ADAPTATION OF AN EXPERT-SYSTEM FOR THE REAL TIME CONTROL OF A SEWERAGE NETWORK : CASE OF BREMEN LEFT SIDE OF THE WESER.

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Abstract: In 1986, the city of Bremen (FRG) started the realization of a computerized system for the real time control of part of its network. It was decided to implement an expert-system as module of control strategy research. The problematic and the chosen solutions are here described.
Keyword: Expert-system, Real time control, Strategy research

Foreword
This research project was supported by the German Ministry for Research and Technology (in german BMFT) under the project number 02-WA86470.

I) Description of the network -Bremen left side of the Weser-

The sewerage network drains a urban catchment whose total area is 920 ha -impervious surfaces 470 ha-. The older part of the network -downstream- is composed of combined sewers, the new extensions -upstream- only drain sanitary water.

Since the catchment is very flat -mean slope of the canalisations <= 1/1000-, the transport of the sewage, within and out of the network, will be performed by pumps.

Upstreams - separate system - there are around 8 pumping stations (=20 pumps), which automatically operate.
The two main pumping stations (the Krimpel station and the HPWL station) are situated downstreams - combined system -.
-The Krimpel station pumps in direction of the HPWL station (maximal capacity: 0.465 m^3/s).
-The HPWL station pumps in direction of the treatment plant (maximal capacity: 1.8 m^3/s).

The latter constitutes the normal outlet. Its maximal capacity is 3.8 m^3/s. Since it cleans in priority the outflow from the network situated on the right side of the Weser, the available treatment capacity is much smaller (maximum around 1.1 m^3/s).

In the station Krimpel, there are 2 retention basins with a total capacity of 8 800 m^3.
In the station HPWL, there are also 2 retention basins with a total capacity of 10 000 m^3.

In case the network is overloaded and the retention basins are filled, combined sewage overflows may occur:
-into the Weser, in station HPWL and at the treatment plant
-into the Wasserlöse (affluent of the Weser), in station HPWL

in very critical situation
-into the Krimplelflet (affluent of the Weser), in station Krimpel in very critical situation.

Figure 1: representation of the catchment in the simulation model

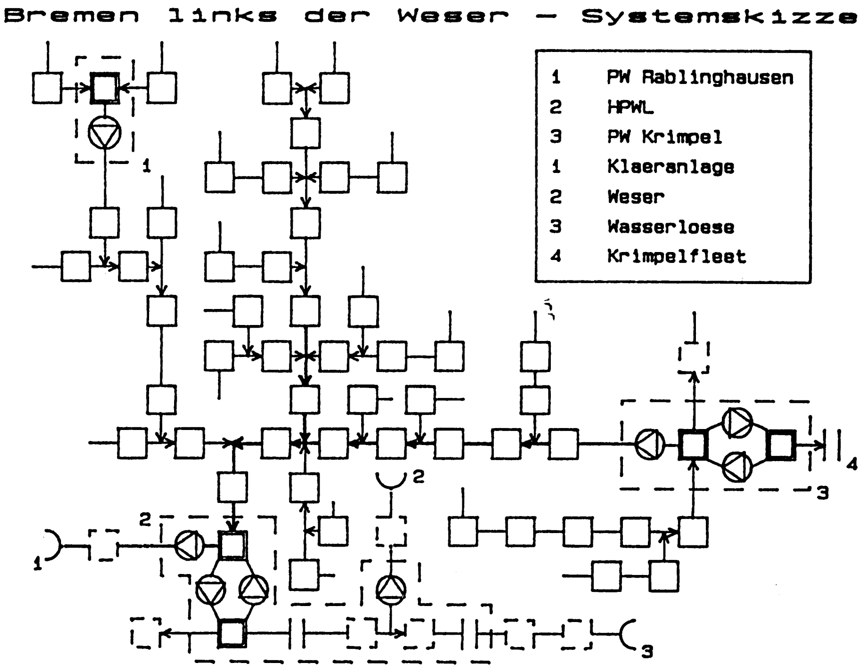
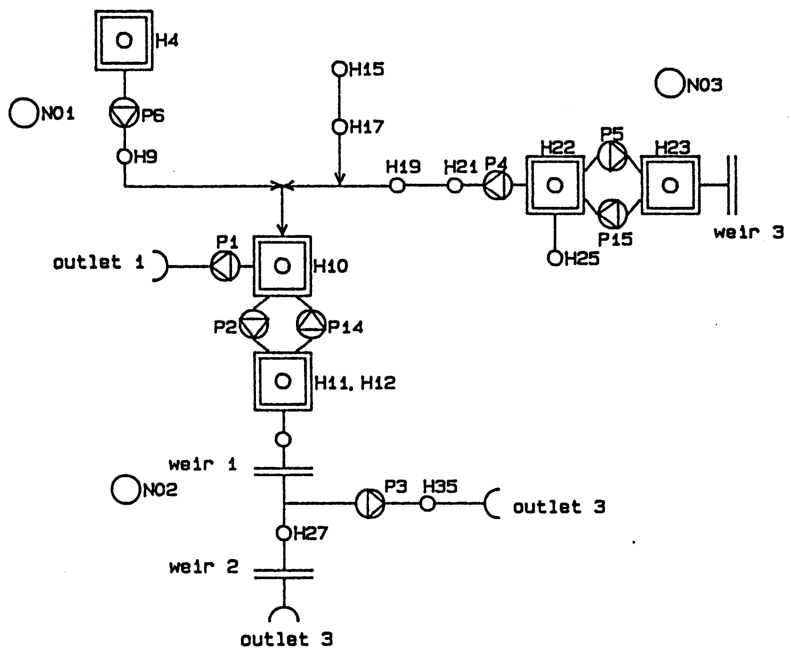


Figure 2: Schema of the monitoring and control system; the main three pumping stations (PS) and the main parameters (NOi: raingauges, Hi: waterlevels, Pi: pumps)



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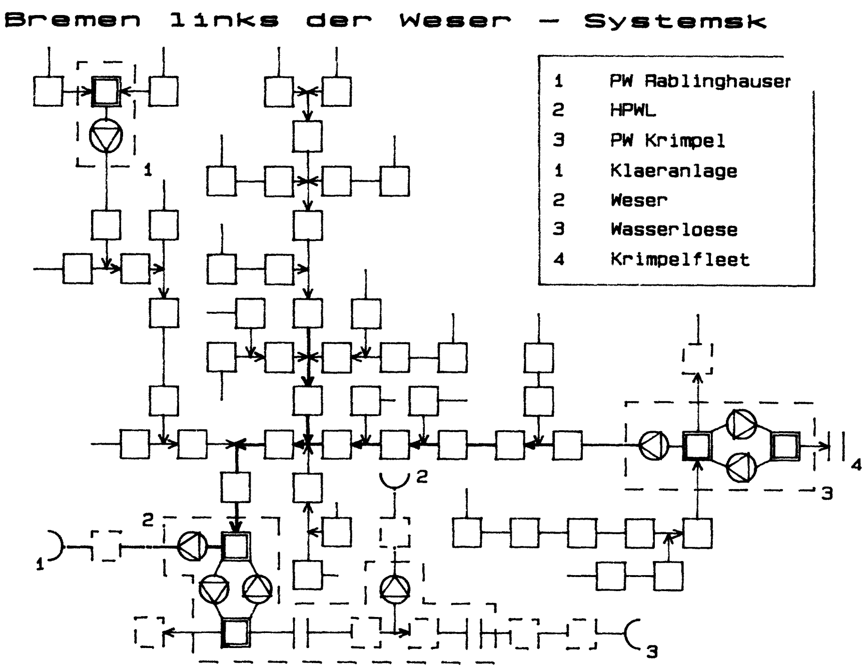

