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DELAQUA – A PROTOTYPE EXPERT SYSTEM FOR OPERATIONAL CONTROL AND MANAGEMENT OF LAKE WATER QUALITY

Frieder Recknagel*, Erhard Beuschold*** and Uwe Petersohn**

*Dresden University of Technology; *Department of Water Sciences; **Department of Computer Sciences; Mommsenstr. 13, 8027 Dresden, Germany*

****Fernwasserversorgung; Elbaue-Ostharz, PO-Box 43; 3720 Blankenburg, Germany*

ABSTRACT

The expert system DELAQUA (Deep Expert system LAke water QUAlity) combines AI and simulation methods to support decision making in water quality control of lakes and reservoirs. It contains a knowledge base (PROLOG 2), a data base (dBASE III+) and a simulation system (FORTRAN 77) by which the following decision aids can be made available:

(1) derivation of recommendations for operational control of undesired impacts on raw water quality by algal blooms or pathogen germs

(2) classification of raw water quality by means of legal standards

(3) drawing of analogy conclusions by the use of measured and simulated water quality data of reference waters

(4) predictions of raw water quality under changing control strategies and environmental conditions of lakes and reservoirs.

The expert system was implemented on an IBM-PC with MS.DOS operating system.

INTRODUCTION

Aquatic ecosystems are open systems with a high degree of natural stochasticity and are living systems with high redundance in structure and behaviour. Successful control of such systems demands deep ecological understanding and sufficient experience in practical handling of them. Both premises seldom can be fulfilled in practical protection of waters; on the contrary an urgent shortage of specialists has to be acknowledged in this field.

According to actual trends of applied systems analysis three directions are followed to support complex decision making problems:

(1) development of simulation libraries (Swartzman and Kaluzny 1988), which dispose alternative models of a class of systems (e.g. of aquatic ecosystems)

(2) development of relational data bases for a class of systems, which dispose historical, actual and

synthetic data (e.g. of the water quality of different reference waters)

(3) development of knowledge bases, which dispose heuristics of specialists and textbook knowledge on a well defined knowledge domain (e.g. water quality control of lakes and reservoirs).

The construction of DELAQUA was based on the concept of deep expert systems, by which it was aspired to connect the three directions mentioned above up to a certain extent (Recknagel, 1989; Recknagel and Petersohn, 1990). Similar concepts are followed by Jones *et al.* (1987), Meszaros *et al.* (1989), Vendegua and Teruggi (1989) and Starfield *et al.* (1989).

The expert system DELAQUA was constructed to cover the following potential uses:

(1) making available decision aids for judgement and prediction of raw water quality as well as for operational control of specific harmful impacts on water quality in lakes and reservoirs.
(2) making available 'teachware' for education and training of collaborators in water quality management.
(3) making available an example for construction and use of a domain-specific knowledge and data base in the field of water quality management.

ARCHITECTURE AND FUNCTIONING OF THE EXPERT SYSTEM DELAQUA

In Fig. 1 the conceptual architecture of the expert system DELAQUA is represented. In addition to the user interface a knowledge engineer interface and an external interface are included. Moreover separate modules for explanation, knowledge acquisition and problem solving are considered whose functions hitherto have been integrated in the control and inference module. At present the knowledge base disposes rule-based modules for classification of raw water quality (WQI), for operational control of algal blooms (CAB) and for operational and preventive control of infections of waters by pathogen bacteria or viruses (CBV).

