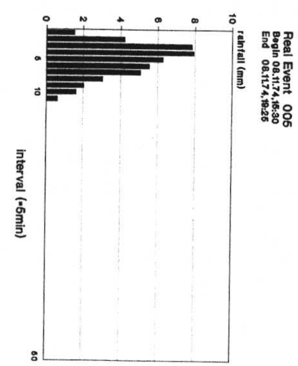
ANF-DAT./ZEIT			END-DAT./ZEIT			RSUM	R
19	71980	2155	20	71980	1015	42.20	9.5045
16	51964	8 0	16	51964	2220	48.66	9.4302
21	61972	21 0	22	61972	525	27.35	9.0264
9	61981	8 0	9	61981	1715	29.70	8.9189
21	61972	120	21	61972	1520	44.60	8.8492
23	91981	9 5	23	91981	2115	38.31	8.7466
2	31966	2120	3	31966	1015	40.67	8.7462
30	71980	555	30	71980	1240	21.17	8.7119
20	71983	1250	21	71983	7 5	53.58	8.1553
23	51980	2335	25	51980	3 0	78.46	7.9493
11	61971	2 5	12	61971	8 0	81.96	7.6100
15	81967	1720	16	81967	750	38.90	7.4521
30	81984	2125	31	81984	1135	37.29	7.3118
6	31966	3 0	6	31966	1745	34.10	6.4218
10	61971	250	10	61971	20 5	37.91	6.1047
29	91971	1055	30	91971	1740	58.96	5.3261
22	71983	2 0	22	71983	1625	24.37	4.6956