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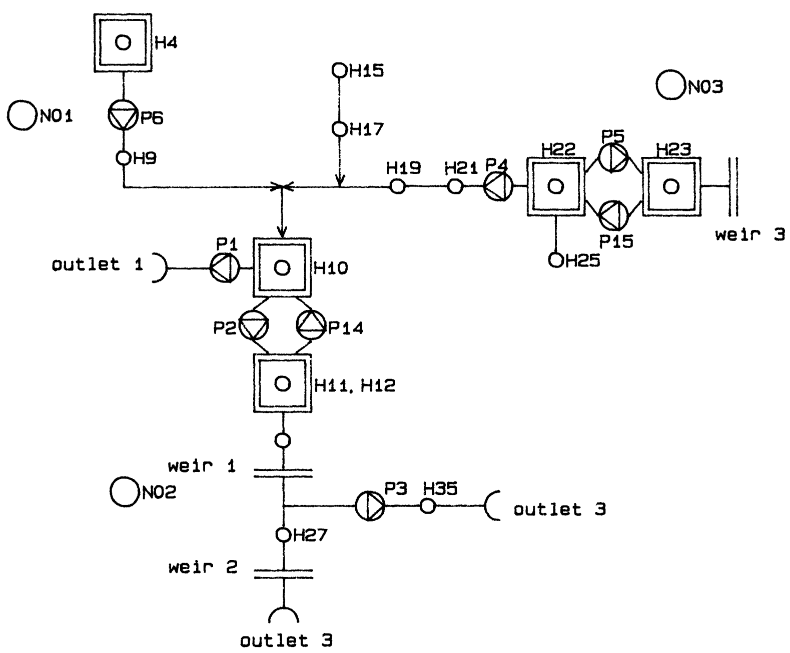

- Flow rates (5 values)
- Pump rates (37 values)

One quality measurement gauge has been installed at the pump pit of the station HPWL. It measures the Biological Oxygen Demand after 3 minutes (BOD 3min). Presently, a study is started to verify how this information can be utilised as pollution indicator and taken into account in the strategy research.

II.3) The strategy research module

One can divide the control strategies into two main categories:
-the local strategies
-the global strategies

In a local strategy, the regulators (pump, sluice,...) are controlled according to process variable at the regulator site.
In Bremen, the pumps and gates at the stations Krimpel and HPWL have been controlled, for years, according to the water levels at the pits of the corresponding station.

By local strategies, difficulties arise when in critical cases a good local strategy at some place of the network may produce disorders at some other place of the network. In these critical cases, only a global strategy is appropriate, in which the set points and controlled commands are specified in accordance with process measurements throughout the system.

The determination of an appropriate global strategy for every possible rainfall configuration, necessitates a very good understanding of the processes and their modeling.
Researches to implement such a global strategy for the network in Bremen links der Weser have been started, 3 years ago, in Hanover (Schilling, Fuchs). Two methodologies were considered:
- a mathematical optimization (Schilling, Petersen, Semke)
- a knowledge base system (Neumann, Fuchs).

It was decided that a knowledge based system connected with the surveying and monitoring system should be implemented.

III) A knowledge based system for the determination of a global strategy in the network Bremen -links der Weser-

III.1) Definition:

The concept of 'knowledge based system' derives from researches in Artificial Intelligence, whose aim can be expressed as following:
'to build systems which are able to tackle special problems, in a way that would be qualified as intelligent if it had been solved by a human being'.

In many fields, experts can solve problems, although a comprehensive mathematical representation of the object ('hard' knowledge) does not exist. Through experience, they have gained a knowledge, which may be difficult to formulate in terms of mathematical modelling but which nevertheless leads to acceptable results. Knowledge based systems are systems which can manipulate this 'fuzzy' knowledge as the experts do. This is the reason why they are often called expert-systems (XPS).

III.2) Organisation:

An expert-system is based on the strict separation of :
-the knowledge itself, stored as data in the 'knowledge base'

II) Real time control: the problematic

II.1) Objectives and choices:
The two main objectives are:
- to prevent inoundation during a rainfall event
- to prevent discharge of uncleaned combined sewage into the environment, during the rainfall.

These two objectives must be realised under the condition of maximal security of the public (during the rainfall) and the operating personal (if some reparations should be performed in the system).

The network in Bremen links der Weser, is so dimensionned that inoundations occur very seldom.
The second objective has become a major priority of the city, since the public opinion in Bremen has become very sensitive to pollution problems.
The local laws prescribe at the present time that at least 85% of the combined sewage must be cleaned at the treatment plant before being discharged into the Weser. Moreover, the objective, complete treatment of the whole sewage, is already in discussion.

The discharge of untreated sewage into the environment can only occur during the pick flow downstreams, when either the treatment capacity of the plant or the transport capacity of the network is overloaded.
To reduce the pick flows during strong events, several ways are possible:
- to modify the network (build additional retention basins, decentralised rainfall infiltration,...)
- to optimize the functioning of the existing network, if proven that it contains capacity reserves that still can be activated, if a proper on-line control strategy is applied.

In Bremen, the in-line storage (in the canalisations themselves) has a capacity of more than 40 000 m^3 (more than twice as much as the storage capacity of every retention basin). Through a proper control of the combined sewage pumps -stations Krimpel and HPWL-, one could, without any modifications within the system, activate this in-line capacity much more efficiently than used to be, in the past.
As a consequence the city of Bremen decided to acquire a computer system for the real time control of its network.

II.2) The on-line surveying and monitoring system:
A real time control system decomposes into two main parts:
- an on-line surveying and monitoring system
- an strategy research module.

The on-line surveying and monitoring system allows, any time, a precise knowledge about the state of the network.
The municipal department responsible for the planning and operating of the network has been developing for 3 years the on-line measurement system.
At the present time, more than 66 parameter values are measured (every 15 seconds) and stored in the main computer of the central station -HPWL- (mean values every 5 minutes):

- Raingauges (3 values)
- Waterlevels (18 values)

of the XPS
-the treatment of this knowledge, stored in form of programms called the '<u>shell</u>' of the XPS.

The knowledge base contains:
-the facts (ex. values of every parameters describing the state of the network at a given time),
-a general knowledge which describes the reasoning process through which the appropriate diagnosis or actions can be defined.

In Bremen, this general knowledge is written as a set of 'inference rules' the so-called productions.
This formalism has one great advantage: the productions look like the instructions that define the already existing local strategy. The personal can understand why the XPS take such or such decision and gain confidence into the system.