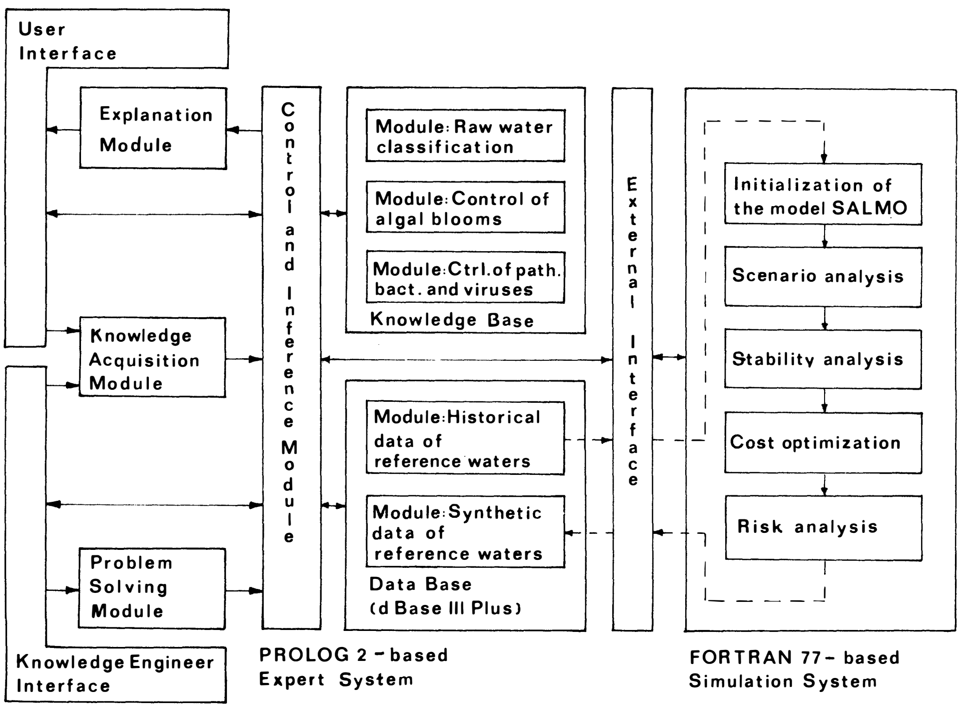

Fig. 1. Architecture of the expert system DELAQUA.

The control and inference module as well as the modules of knowledge base were built by using the tool system ETA-P (Petersohn, 1990), which is based on the language PROLOG 2. The data base includes the modules"historical water quality data" (HIDA) and "synthetic water quality data" (SYDA) of reference waters. Both data bases have been written with dBASE III+. According to the definition of Denning (1986) and the taxonomy of O'Keefe (1986) for deep expert systems it is aspired to couple the expert system with the simulation model SALMO in a parallel manner via the external interface. The model is programmed in FORTRAN 77 and works with the dBASE data files.

In Fig. 2 a diagram is given to illustrate the manner in which modules of the expert system can support decision making for control of raw water quality in lakes and reservoirs, where two approaches are distinguished: derivation of strategic therapies for eutrophication control and derivation of tactical therapies for operational control of harmful impacts on raw water quality.

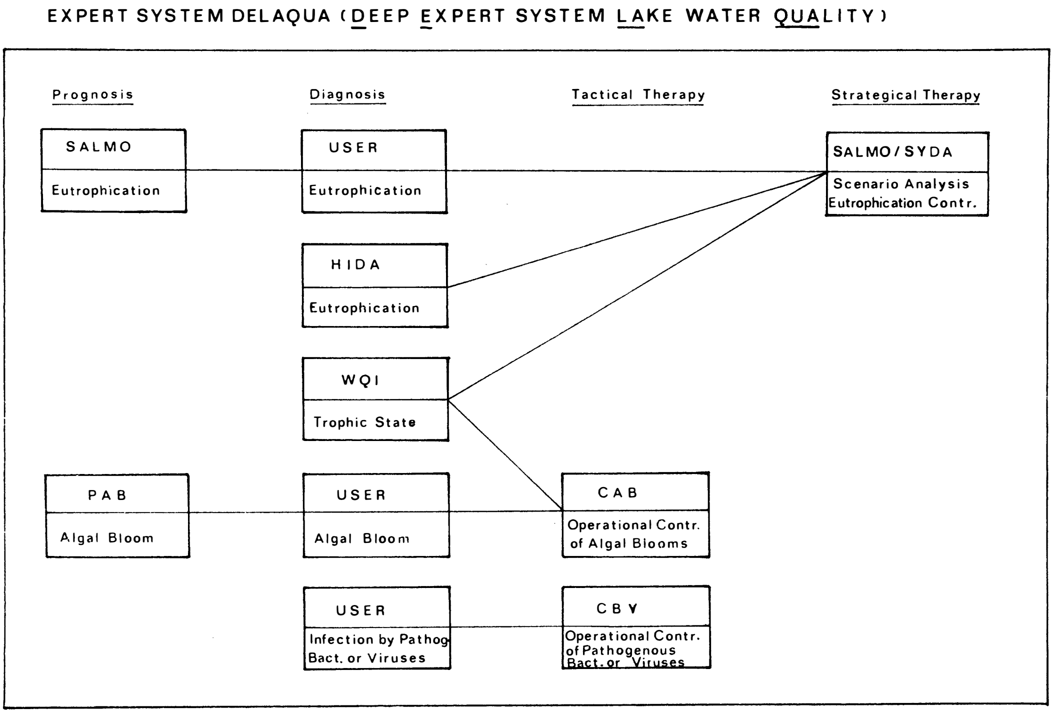

Fig. 2. Principles of functioning of the expert system DELAQUA.