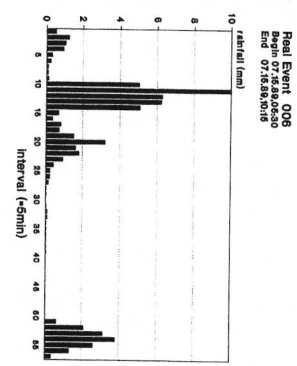






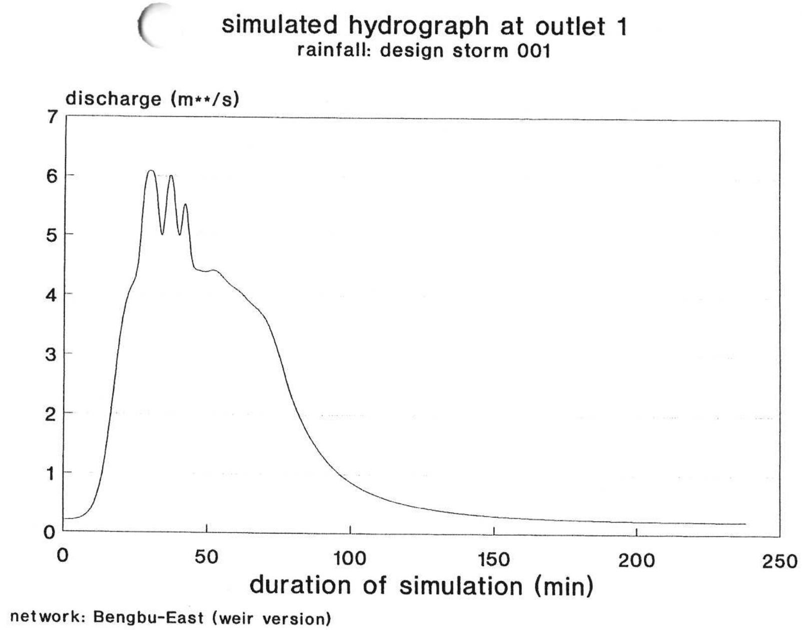


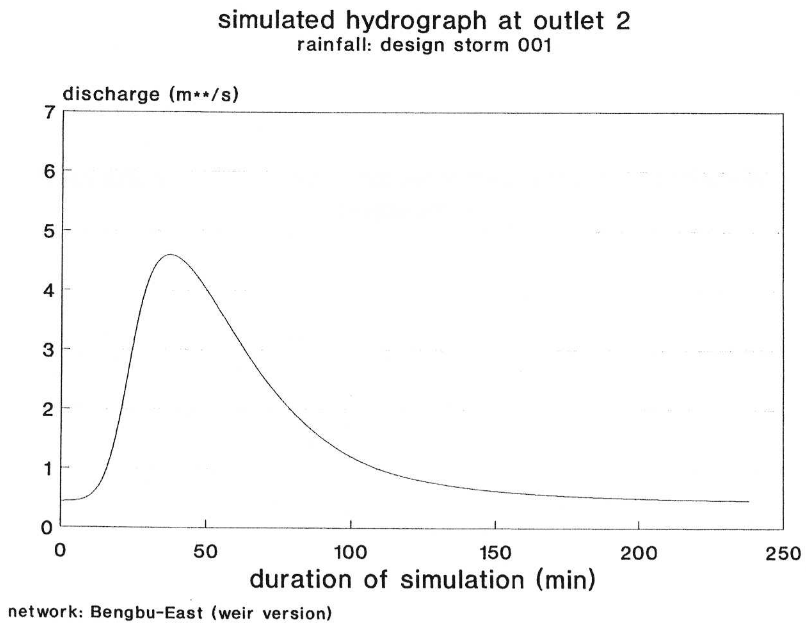


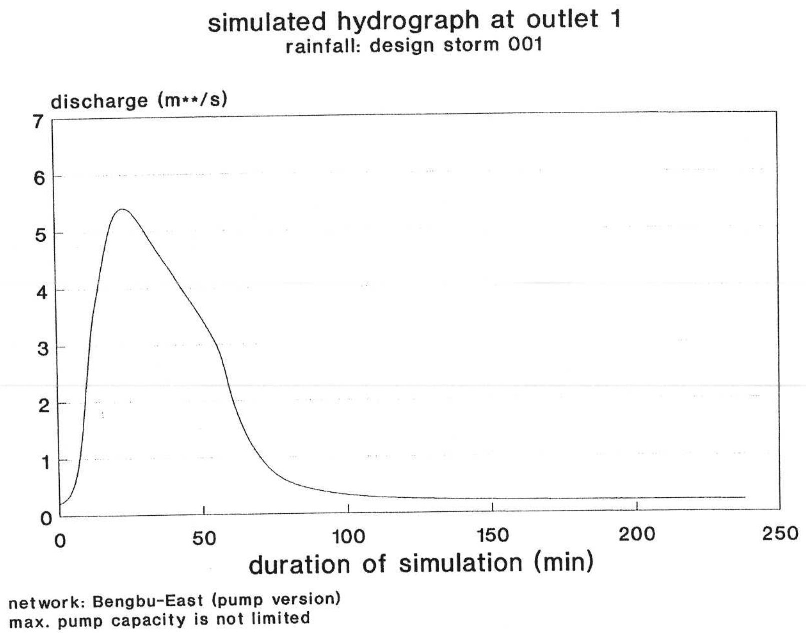


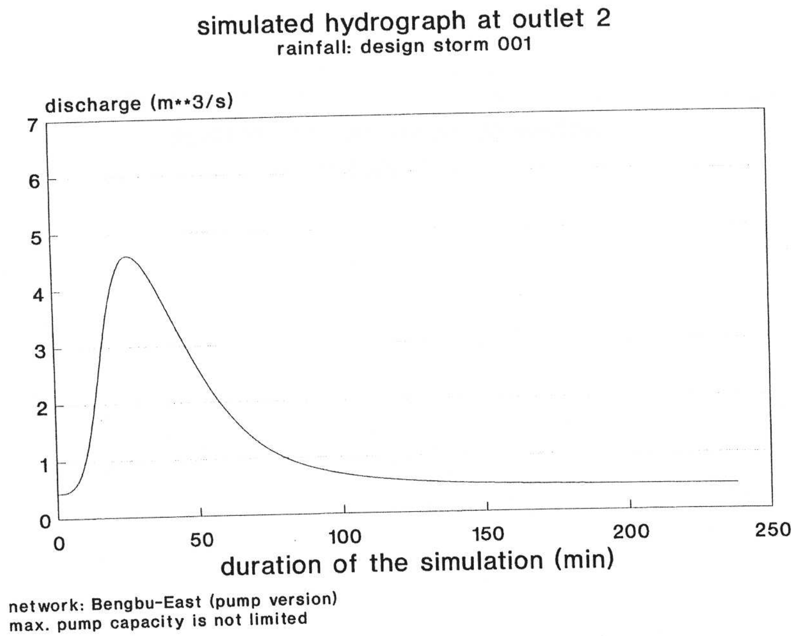
APPENDIX 3

ANALYSIS OF THE PUMPS CAPACITIES







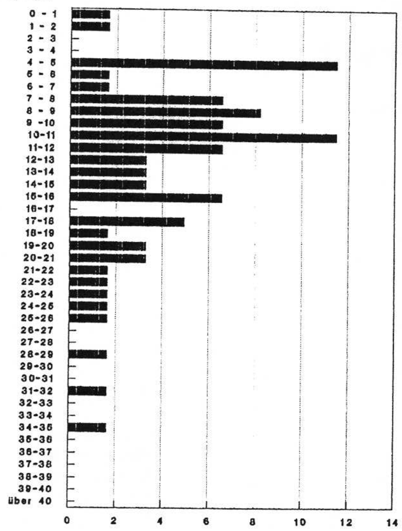


APPENDIX 4

ANALYSIS OF THE SANITATION MEASURES WITH DESIGN STORMS

Darstellung der Einstauzeitklassen
Simulation des Kanalnetzes BENGBU-OST
MODELLREGEN 1

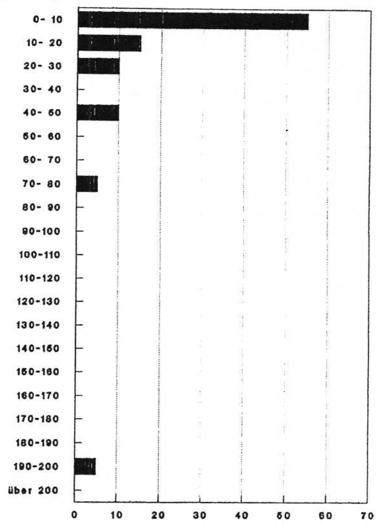
Einstaudauer [min]