III.3) Elaboration and verification of the set of productions.
The elaboration of a reliable set of productions include the following steps:

- <u>analyse of the existing strategy</u> and discussion with the staff.
In Bremen, the set points of the regulators in the two main control stations (Krimpel, HPWL stations) are determined according to the water level at the corresponding pump pit.
If this level exceeds a certain value, the filling of the retention basins begins. If the pumping still goes on, a discharge occurs.

- <u>Exploitation of the measurement data</u>
Using the data stored by the surveying system, it is possible to play back some <u>significant events</u>, during which discharges of combined sewage were performed (particularly in HPWL), although inline storage capacity was possibly still available.
In this way, the effects of the existing control strategy are evaluated and its weak points become obvious.

- <u>Calibration of the simulation model</u>
The suitability of one control strategy (characterised by its corresponding set of rules) should be evaluated.
We dispose of a simulation model. The modeling composes of :
- a rainfall-runoff part (hydrological simulation): calculate the inflow wave to the canalisations
- a transport part (hydrodynamic simulation = resolution of the Saint-Venant equations): calculate the wave transport in the canalisations.
The model allows a precise simulation, even in case of impoundage. But, because of the required calculation time, it is mendatory to use a rough description of the network (cf figure 1), which nevertheless give a proper idea of what happens. Especially, the inline storage capacity at each decision step, should be properly approximated.

- <u>Connection of the expert-system with a simulation model</u>
A judgment about the strategy rules implemented in the expert-system can only be assured through results of simulations, after the connection expert-system + simulation module, has been realized.

Moreover, such simulations constitute the only possibility to consider extreme cases (pump failures, extremly strong rainfalls).

III.4) The event at 01.06.1988

Some measured values:
-Rainfall: total amount = 11 mm, duration: from 13:00 till 19:00 in several periods, maximal intensity = 21.6 mm/h.
-Waterlevels: In figure 3, the measured water levels -downstream- are shown. From 16:00 h the levels on the gauges (H10, H09, H19) are the same. At that time, around 40% of the storage capacity of the network is utilized.
-Pumps: In figure 4, the filling of the retention basin at HPWL (pump P2) is represented. At 19:00 the basin (10 000 m^3) was filled up. A few hundred m^3 of combined sewage were even discharged into the Weser.

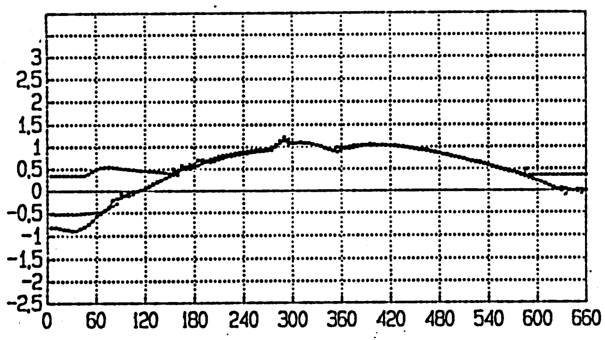

Figure 3: water levels downstream at H09, H10 and H19, in mNN, between 13:00 h and 24:00h

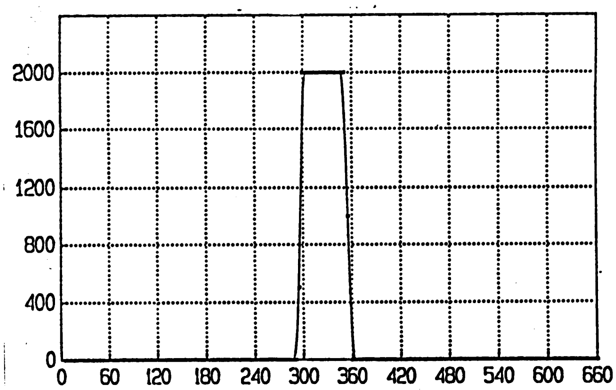

Figure 4: The filling of the retention basins in HPWL between 13:00 h and 24:00h (in l/s)

The simulation:
In this case, simulations have shown that a filling of the basin was not necessary. The whole quantity could have been stored in-line, without any complications on other parts of the catchment. The new rules implemented in the expert-system take this into account.
Nevertheless, the first conclusions after the simulation of a few events are not sufficient. Some more simulations especially in very extreme cases are planed. Eventually, a long-term simulation with the expert-system should be performed to really estimate the winnings.

References
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Final Objective of the study:
Development of Computer Tools to assist the Operator in the On-line Control of Urban Drainage System UDS.

The major function of a UDS is to transport the sanitary water flow into the treatment plant before it is discharged into the environnement. Normally is the UDS so dimensionned that in dry weather condition the network as well as the treatment plant meet the requirement.
During wet weather in combined sewerage system, the storm water inflow wave is so big that some perturbations can occur:
- within the network (impoundage, submersion)
- in the treatment plant (the capacity is exceeded)..

In the first case, impoundages, submersions or inoundations happen, which may cause financial damage and even endanger human beeings.
In the second case, combined sewerage overflows happen, which may cause ecological disaster.

How critical each of the aspects are, depends of the configuration the network and of the priorities of the local authorities.

In the city of Bremen, the canalisations ~~have~~ are been rather big dimensionned so that the second point represents the key issue. During wet weather CSO can discharge in ~~so~~ small affluents of the river Weser, which are very sensitive to pollution chocs. Under the pression of the public opinion during the last years, the local authorities have adopted a very strict reglementation.
More than 90% of the whole sanitary water should be cleansed. The trend is to set even stricter reglementation in the next years.

In order to tackle the problem, several solutions are possible, which can be ordered into 3 main categories:
- solutions that imply an alteration of the drainage concept (installation of a separate system, reduction of storm water inflow through infiltration)...
- constructive measures ex. the construction of supplementary storage capacities (retention basin, sewer trunk).

- solutions whose purpose is to optimaly dispose of the latent capacities within the network during the rainfall event through control, in other words real time control.

Real Time Control has in Bremen a long tradition. Pumps are necessary to extract the water of the system, since the watershed is very flat (mean slope of the canalisation is smaller than 1 / 1000) and the lowest points of the drainage system are situated under the level of the treatment plant or the river.

Four years ago, the city of Bremen decided to completly update its on-line surveying and monitoring system.
At the present time, 66 parameter values are measured every 15 seconds and stored on the hard disk of the central computer on the central pump station (HPWL).

- 1 raingauge information on each combined sewerage pumping station (3 values))
- waterlevel informations (within the network, in the pump pits, on the river Weser, in the retention basins, at the overflows) (18 values)
- flow rates (the flow rate in direction of the TP from the left side and the right side of the Weser) (5 values)
- pump delivery in the separate sewerage system upstream and in the combined sewerage system downstream (37 values).

One quality measurement gauge had been installed at the pump pit of the main pumping station (BOD 3minute measurement) but the proximity of the pumps has proven to create such great perturbations specially through resuspension of solids that the measured data are of no use. The gauge must be reinstalled elsewehre.

The question is to be solved is the following:
Is it possible by using the on-line information about the state of the system collected by the surveying system to develop an optimized control strategy that would reduce the CSO quantities without producing inoundation ?
In the case of Bremen, a control strategy is defined by the set point values for the delivery of the main pumps (Station HPWL and Krimpel).