Support of Strategical Water Quality Control

For derivation of strategic therapies the system makes use of the simulation model SALMO as well as of the data base modules HIDA and SYDA. By using the dynamic eutrophication model SALMO (Benndorf, 1979; Recknagel, 1980) trophic states of waters can be judged by means of state trajectories but also of the trophic state index (TSI) according to Walker (1979). In Fig. 3 methods of model-aided decision making are documented in the framework of the case study "eutrophication control of Eibenstock Reservoir". The procedure in Fig. 3 results in an evaluation of reliability of optimum control trajectories for dynamic phosphorus elimination from inflowing water. The included scenario analysis, stability analysis, dynamic cost optimization and risk analysis can be applied at present in an integrated manner by means of a BASIC 4.0 version of SALMO at HP-PC. In the framework of the expert system scenario analysis by the FORTRAN 77 version of SALMO can be applied in a routine manner. Methods and results of validation and application of SALMO are documented in detail in Recknagel (1989).

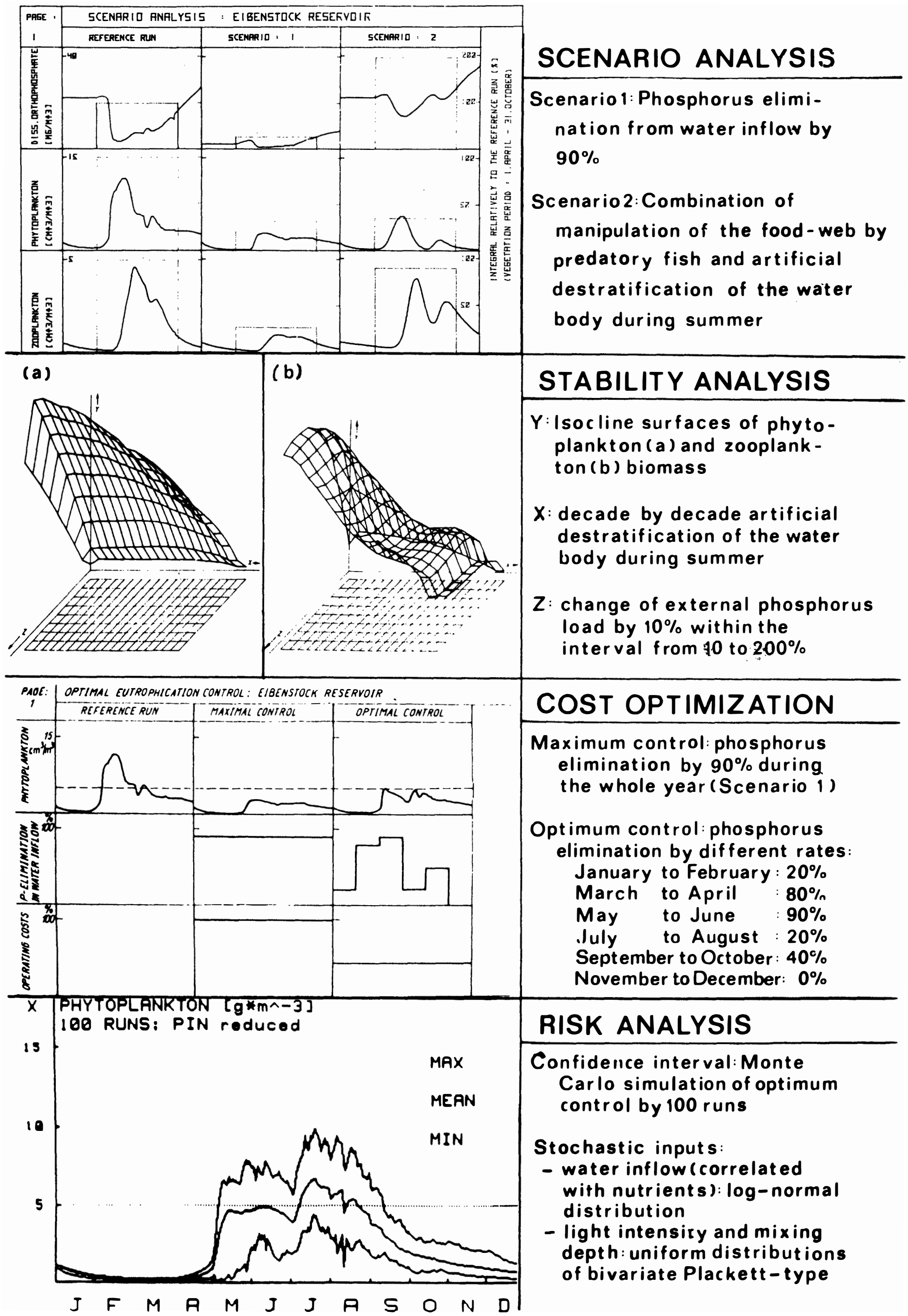

Fig. 3. Simulation methods for decision making support by SALMO.

DATA ACQUISITION REFERENCE WATERS (HEAD DATA)

WATER						
YEAR		DRY	WET	MEAN		
SURFACE		HA				
VOLUME		M↑3				
MAXIMUM DEPTH		M				
TYPE OF INFLOW	SURFACE	GROUNDW.				
RESIDENCE TIME		A				
P-AREA-LOAD						
ORTHOPHOSPHATE - P		G/(M↑2·A)				
TOTAL PHOSPHORUS - P		G/(M↑2·A)				
DEGREE OF EUTROPHICAT.	OLIGO-	MESO-	EU-	POLY-	HYPER-	
P-LOAD LIMIT VALUES	LOWEST		G/(M↑2·A)	UPPER		G/(M↑2·A)
EXTINCTION COEFF.	SUMMER MEAN		1/M	ANNUAL MIN.		1/M
CARBONATE HARDNESS	LOW	HIGH				
HEIGHT ABOVE SEA LEVEL		M				
WIND EXPOSITION	STRONG	MEAN	LOW			
DOM. ALGAE IN SPRING / DOM. ALGAE IN SUMMER	A – B	C – D	E – F	G – H	I1 – I2	I3
USES OF DRAINAGE AREA %	FOREST	AGRICULT.	MUNICIPAL	INDUSTR.		