Anteil der Schächte [%]
Kanalnetz mit Pumpen an den Auslässen

Darstellung der Überstaumengenklassen
Simulation des Kanalnetzes BENGBU-OST
MODELLREGEN 1

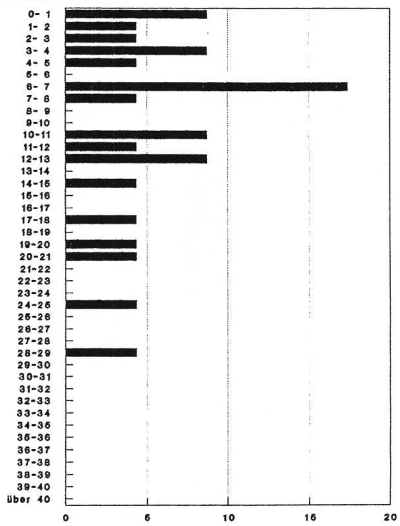
Überstaumenge [m**3]



Anteil der Schächte [%]
Kanalnetz mit Pumpen an den Auslässen

Darstellung der Einstauzeitklassen
Simulation des Kanalnetzes BENGBU-OST
MODELLREGEN 4

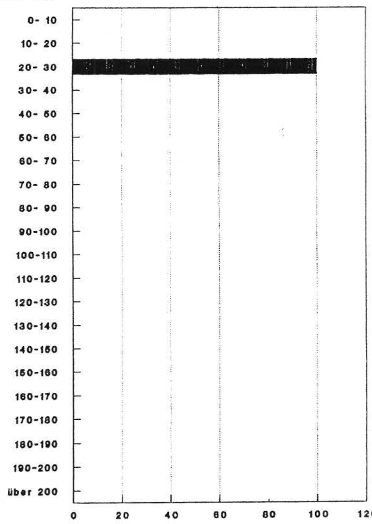
Einstaudauer [min]



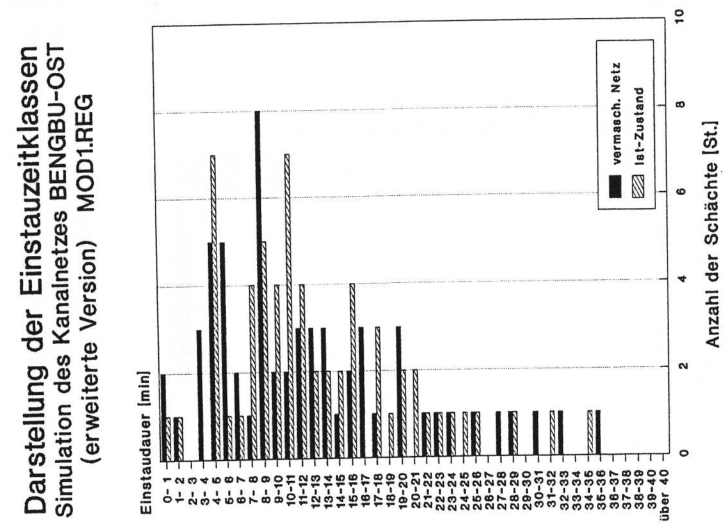
Anteil der Schächte [%]
Kanalnetz mit Pumpen an den Auslässen