The two objectives are contradictory:

- On the one hand, the existing on-line (retention basin) and in-line (sewer trunk) storage capacity should be used to the last extent in order to store the quantity that can't be treated by the TP.
- On the other hand, security against inoundation requires that at any time sufficient storage capacity should remain free to store a peak inflow wave that could not be transported through the system because of the limited flow capacity of the pipes.

To tackle the problem we considered two possibilities:

- to develop an optimization model
- to develop a knowledge base system (expert system).

Linear or dynamic optimization models has already been used to find out a optimized control strategy. They base upon:

- a simplified modelization of the UDS (in most case as a linear system with very few state variable)
- a search modul to minimize a cost function.

Advantages:
Providing the modelization is accurate and the cost function is relevant, the results shall be very good.
Shortcomings:
- to simplify the UDS system as well as to determine the cost function require a lot of skills.
in the first case, hydrological knowledge is required to analyse the behavior of the system. In the second case, mathematical knowledge is required to correctly evaluate the non financial costs.
The main difficulties are neverthless practical ones.

- first, in case the system be on-line implemented, it will be very difficult to explain the operator how and why the computer system make this or this recommendation. (In fact there is no why!)
- secondly, the method is relatively unflexible. For example, in case a control gauge or a measurement gauge fails during the rainfall event, the optimization theretically can not

give accurate recommendation anymore, unless a new corresponding modelization of the system already exist.
The same if some modifications in the UDS are performed. It will hardly be the case that the personal that control the UDS, itself makes the necessary modifications.

T3 A knowledge base system is based on a strict separation between:

- the knowledge about the actual problem stored in a file as a set of fact (values of the state variables and the perturbation variables).

- the knowlege itself that is required to solve a special problem. This knowledge is stored in a file as a set of 'declarations'. These declarations are in most cases written in the form of rules, which specify when or why this or this decision is to be made.

- the treatment of this knowledge (rules + facts) stored in programs, which constitutes the shell, whose main part is the inference engine.
  During a decision process the rules that are appropriate to the situation described by the facts, are found out and fired. It means their conclusions are considered true. The set point values of the control variables are a part of these conclusions.

Shortcomings:
- the notion of optimal solution is abandonned. It is replaced through the notion of good solution with all the incertainties that it implies.
- The system will only be as good as the knowledge base, which is stored in it.
- Commercial shells for the writing of the rule base are not admissible, insomuch the modul should communicate with the surveying system, whose programms are written in FORTRAN. ~~that are~~ In this case one should build the shell itself

(respectively the inference engine) in the computer language FORTRAN, so that any interface problems are solved.

Advantages:

- the 'logic' of the decision making is written in a file in a form that is understandable for the operator. He can any time check the file and analyse and criticise the existing rules.

- the system is very flexible, in case of failure of measurement or control gauges special rules can be started, in which control priorities may be rearranged (to meet security requirements for example).

- It is possible to make profit of the knowledge which have been gained over the years through experience at least as a basis for the further development.
  A manual exists, in which the control strategy recommendation have been written. These recommendations should normally be followed by the operators.

Both methods were tested at the Institute of Hydrology of the University Hanover. We finally gave the preference to the knowledge based system. One version was implemented on the PDP 11 computer situated at the central pump station HPWL.

(T4) In this transparency the structure of the information flow is described.

Some informations :

(T5)
- How many rules ?
- How many facts ?
- How many variables are manipulated?
- How many recommendations are possible?

As already noticed, a knowledge based system can only be as good as its knowledge base. The acquisition of the knowledge constitu-

tes therefore a key task, which unfortunatly requires a lot of skills, time and effort.
As sources of knowledge about the behaviour of the system, we listed:

T6 - Analysis of the existing strategy and discussion with the staff; elaboration of a representation of the network.

T7 - Exploitation of the existing measurement data; analysis of significant events to verify whether the standard strategy is always followed (if not why, which could be the reasons) and find out the weak point.

- Simulation of the drainage system.
  Simulation of the drainage dystem is necessary to evaluate the influence of modifications of the rule base. Since a comparison with the measurement data should be possible, the requirements to the simulation model are high.
  T8 A hydrological simulation was discarded because:
  - the catchment is very flat (possible backwater effects),
  - the modell has to perform a good simulation even if the pipe is under pressure.

  A hydrodynamic simulation, on the other hand, needs a lot of calculation time.

  As a compromise we decided to make hydrodynamic simulation with a simpfified description of the drainage system.
  The obtention of a simplified network description, which neverthless allows a good estimation of the respective state variable values, implies a difficult calibration phase (in-line storage capacity and flow condition within the pipes must not be distorted).

Difficulty: The original simulation model is very limited regarding the permitted control strategy. The decision module only allows local control and gives no possibility to simulate the emptying of the on-line retention bassin.

We decided to develop a extended simulation model in which the old simulation core is connected with the knowledge based system (programs implemented on PC Compaq). We have now the possibility to test through simulation any modifications of the rule bases

At the present time, we work with the extended version and try to evaluate the standard rule base as well as evaluate its modifications. Final results are expected at the end of the year.

- the subject of the presentation refers to Transparency (1)

- A brief description of the different topics that I will speak of.

→ A short description of the Bremen situation (T2)

- Description of the catchment
- Description of the network.

Real time control has a tradition since

→ • The renovation of the ~~real time~~ ~~con~~ monitoring and surveying system.

→ • The real time control problematic in Bremen

- The problem
- The Question
- The methods for finding out the proper strategy
- The choice (~~Advantag~~

→ The presentation of the structure of a knowledge base system. (T3)

- Advantages
- Shortcoming

→ The implemented system in Bremen. (T4)

- the structure of the information flow
- Some characteristics of the implemented system (T5)

→ The question of the validation of the knowledge base and improvement. (T6)

. First step Elaboration of the Standard set of rules

Source of information

. The staff } The experience
. The documents that are available }

. The measured data about 2 years) precise Analysis of some events.

(T7) Description of the system relevant for control purposes.

. Second step { Validation
Evaluation
Improvement

first possibility
As the system is implemented to wait for some significants event and ask the operators if they have some remarks about the recommendations that the system ~~did~~ made.
→ rather hazardous - depends on a lot of factors on which we have no influence.
second possibility
to simulate the system (the whole system).
What we need is
. Hydrodynamic model } Already existed in the first step of the study.
. A description of the Network }
. A connection with the knowledge base (with any knowledge base)
In the last year we realise the new extended simulation model

In the current of the year we hope we shall make the first long term simulation - to have a generall evaluation
Parallely the simulation of single events shall be made. to analyse the sensitivity of the rules.

Description of the catchment

Transparency 2

1000 ha (50% impervious area)

→ the catchment is very flat (mean slope < 1/1000)
1 to 1000

→ Upstream separate drainage system
(new urban areas)
Downstream combined sewerage system
(the old kernel of the city)

Because of the flatness Pumpstations all through the system
- small pumpstations upstream
- great pumpstations downstream

In the simplified representation of the network (~~in~~ only the combined part is shown) you can see the 3 most important Pumpstations:
- Kumpel
- Balenighausen
- The main PS

The capacity of ~~the~~ storage is distributed in 3 places.
- RB Kumpel (8000)
- RB main pumpingstation (10000)
- in-line capacity (40 000) at least

Description of the Problem

Because of the dimensioning of the pipes and the relatively small rainfall intensities } flooding is not the key issue.