USES OF WATER %	DRINKING	INDUSTR.	COOLING	IRRIGATION	RECREATION	FISHERY

A: Diatomeen
B: Cryptomonaden
C: Chrysomonaden
D: Dinoflagellaten

E: Euglenophyceen
F: Volvocales
G: Chlorococcales
H: Desmidiales

I : Types of blue-greens
I1 : Oscillatoria
I2 : Microcystis/Anabaena/Aphanizomenon
I3: Synechococcus

Fig. 4. Structure of head data of reference waters in module HIDA.

DATA ACQUISITION REFERENCE WATERS (WATER QUALITY MEASUREMENTS)

VERTICAL MEAN VALUES																	
Day No	Date	Orthophosph	Orthophosph Hypol.	Inorg. Nitrog.	Inorg. Nitrog. Hypol.	Nitrate	Nitrate Hypol.	Phytoplankt. Vol.	Phytopl. Vol. Hypol.	Chlorophyll-a	Chlorophyll-a Hypol.	Zoopl.	Zoopl. Hypol.	Oxygen	Oxygen Hypol.	Secchi Depth	pH at 0m
		mg/m³	mg/m³	g/m³	g/m³	g/m³	g/m³	cm³/m³	cm³/m³	mg/m³	mg/m³	cm³/m³	cm³/m³	g/m³	g/m³	m	

Fig. 5. Structure of quality data of reference waters in module HIDA.

Medium- and long-term eutrophication control can also be supported by analogy conclusions using the data base of DELAQUA. In this case the user is able to consult measured and simulated water quality data of reference waters which have to be "similar" to the water under consideration. The module HIDA contains historical water quality data of reference waters according to the formats in Figs 4 and 5.

The module SYDA contains synthetic water quality data, which were generated by means of the model SALMO. SYDA involves the following state variables as dBASE-output files of SALMO: phytoplankton and zooplankton biomass, dissolved inorganic nitrogen, dissolved phosphorus, detritus and dissolved oxygen. Data files of SYDA can also be used for analogy conclusions where additionally scenario analysis with reference waters can be performed. Whereas HIDA disposes different annual files of four reference waters of the trophic scale SYDA stores 22 files of reference waters including for example hypereutrophic Thamse Reservoirs and a dystrophic Finnish lake.