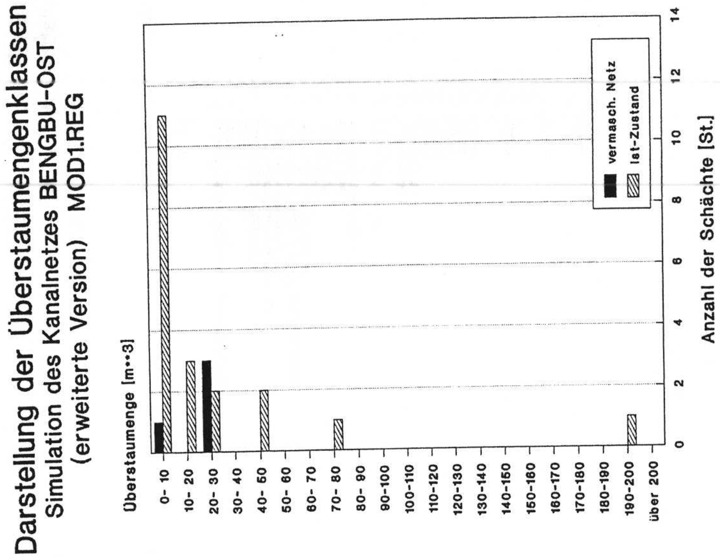
Darstellung der Überstaumengenklassen
Simulation des Kanalnetzes BENGBU-OST
MODELLREGEN 4

Überstaumenge [m**3]



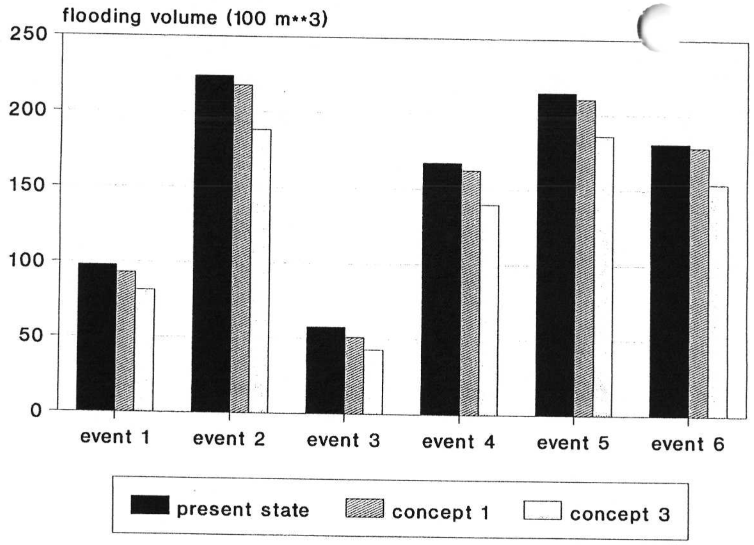
Anteil der Schächte [%]
Kanalnetz mit Pumpen an den Auslässen