The ~~big problem means~~ main concern relates to the reduction of the CSO. There are 3 CSO places within the network.
1) Kumpel
2) the main pump station
3) the treatment plant.

At the main pumping station and at Krimpel station the combined severage water discharges into small creeks which are very sensible to pollution dross.

- The Public Opinion is very concerned about the pollution in West Germany especially about discharges of untreated sanitary or combined sewerage water into the environment. Under its pressure the local govt ~~decided very~~ adopted a very restrictive reglementation. More the 90% of the sanitary water must be treated.

~~Instead of~~
The adopted way

Instead of trying to build some more retention tanks the idea to reach the objective and reduce the CSO to the maximum ~~was~~ is to try through real time control to activate the in-line storage capacity.

(Real time Control has already a tradition in Bremen, ~~since anyway pump almost since sur~~ due to the configuration of the catchment.

The Renovation of the surveying and monitoring system.

~~HHH~~ Five years ago, the city of Bremen decided to completly update and enlarge its surveying and monitoring system. A consulting firm was charged to realize ~~the system~~ and implement the system.

Measurement data are picked up every 15 seconds and sent to the main computer. Every five minutes the mean values are stored in the hard disk and can on line be graphically displayed.

° At the present time we obtain on-line 66 values, among them

- 3 Raingage values
- 18 Water level values
- 5 Flow rate values
- 37 values of the pump deliveries

° A quality measurement has even been performed (BOD_2 measurement) continously. But because of the location of the gauge at the pump pit lot of perturbation were constated ~~so~~ (due to the ~~xxx~~ suspended solids) so that the measure ~~xxx~~ are now not available. The gauge will be relocated.

Determination of the control strategy

The problem of the determination of the control strategy is a key task. The institute of technology of the university Hannover was asked to realize a computer ~~tool~~ that would ~~on~~-line assist the operator in the decision for a strategy.

Two methods were considered a priori possible

- ~~A package based on optimization~~
- A Research modul based on optimization.
- A Reasearch mod based on a knowledge based system.

→ ~~It was decided to bui~~ Because of lack of time I will
- only speak about the knowledge based system that finally was implemented.

Structure of a knowledge based system

A few words about. (Transparency. 3)

It consists principally in 3 parts. | 2 files | 1 programm

1. base of fact
2. base of rules
3. The ~~engi~~ inference engine, which is the main part of the ~~know~~ shell of knowledge based system. The part that read the rules and depending of the situation infers the solution(s) of the problem.

Shortcomings - Problems

general problem
- the notion of best strategy is abandonned, ~~that~~ to be replaced through the notion of good solution
- the system is only as good as the knowledge base

(practical) one
- the shell in our case must be written, in Fortran by us in order to assure the compatibility of the data transfer between the monitoring and surveying system and the knowledge based system

Advantages Among them

- the logic of the decision making is transparent. One can answer the question (WHY)
- the system is flexible. It can ~~very simply~~ without a lot of work take special case into account. (the failure of some measurement gage or control gage).
- It is possible to make profit of the knowledge which has been accumulated through experience - At least as a basis for the next developpement.

The implemented system

- ~~the information flow and~~ the sequences of the information treatment. (Transparency)
- ~~the~~ Some characteristics of the system (Transparency)

The determination of a knowledge base (This is a work in progress, whose achievement is not yet completed)

Transparency

We see 2 main steps.

1. Elaboration of a ~~standard strategy rul~~ set of ~~sta~~ standard strategy rules
2. Validation - Improvement.

1 - A. Discussion with the staff, Analysis of the existing documentation

B. Analysis of the measurement data

⟹ A Description of the network relevant for the control.

2. To validate.

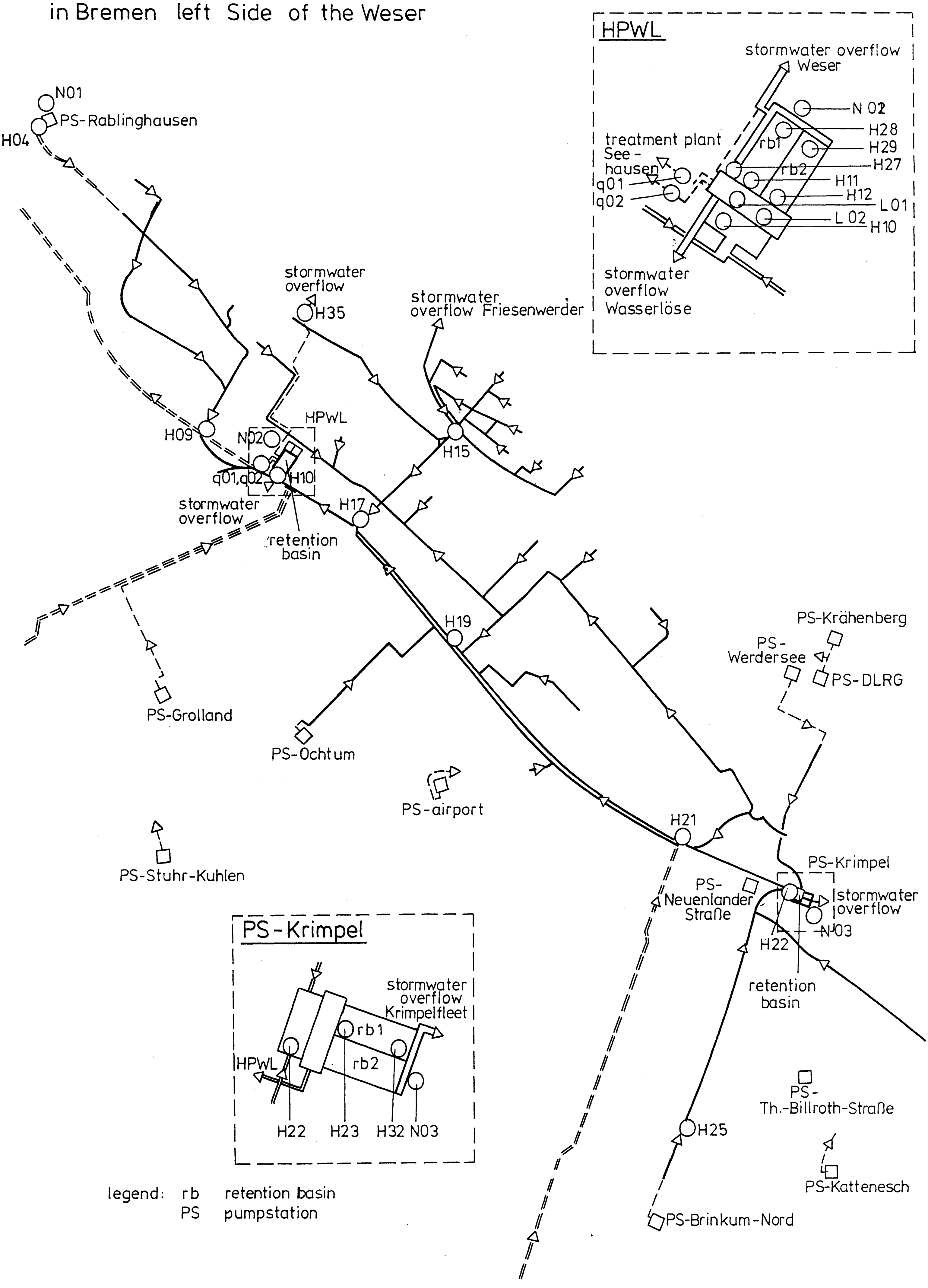
→ As the system is already implemented and gives on-line recommendation. One possible way would be to wait till several events occur and ask the operator or the responsible persons for their opinion or their comment.
This is of course very important but subject to a lot of uncertainties or parameters ~~to~~ over which we don't have any influence.