With respect to Fig. 2 the module WQI can also be used for reasoning of strategic therapies for eutrophication control. The module WQI permits classification of raw water quality according to the standard TGL 27885/01 which represents a rule base for judgement of raw water quality by consideration of 75 water quality criteria. The index scale of WQI corresponds to the trophic scale of waters. By the use of calculated water quality indices restrictions for uses of waters and requirements for raw water treatment in water works are concluded. In addition the module WQI calculates the trophic state index (TSI), which only considers the mean phosphorus concentration in spring, the mean chl-a concentration in summer and the mean secchi depth in summer.

In Fig. 6 the rule base of module WQI is roughly represented.

KNOWLEDGE BASE : MODULE CLASSIFICATION OF RAW WATER QUALITY (WQI)

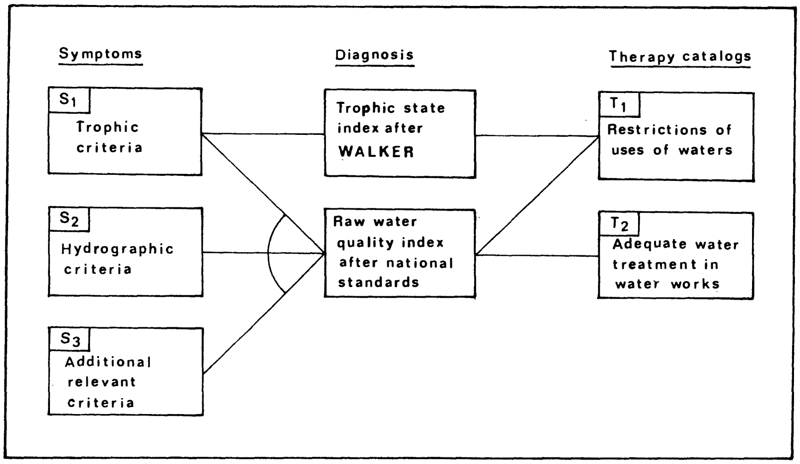

Fig. 6. Raw structure of rule base of the module WQI

Support of Tactical Water Quality Control

While time horizons for strategic therapies amount to months or years, tactical therapies for operational control of harmful impacts on water quality have to be decided within hours or days. Decision makers need fast consultation to select and carry out adequate control measures. The knowledge base of DELAQUA permits consultations of the modules CAB and CBV. The module CAB disposes rules and heuristics assisting in control of algal blooms. According to Fig. 2 it can be consulted:

(1) when the potential risk of an algal bloom is high and preventive measures have to be introduced quickly

(2) when an algal bloom was diagnosed and an operational control in waters and water works has to be performed immediately.

At present preventive consultation of CAB takes for granted risk assessment of experts for algal blooms. This will be supported shortly by means of the module PAB for prognosis of algal blooms which is under construction. This module should be able to quantify the possibility of algal blooms depending on trophic, meteorological and plankton-specific symptoms where the rule base is represented by methods of predicate calculus, fuzzy logic and time-dependent logic. Structures of the modules CAB and PAB are represented in Figs 7 and 8. The module CBV contains a rule-base assisting in control of infections of waters by pathogen bacteria and viruses. According to Fig. 2 it can be consulted: (1) when risk estimates of specialists indicate the potential danger of such an event and preventive measures have to be introduced (2) when an infection of water was diagnosed and operational control measures have to be applied. The raw structure of module CBV can be seen in Fig. 9.

KNOWLEDGE BASE: MODULE CONTROL OF ALGAL BLOOMS (CAB)