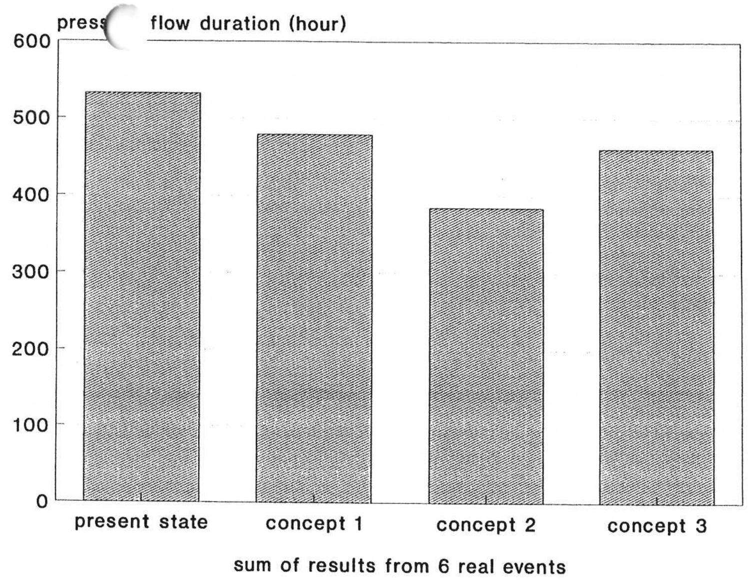


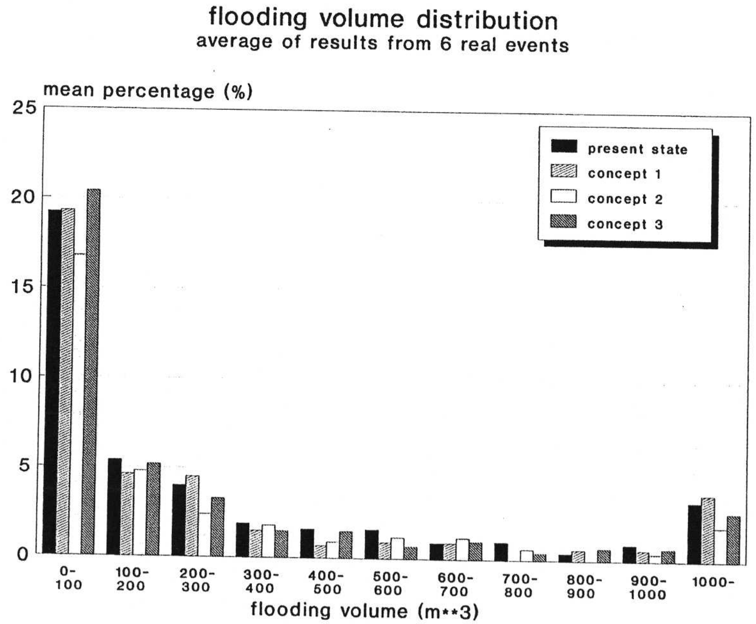


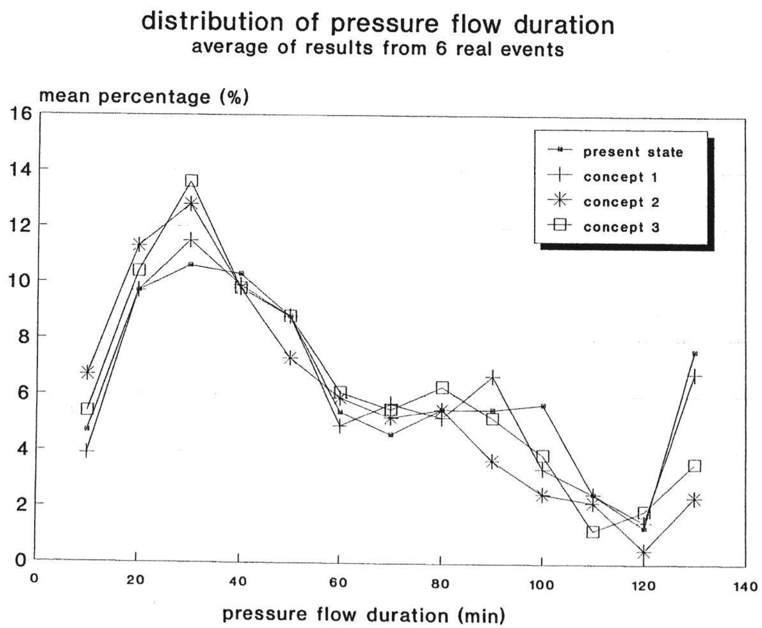
APPENDIX 5

ANALYSIS OF THE SANITATION MEASURES WITH THE SELECTED REAL EVENTS


flooding volume (100 m**3)
250
200
150
100
50
0
event 1
event 2
event 3
event 4
event 5
event 6
present state
concept 1
concept 3


flow duration (hour)
600
500
400
300
200
100
0
present state
concept 1
concept 2
concept 3
sum of results from 6 real events


flooding volume distribution
average of results from 6 real events
mean percentage (%)
25
20
15
10
5
0
present state
concept 1
concept 2
concept 3
0-100
100-200
200-300
300-400
400-500
500-600
600-700
700-800
800-900
900-1000
1000-
flooding volume (m**3)


distribution of pressure flow duration
average of results from 6 real events
mean percentage (%)
16
14
12
10
8
6
4
2
0
present state
concept 1
concept 2
concept 3
0
20
40
60
80
100
120
140
pressure flow duration (min)