→ the other way is the simulation way. The conditions of such a simulation ~~as~~ are very restrictive

- Hydrodynamical simulation model }
- simplified description of the network }
- connection with the knowledge based system.

Transparency

Simplified representation of the UDS in Bremen left Side of the Weser



legend: rb retention basin
PS pumpstation

Analysis of the network

Bremen lefthand of the Weser

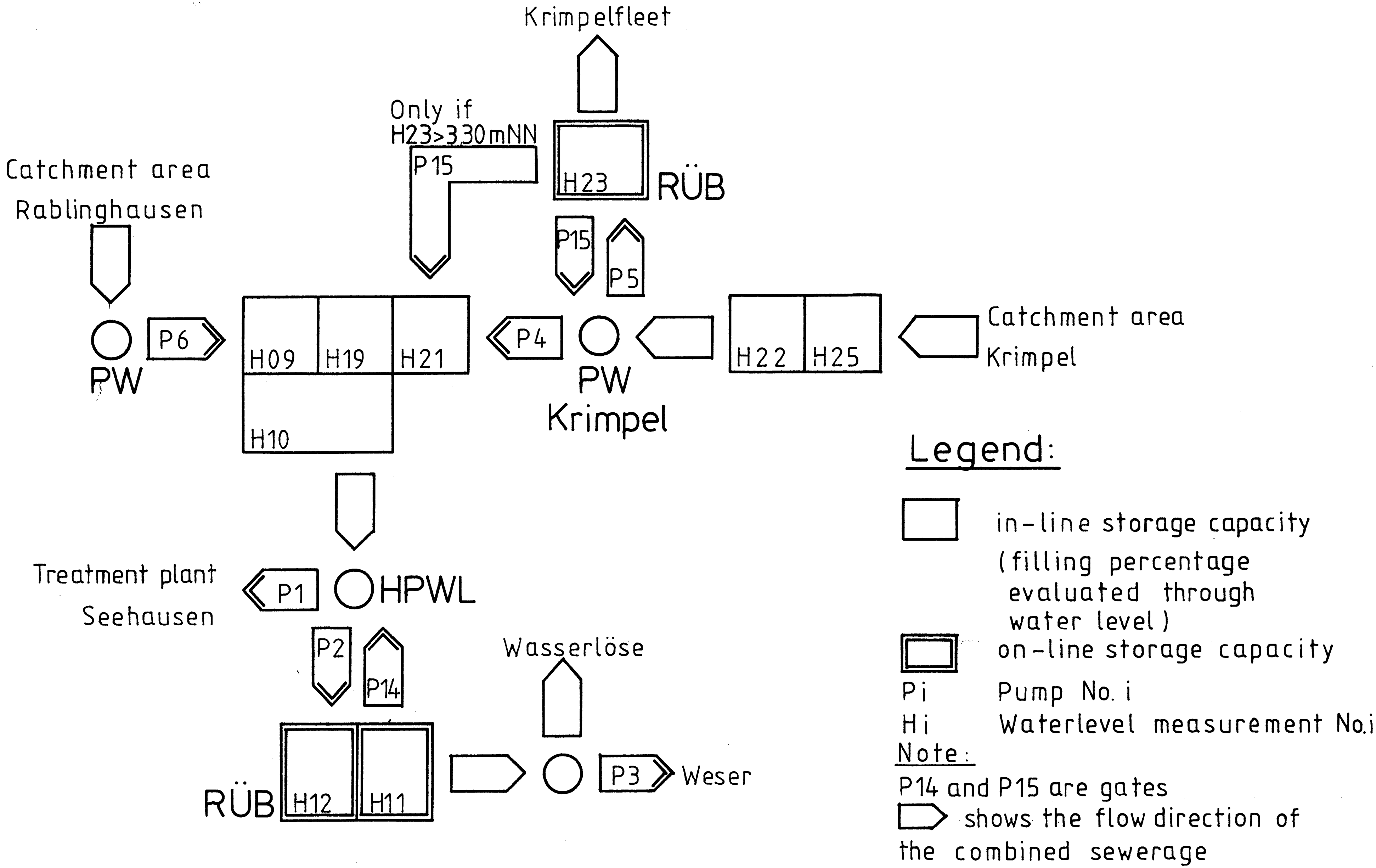
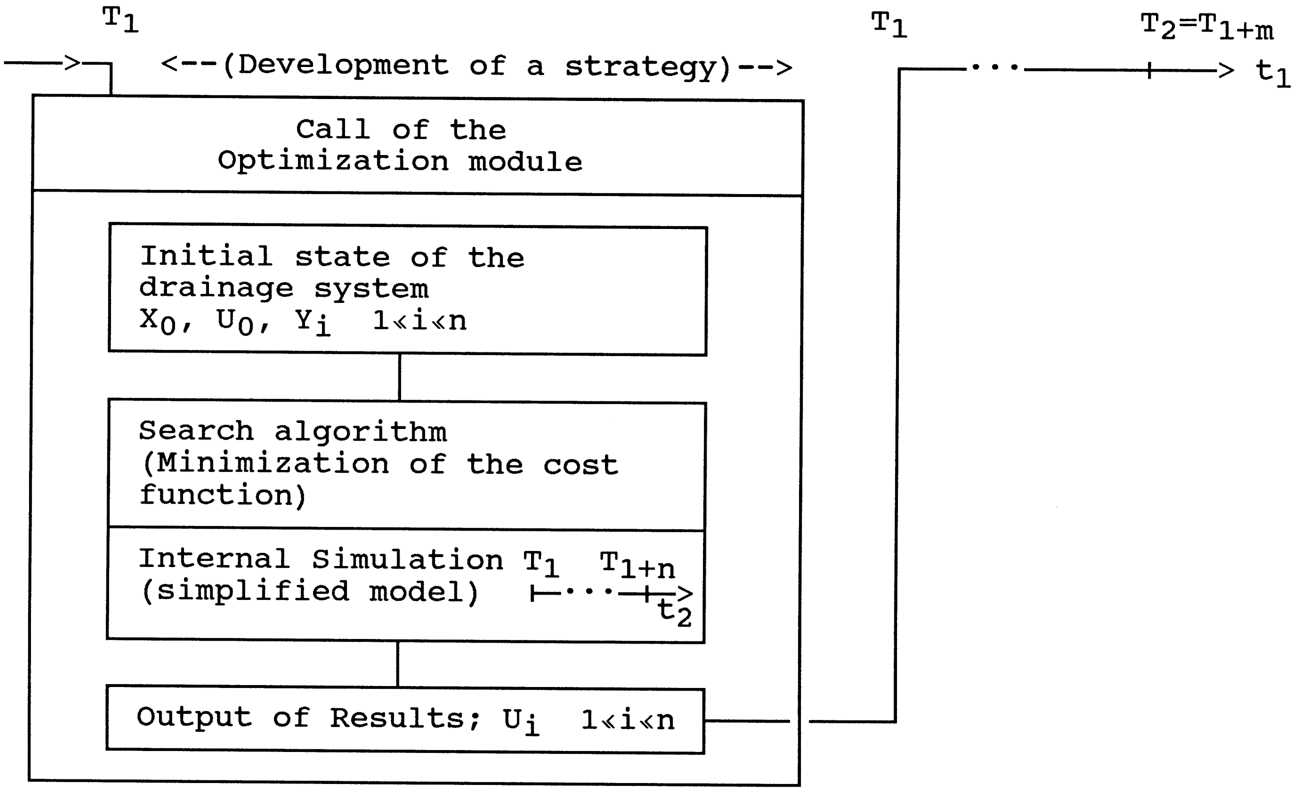