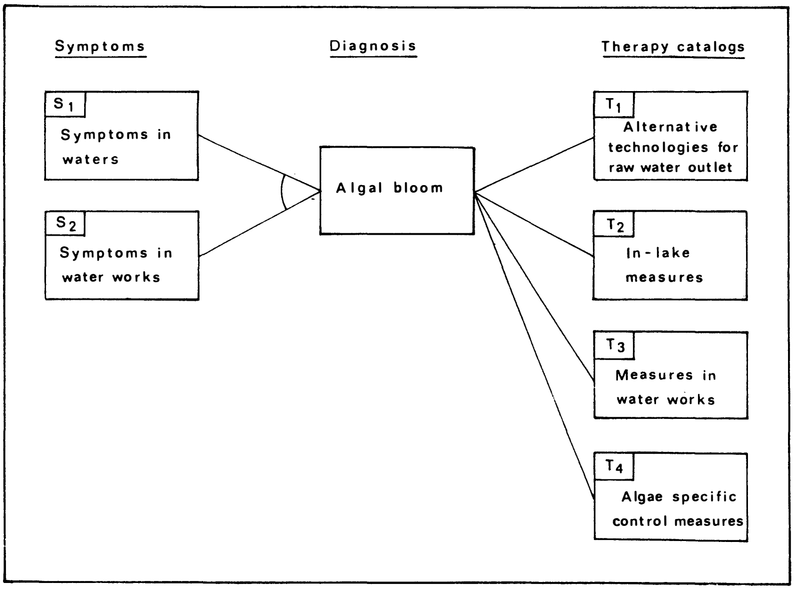

Fig. 7. Raw structure of rule base of the module CAB.

KNOWLEDGE BASE: MODULE PREDICTION OF ALGAL BLOOMS (PAB)

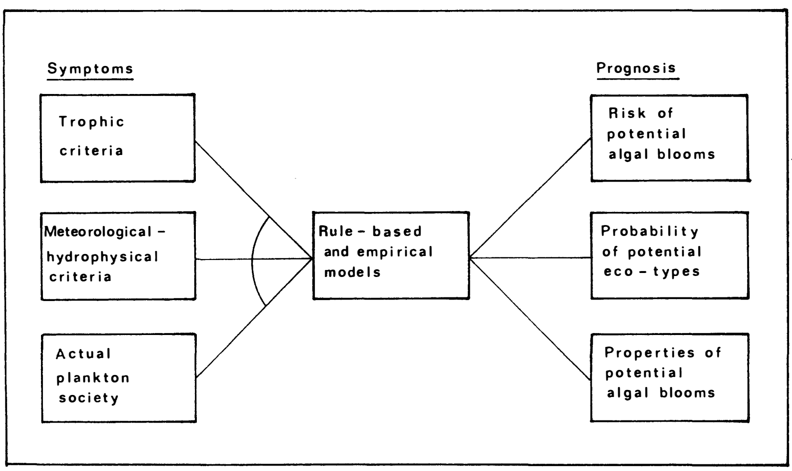

Fig. 8. Conceptional structure of the module PAB

4. CONCLUSIONS

Work on DELAQUA is an exemplary contribution to the toolkit which will be needed to establish successfully ecological engineering as proposed by Mitsch and Jorgensen (1989). The synthesis of simulation and AI methods makes it possible to facilitate ecological reasoning by models and bring it together with heuristics for adequate ecosystem control by knowledge engineering.

KNOWLEDGE BASE:MODULE CONTROL OF INFECTIONS OF WATERS
BY PATHOGEN BACTERIA AND VIRUSES (CBV)

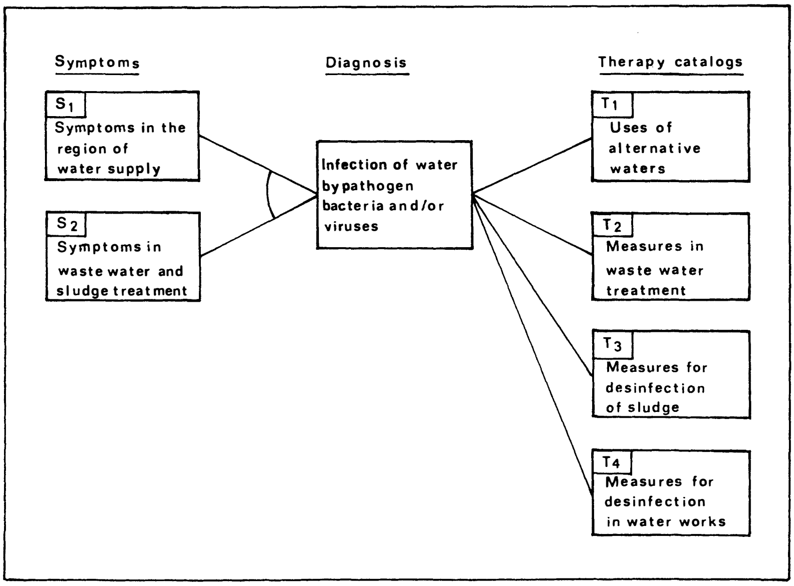

Fig. 9. Raw structure of rule base of the module CBV

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