Fig 9: Possible Sequence of Optimization of a Control Strategy in a Connected Version (e.g. Optimization + Hydrodynamic Model)



t_1: First time axis; level of the (exact) simulation model

T_1, T_2: Instant of decisionmaking on the axis t_1

m: Decision interval

t_2: Second time axis; level of the internal simulation

T_1: Beginning of the internal simulation

T_{1+n}: End of the internal simulation

n: Optimization horizon

X_i: State variables of the the drainage system

Y_i: Perturbation variables (rainfall prediction over the horizon n)

U_i: Setpoint values of the control gages

Fig 10: Functional structure of an expert system (including a learning module)

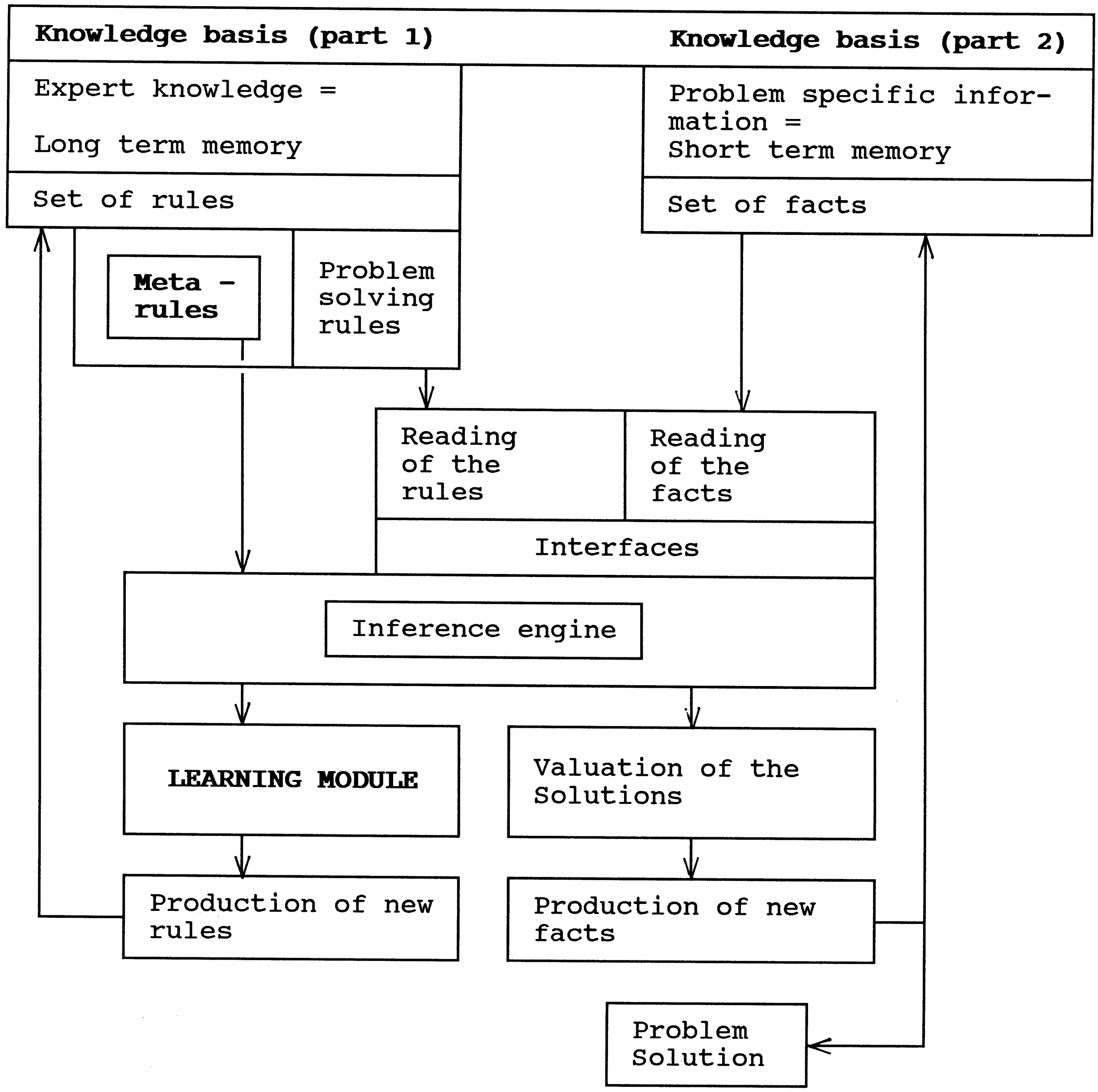
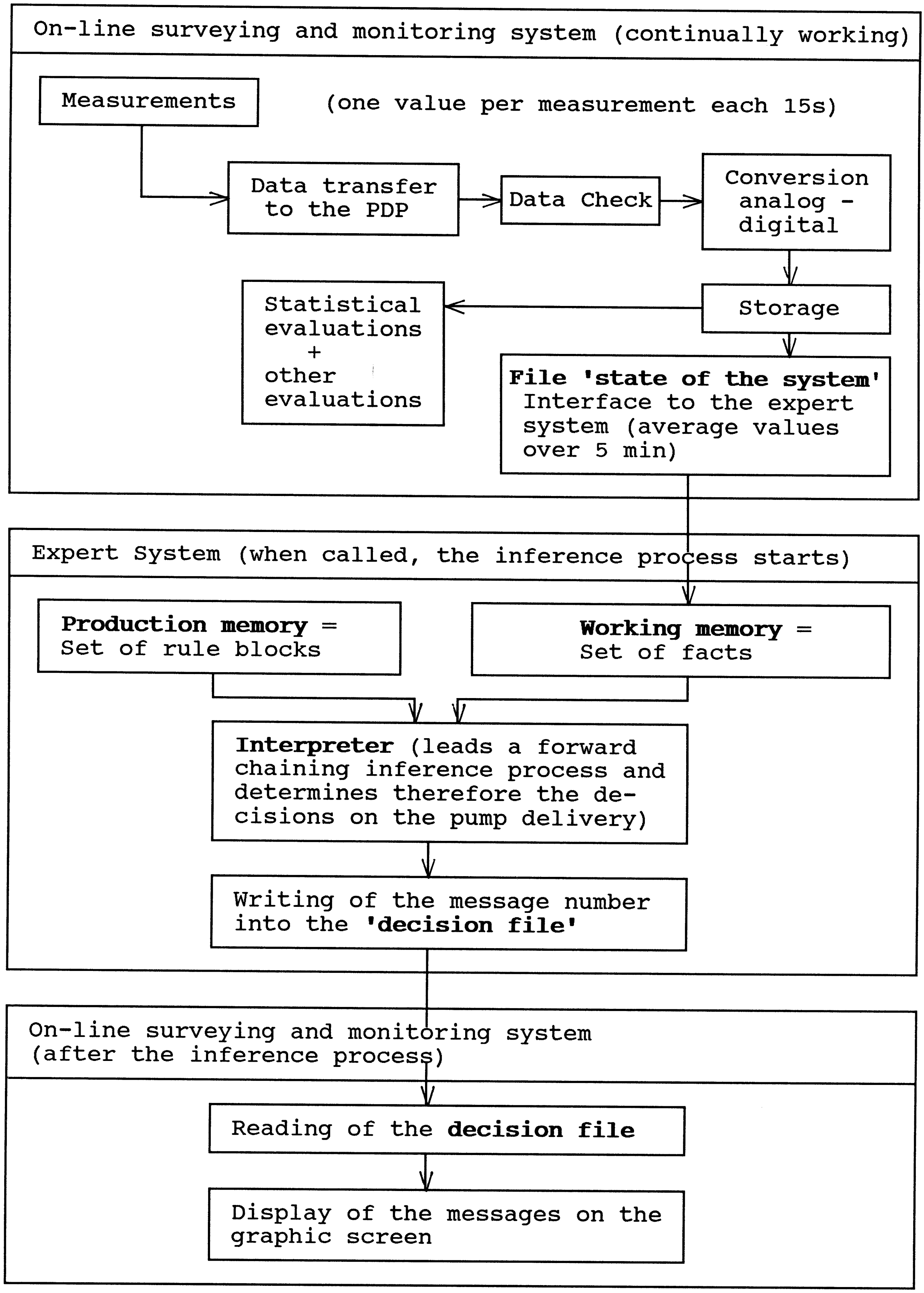


Fig 11: Sequences of Information Treatment in On-Line Operation



Development of an Optimized Basis of Control Strategy Rules

- Analysis of the existing control strategy
- Analysis of the existing measurement data

---> **Standard control strategy (implemented on-line)**

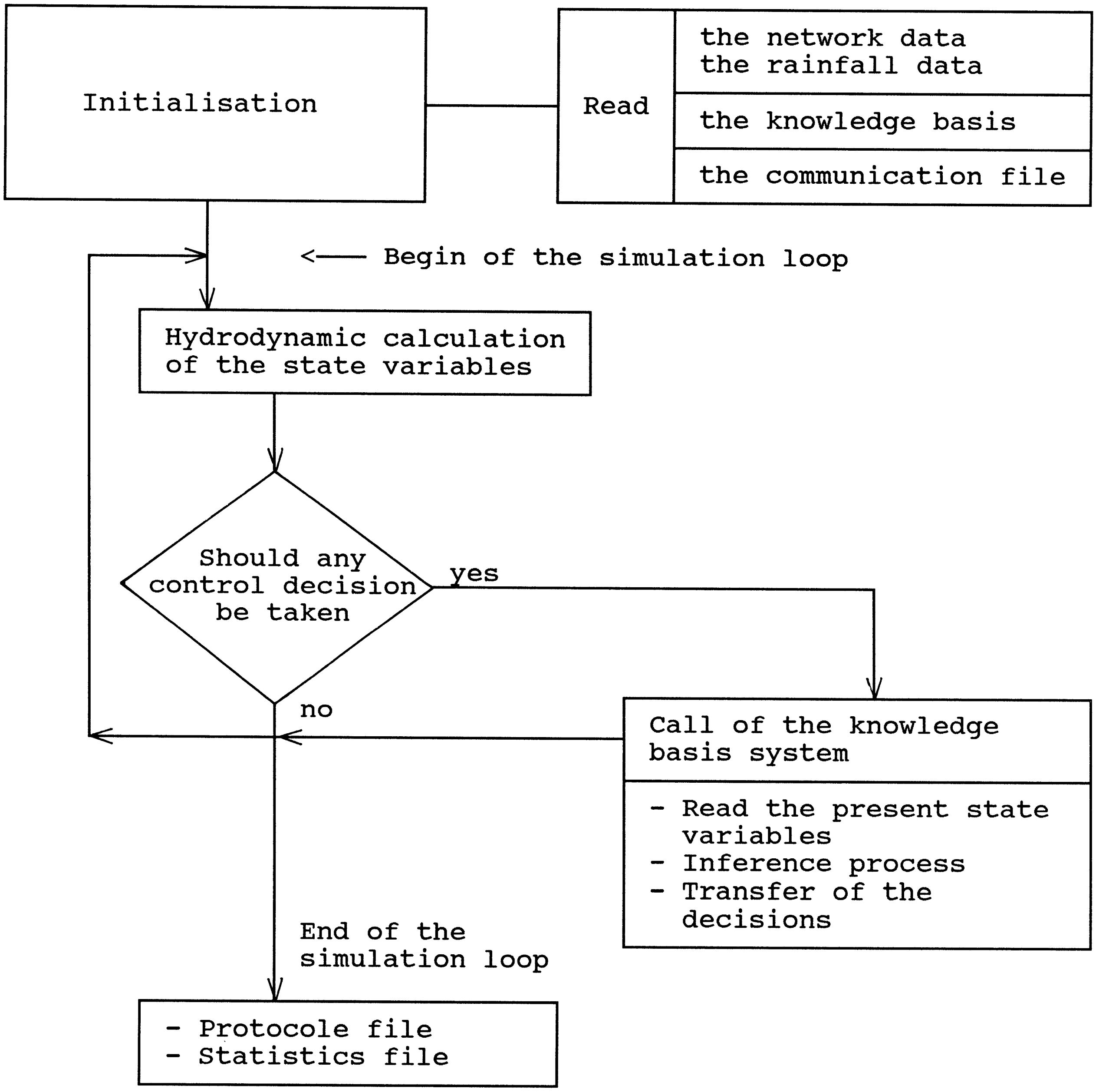
- Simulation
    - Hydrodynamic model
    - Development of a calibrated simplified description of the network
    - Connection simulation - knowledge base system in an extended version
    - Long term simulation

    ---> **Evaluation of the standard strategy rules**

    - Special study of significant events

    ---> **Modification rules**

Sequence of Information Treatment in the Simulation



Implemented On-line Knowledge Basis

- Number of variables: 150
  - state variables
  - rainfall variables
  - control variables
- About 350 rules
  - Set the values of intermediate variables
  - Set the value of the decision variables
  - Find out which recommendations should be sent out
- 86 possible recommendations